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## Changes in daily and nightly day-to-day temperature variability during the twentieth century for two stations in Switzerland

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With 7 Figures

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### Summary

An analysis of day-to-day variability was performed on two century-long daily minimum and maximum temperature series from Switzerland. Warmer temperatures during the 20<sup>th</sup> century have been accompanied by a reduction in day-to-day variability, particularly for minimum temperatures and for winter. There is a significant negative correlation between day-to-day variability and the skewness of the temperature distribution, particularly in winter and for minimum temperatures. Lower variability is linked to a reduced number of cold days and nights. Higher NAO index values tend to be associated not only with warmer temperatures but also with lower day-to-day variability. This paper confirms that the temperature warming during the 20<sup>th</sup> century has happened mainly through the loss of the coldest part of the series, not only in the 24-hour or yearly cycle, but also through the loss of the coldest episodes in each month.

### 1. Introduction

The impacts of changes in temperature extremes on natural ecosystems and on human infrastructure are now widely recognized as being more important than changes in average values (Katz and Brown, 1992; IPCC, 1996). Climatic variability is also important for the human perception of climate (Rebetez, 1996). However, there is still insufficient information about changes in climate extremes and variability (IPCC, 1996; Karl et al., 1999).

Previous studies have shown that the global warming measured during the 20<sup>th</sup> century has occurred through a general decrease in daily temperature range, i.e. a stronger increase in nighttime temperature compared to daytime temperature (Karl et al., 1993; Plummer, 1996; Lough, 1997; Zheng et al., 1997). This is also the case in Europe (Heino et al., 1999), particularly in Switzerland (Rebetez and Beniston, 1998a).

The decrease in daily temperature range has been particularly marked at lower elevations (Weber et al., 1994; Rebetez and Beniston, 1998a and 1998b). This decrease may be linked to an increase in cloudiness and to the effects of anthropogenic aerosols, as suggested by Karl et al. (1993), Hansen et al. (1995, 1997a, 1997b) and Rebetez and Beniston, (1998b); the large negative aerosol forcing may have offset greenhouse warming substantially since the industrial revolution in certain regions by keeping maximum temperatures lower than they would otherwise have been.

Jones et al. (1999) have analyzed the 225-year-long daily Central England temperature record and shown that there has been a marked decrease in the frequency of very cold days during the last two decades but no significant increase in very warm days. Using monthly data from around the world, they have also shown that the recent global temperature rise was accompanied both by

reductions in the areas affected by extremely cool temperatures and by increases in the areas with extremely warm temperatures.

Moberg et al. (2000) have shown that in Europe recent warming has been accompanied by changes in mean temperature day-to-day variability. They have calculated a decrease in northeast Europe and an increase in southwest Europe.

