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Asymmetric diurnal temperature change in the Alpine region

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Abstract. By now there is general agreement that the annual mean temperature of earth's surface has increased during the last century. Recently, it has become obvious that this warming is quite inhomogeneous in various respects. Besides the spatial and seasonal variability of the temperature trend a diurnal asymmetry of increase has been observed. In large continental regions the annual mean of the daily minimum temperature has increased noticeably faster than the annual mean of the daily maximum. The same behaviour is found in the present study for low-lying stations in Central Europe. However, data from mountain top stations show a similar increase for both minimum and maximum of daily temperatures. No diurnal asymmetry was observed for these stations. The good agreement of the time series from different mountain stations leads us to believe that the observed trends of minimum and maximum temperature are not caused by particular local influences or observation errors. An analysis of monthly and seasonal means shows that most of the warming took place in fall.

Introduction

It is by now widely accepted that the annual global mean temperature of earth's surface has increased during the last hundred years by about half a degree Celsius [*IPCC*, 1990; *IPCC*, 1992]. The warming has been neither uniform throughout the year nor spatially uniform over the globe, but shows pronounced differences between both the seasons and various geographical regions [*IPCC*, 1990; *IPCC*, 1992; *Jones and Briffa*, 1992; *Hunter et al.*, 1993]. Whether the observed temperature changes are signs of natural fluctuations of the climate system or a sign of changing climate caused by man-made alterations of the greenhouse effect in the atmosphere is an open question. In any case it is important to analyze the detailed temporal and spatial variability of the observed warming. Besides the observed seasonal differences in temperature change there has also been noticed a diurnal asymmetry in the warming [*Karl et al.*, 1984; *Karl et al.*, 1991; *Karl et al.*, 1993]. Over large regions of the continents the daily minimum temperature has increased at a larger rate than the daily maximum temperature. As the minimum temperature is assumed to be representative of the nighttime temperatures and the maximum for the daytime, this asymmetry is also termed day–night asymmetry [*Kukla and Karl*, 1993]. In *Karl et al.* [1993] and *Kukla and Karl* [1993] several possible causes for the observed diurnal asymmetry are discussed. There are indications that an increase in cloud cover, including low clouds, is the probable cause of the observed diurnal asymmetric warming [*Karl et al.*, 1993]. *Charlson et al.*, [1991, 1992] provide evidence that the anthropogenic increase in sulfate aerosol may regionally lead to an increase in cloud cover and may also by direct aerosol forcing counteract the present–day anthropogenic greenhouse forcing during daytime.

It is not clear whether the observed diurnal asymmetric warming exists only in the near surface atmosphere or whether it takes also place higher up in the troposphere. The answer to this question may help to identify the mechanisms causing the diurnal asymmetric temperature change. As no daily minimum and maximum readings from balloon soundings are available, we took resource to data from some stations on mountain tops in the Alps. For comparison, data from nearby midland stations at lower altitude were analyzed, too. In *Bücher and Dessens* [1991] maximum and minimum temperatures from a French mountain station in the Pyrenees on the Pic du Midi were analyzed. An increase of the minimum but no warming of the maximum was reported. However, it was mentioned that the Austrian station on Sonnblick shows a similar increase in both minimum and maximum temperature.

Data

Records from Swiss, German and Austrian stations were made available to us by the respective national weather services, namely the Schweizerische Meteorologische Anstalt in Zürich, the Deutscher Wetterdienst in Offenbach and the Zentralanstalt für Meteorologie und Geophysik in Wien. Stations were selected which had a record extending back to the beginning of the century. Only three stations located on fairly high mountains had long enough records of daily extreme values. For a comparison of the mountain region with stations at lower altitude, some stations of the Swiss midland, which are close to the Alps, were chosen. A list of the selected stations and geographical information, including height above sea level, is given in Table 1. Some

Table 1. Location of the stations

Station	Location	Height	Years
Sonnblick	47°03′N, 12°57′E	3105 m	1887–1990
Säntis	47°15′N, 9°21′E	2490 m	1901–1992
Zugspitze	47°25′N, 10°59′E	2960 m	1900–1992
Basel–Binningen	47°33′N, 7°35′E	316 m	1901–1992
Zürich–SMA	47°23′N, 8°34′E	556 m	1901–1992
Bern–Liebefeld	46°56′N, 07°25′E	565 m	1901–1992
Neuchâtel	47°00′N, 06°57′E	485 m	1901–1992

In cases where a station was relocated the newest geographical location and height is given.

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of the stations had major changes like station relocations or change of the shelter type which were corrected by means of several years of parallel measurements as in the case of Basel [*Bider*, 1948; *Krammer*, 1972].

Daily minimum and maximum temperature records were checked by two simple test procedures. First, it was tested whether the reported minimum of a day is smaller than the maximum. If this was not fulfilled the data for that day was discarded. Only a few isolated days did not pass this crude test. Second, for all pairs of stations the difference of the annual mean of daily minimum (maximum) was computed. Plots of these differences can reveal inhomogeneities, especially sudden constant shifts, of the records. By comparison of all difference plots for the seven stations listed in Table 1 and other Swiss and German stations, few inhomogeneities could be discovered. Those found were corrected by adjusting the means of the differences before and after the break to the same value. The corrections applied in this way were −0.6°C to the minimum temperature on Zugspitze for data prior to 1976, −0.7°C to the maximum at Zürich prior to 1971, −0.9°C to the minimum at Bern prior to 1978, and −0.5°C to the maximum at Bern for data prior to 1919. As the stations on Säntis and Sonnblick had no inhomogeneities they were chosen as representative for the mountain stations. Basel and Neuchâtel also had no corrections applied and were taken as representative for the midland stations. All four midland stations are situated close to towns and, hence, their data may have been influenced by changes in urbanization. Based on the growth of population during this century, we estimated from Table 7 of *Karl et al.* [1988] that the daily minimum has been enhanced due to urbanization by 0.1°C in the smallest town, Neuchâtel, and by 0.3°C in the largest town, Zürich. The respective estimate of the change in the daily maximum is about a factor of ten smaller and, hence, negligible. These urbanization