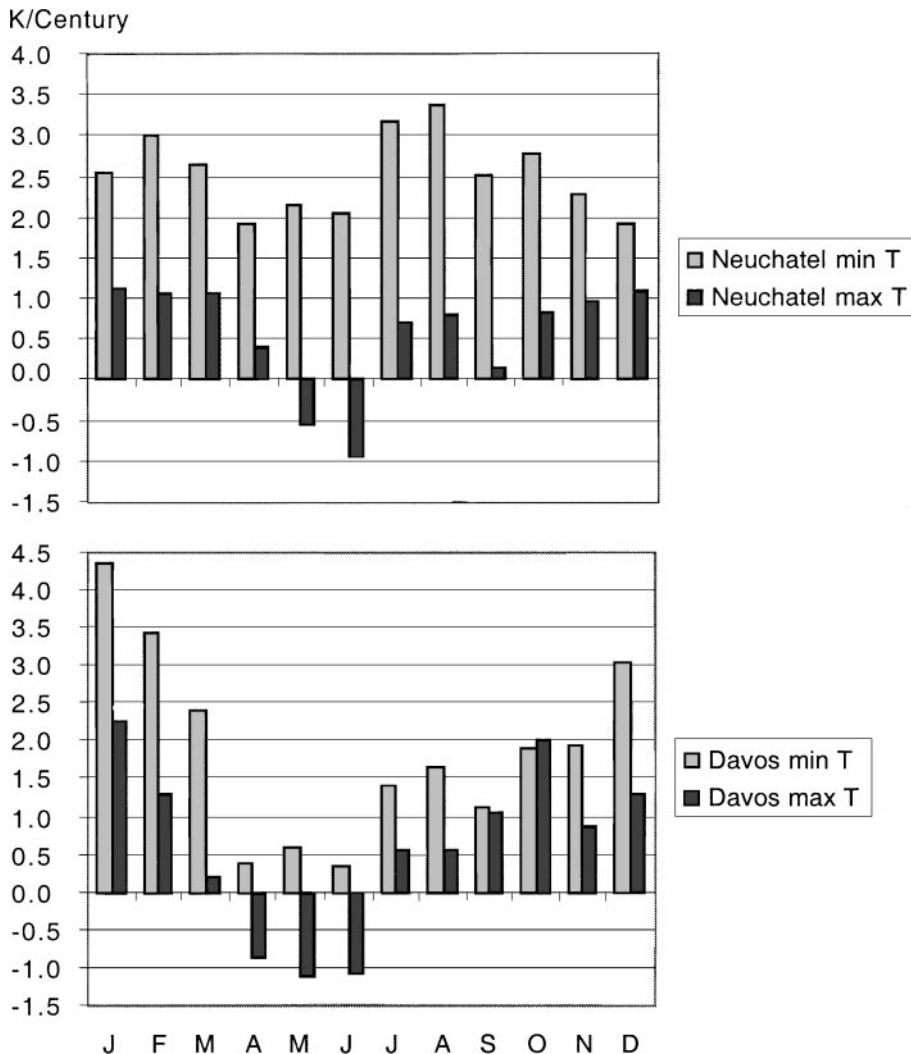
Switzerland is a central European region particularly concerned by climate change, as the observed warming to date has been twice that of the global average value (Rebetez, 1999). In addition, the decrease in daily temperature range has been stronger, by a factor of four, than the mean values for the Northern Hemisphere for the period 1950–1990 (Rebetez and Beniston, 1998a). It is a mountainous region where there is considerable concern about the impacts of changes in climate extremes. Daily minimum and maximum values are avail-

able since the beginning of the century, enabling an analysis of day-to-day variability in more detail than has been done elsewhere until now.

In this paper, I analyse two century-long temperature series from Switzerland in order to better understand the changes that have occurred in day-to-day variability during the 20<sup>th</sup> century. Particular attention has been paid to seasonal and nightly versus daily temperatures in order to better understand the behavior of temperature extremes in the present warming climate.

## 2. Data

Two Swiss stations were used for the study. They both have daily minimum and maximum temperature data spanning the period 1901 to 1999. One of them (Neuchatel) is a low elevation site (487 m) where the meteorological station has



**Fig. 1.** Secular trends in monthly minimum and maximum temperature in Neuchatel and Davos

remained in the same position since the beginning of the 20<sup>th</sup> century and the population has remained roughly constant, at about 30,000 inhabitants, since the beginning of the century. The other (Davos) is situated in a mountain village (1590 m) where the station has been moved only slightly in 1962 and 1976. The two series appear to be remarkably homogenous (Jungo, 2001). Secular trends in monthly minimum and maximum temperature in Neuchatel and Davos are illustrated in Fig. 1. Mean annual increase in temperature reaches 1.5 K in Neuchatel and 1.2 K in Davos.

### 3. Methods

As a measure of temperature variability, Moberg et al. (2000) have compared the use of the standard deviation of daily temperature anomalies in each month with other methods, including the median absolute deviation from the sample median, the sample inter-quartile range and five different N-day change series. (These are based on earlier works by Karl et al. (1995), and are defined as the absolute difference between the average of a sequence of temperature anomalies during the N days, that ends up at day  $t$  and the average for the N-day long sequence ending up at day  $(t - 1)$ ). Moberg et al. (2000) show that the intra-monthly standard deviation is a measure of daily variability that is well correlated with all the other measures. As it is also a widely used measure of variability and easy to interpret they conclude that it is a good general measure of daily temperature variability.

The intra-monthly standard deviation has been used in this analysis as a measure of the day-to-day variability. A monthly measure of skewness has also been used to characterize the types of

distributions. Monthly North Atlantic Oscillation (NAO) index values (see Hurrell (1995), Hurrell (1996) and Hurrell and van Loon (1997)) provided by the Climate and Global Dynamics (CGD) division at the National Center for Atmospheric Research (NCAR) have been used to detect a possible relationship between large pressure systems and temperature variability. All analyses have been performed for minimum and maximum temperature values.

### 4. Results

Trends in intra-monthly standard deviations of mean daily temperature are negative for all seasons in Neuchatel, the lower elevation site, and negative in winter in Davos, the higher elevation site. In Davos, for all seasons, trends in intra-monthly standard deviations are negative for minimum temperatures and positive for maximum temperatures. In Neuchatel, trends are negative for both minimum and maximum temperature values for all seasons except summer, when they are slightly positive (Fig. 2).

There is a significant negative correlation between temperature and standard deviation of temperature, mainly in winter, for both minimum and maximum temperature. In Davos, for minimum temperature, the correlation is significant nearly all year round, with the exception of May and June (Fig. 3).

At both sites, and for both minimum and maximum temperature values, a significant correlation exists between NAO index values and temperature on the one hand (Fig. 4), and standard deviation of temperature on the other (Fig. 5). All year round, the correlation is positive with

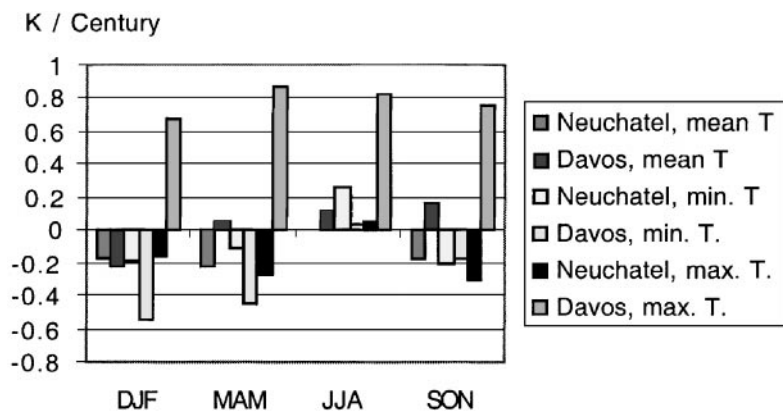
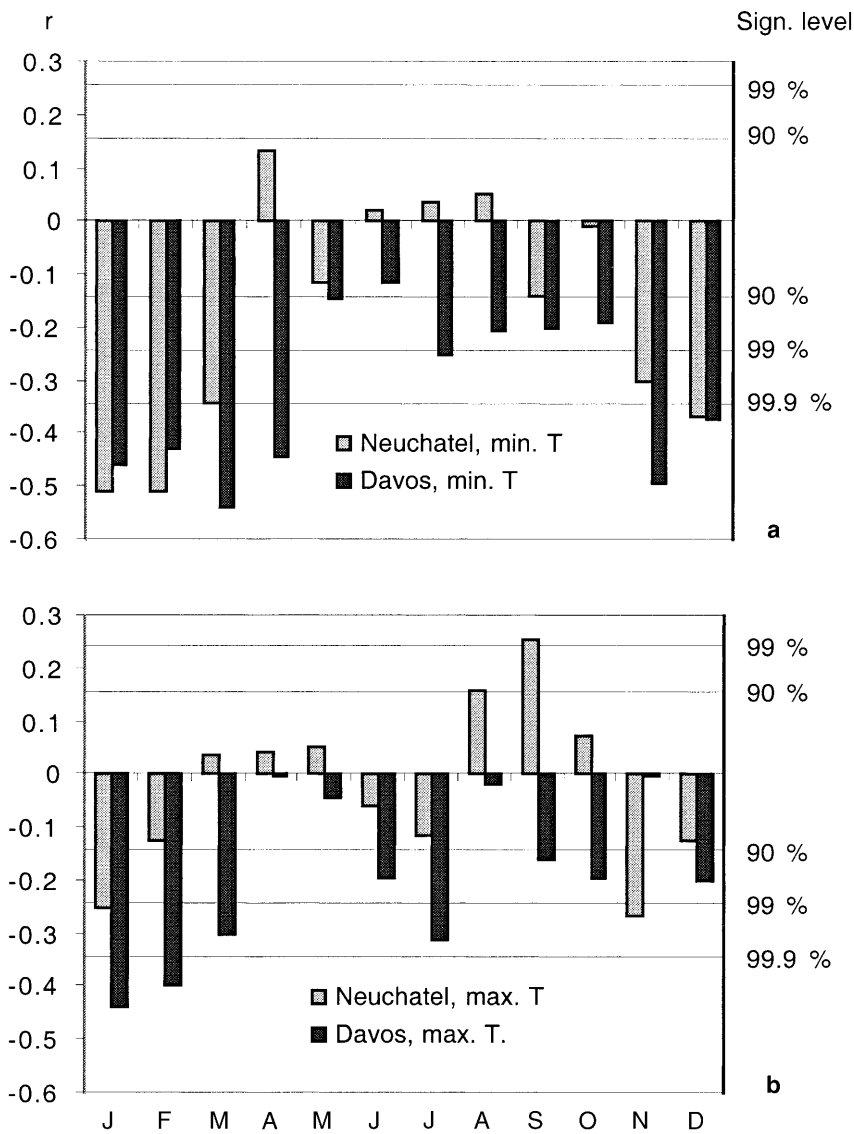


Fig. 2. Secular trends in monthly standard deviation of temperature in each of the four seasons



**Fig. 3.** Monthly correlation coefficients and significance levels (Fisher's test) between minimum/maximum temperature values (a) and standard deviation of temperature (b)

temperature and negative with standard deviation (apart from some exceptions in spring), but it is mainly significant in winter.

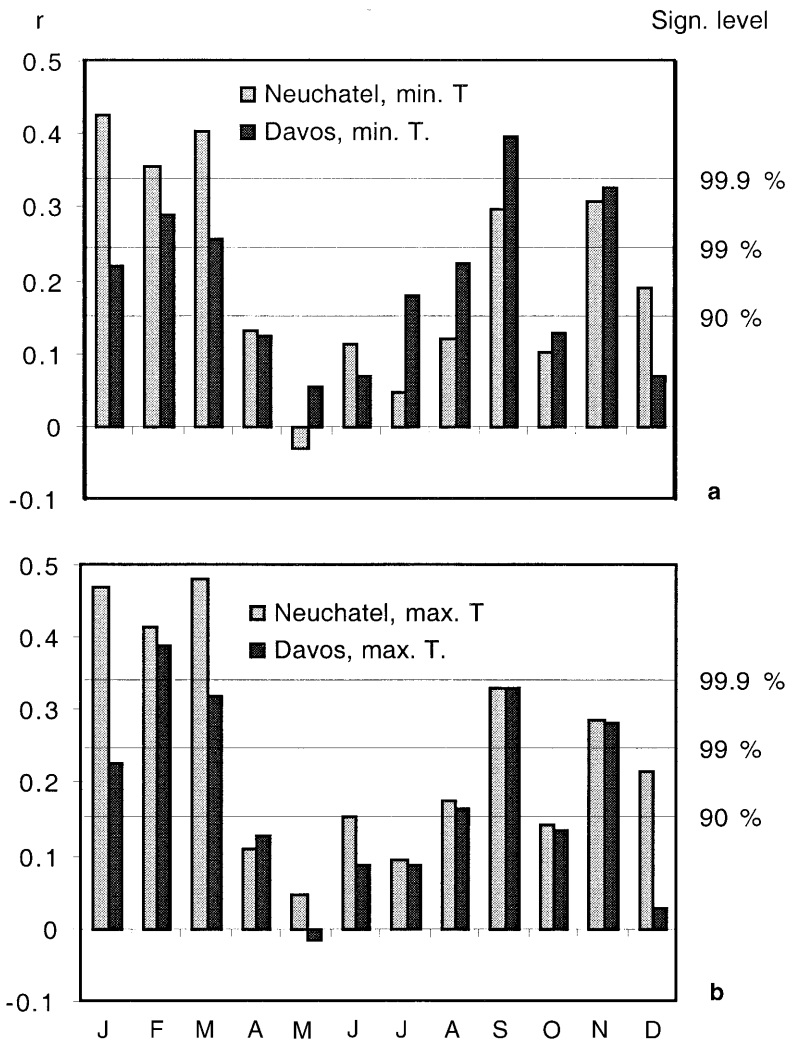
There is a negative correlation between day-to-day variability of temperature, measured by standard deviation, and the skewness of the monthly distribution of daily temperature values, at both sites, for all seasons, and for both minimum and maximum temperatures (Fig. 6). The correlation is mainly significant in winter and more often so for minimum temperature values separately.

## 5. Discussion

The results show that the day-to-day variability for mean daily temperature at the low elevation site is

decreasing for all seasons, though very lightly in summer. The differences observed between the mountain site and the low elevation site may be explained by the stronger atmospheric instability observed in the mountains, as trends are positive in Davos for maximum temperature and in summer for minimum temperature.

The analysis of day-to-day variability for minimum and maximum temperature shows that it is decreasing mainly during the coldest part of the year or in the 24-hour period, and increasing mainly during the warmest part of the year or in the 24-hour period. For minimum temperatures, day-to-day variability is reduced when temperature is warmer, except in May and June. For maximum temperatures, the situation is not very



**Fig. 4.** Monthly correlation coefficients and significance levels (Fisher's test) between minimum/maximum temperature (a) and the NAO index (b)

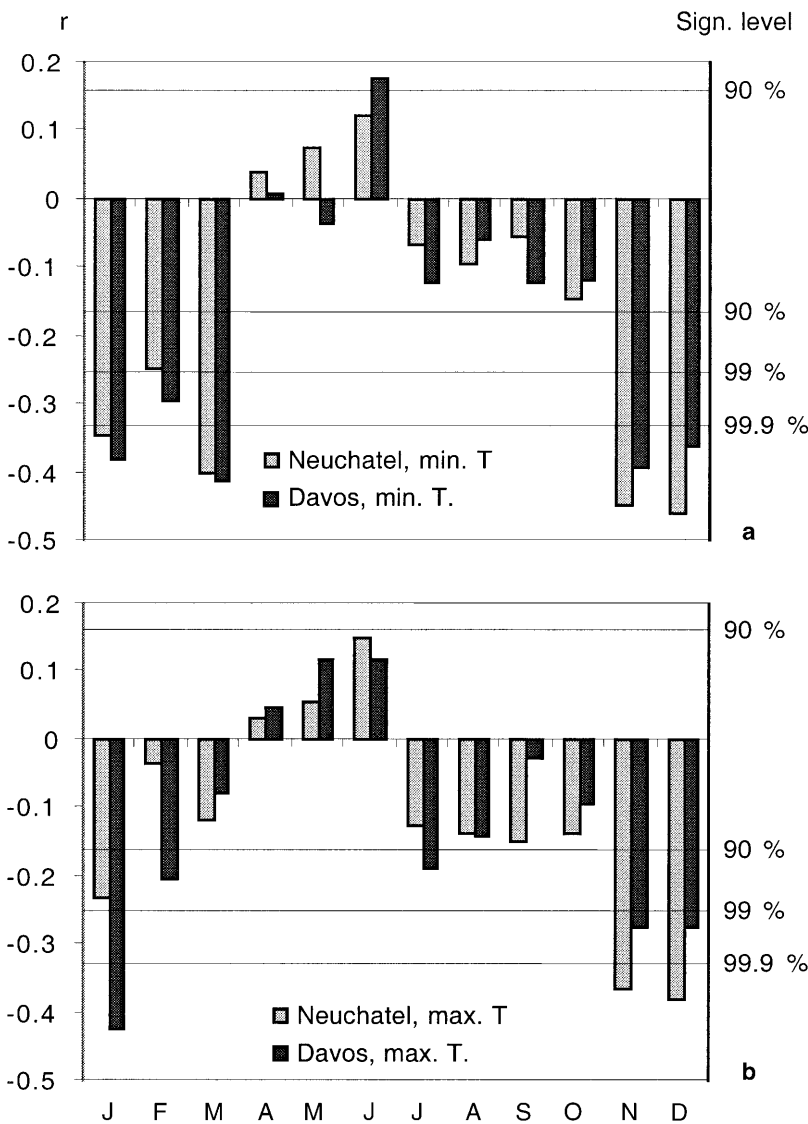
different from minimum temperatures in Davos, except that the relationships are generally less strong. In Neuchatel, there are important differences throughout the year for maximum temperatures, with significant negative correlations only during the cold season.

The observed discrepancy between the variability of temperatures in spring, particularly of maximum temperatures, compared to the rest of the year, can be explained, at least in part, by the fact that in contrast to the rest of the year, absolute values of temperatures are only increasing in smaller proportions for minimum temperature and even decreasing for maximum temperatures (Rebetez and Beniston, 1998a). The discrepancy between spring and the rest of the year thus con-

cerns the absolute values of temperature as well as day-to-day variability.

More generally, the increases in absolute values of temperature are much stronger for minimum than for maximum temperatures. This may be why the centennial trends and the relationships with absolute values of temperature are less clear for maximum than for minimum temperatures.

The analysis of skewness helps to explain how these changes have occurred. There is a negative correlation between day-to-day variability and skewness, and again, this is particularly the case in winter. As illustrated by an example in Fig. 7, this negative correlation means that the reduction in day-to-day variability occurs through the loss of the coldest extremes in the monthly distribution,

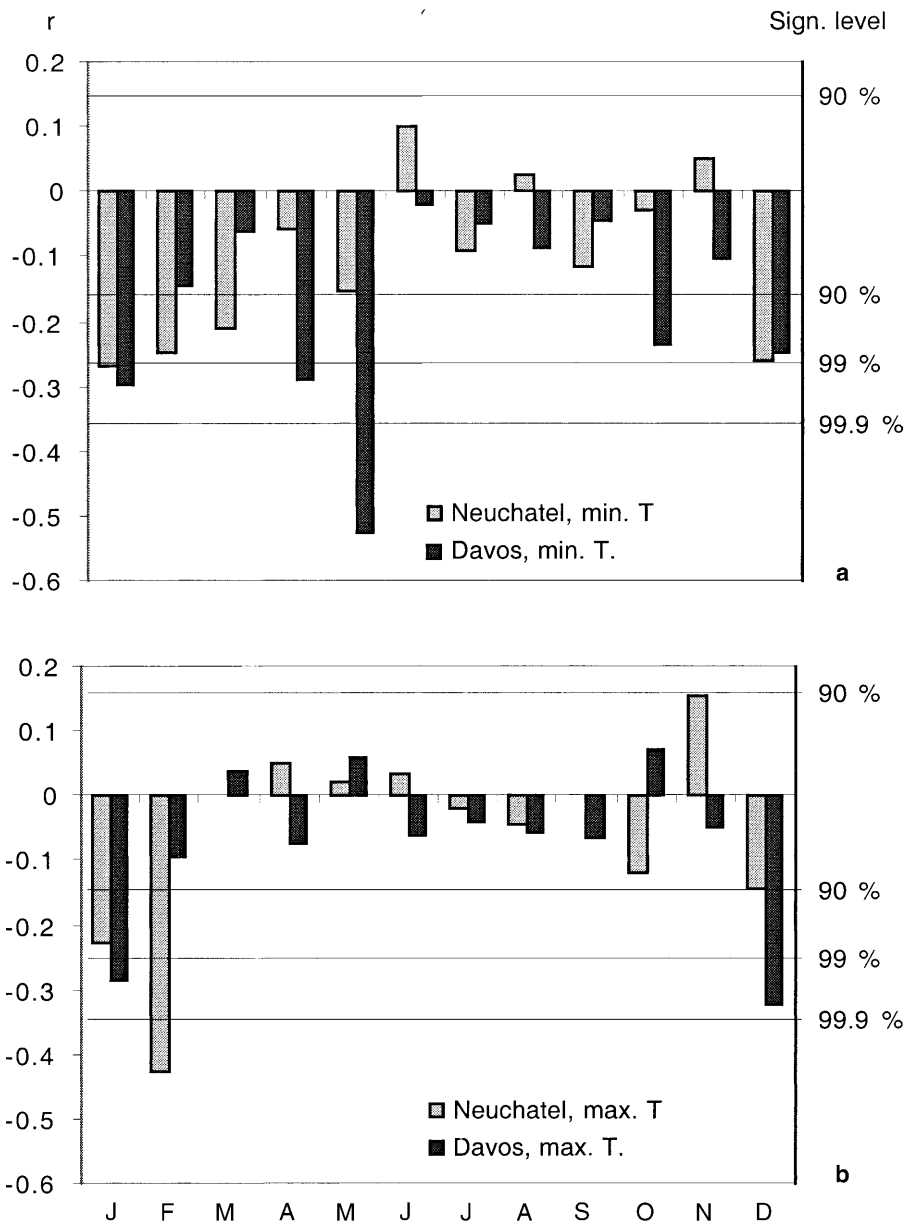


**Fig. 5.** Monthly correlation coefficients and significance levels (Fisher's test) between the standard deviation of minimum/maximum temperature (a) and the NAO index (b)

and particularly through the loss of the coldest extremes in winter. These results are in agreement with Jones et al. (1999), who recently showed a decrease in the frequency of very cold days during the last two decades in England.

The results presented here indicate that day and night, at least in winter, but to a lesser extent also in summer and in autumn, stronger NAO values are accompanied by warmer temperatures and by a reduction in day-to-day variability. This is consistent with a meteorological situation linked to a strong NAO index, i.e. higher pressure over a large region including Switzerland (Wanner et al., 1997; Rodwell et al., 1999). Pressure values stay

relatively high during long time spans and the weather type and temperatures change very little, particularly in winter. Winter is the season when alpine weather is best correlated with the NAO index, with autumn as the second best correlated season, in agreement with previous studies (Luterbach et al., 1999). The correlation between temperature and NAO is equivalent between minimum and maximum temperatures. The correlation between temperature variability and NAO is stronger during the cold season, (particularly in February and March) for minimum temperatures compared to maximum temperatures, meaning that the NAO is more strongly linked to a



**Fig. 6.** Monthly correlation coefficients and significance levels (Fisher's test) between the standard deviation of temperature (a) and the skewness of the temperature distribution (b)

reduction of night-time temperature variability than daytime variability.

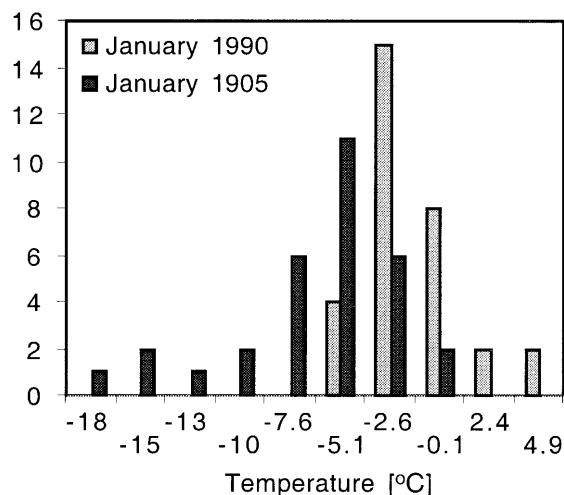
## 6. Conclusions

The results presented here show that there is a correlation between warmer temperatures and a reduction in day-to-day variability. This applies to both the mountain and the low-elevation sites. It is particularly apparent during the cold season, and much less obvious in spring. The relationship is also more pronounced for minimum temperatures

than for maximum temperatures. For maximum temperatures, the relationship is stronger at the mountain site than at the low-elevation site. The analysis of the monthly distributions of temperature reveals that the reduction in day-to-day variability is caused by the loss of the coldest extremes and particularly the loss of the coldest extremes in winter.

This indicates that a warming climate is not only accompanied by a reduction in diurnal temperature range, i.e. a reduced warming of daytime temperature compared to nighttime temperature,

Frequency [Nr. days]



**Fig. 7.** Comparison of minimum temperatures in January 1905 and 1990 in Neuchatel. 1905: Mean =  $-5.4^{\circ}\text{C}$ , Std Dev =  $4.32^{\circ}\text{C}$ , Skew =  $-1.2$ . 1990: Mean =  $-2.8^{\circ}\text{C}$ , Std Dev =  $2.46^{\circ}\text{C}$ , Skew =  $1.1$

but also by a reduction in day-to-day variability in the monthly series. The reduction in day-to-day variability is particularly strong for nighttime temperatures, which may be explained by more rapid increases in night-time temperatures than daytime temperatures.

The decrease in diurnal temperature range indicated that the warming process happens through the loss of the coldest part of the 24-hour period; the decrease in day-to-day variability shows that it also happens through the loss of the coldest episodes in the year and in each month.

NAO index values exhibit a positive correlation with temperature and a negative correlation with day-to-day variability, particularly in winter. This implies that higher NAO are not only accompanied by warmer temperatures but also by a reduction in day-to-day variability, as might be expected as higher NAO are linked to more stable weather situations and usually higher pressures in the study region, particularly in winter.

The general picture implied by the results is that warmer temperatures are accompanied by a general reduction of variability, both in daily temperature range and in the monthly day-to-day variability. The warming process takes place during the whole 24-hour cycle but mainly during the night, and it takes place throughout the year but mainly in winter and with very little change in

spring. An important part of the warming process is linked to a decrease in the number of very cold nights and of very cold episodes in general.

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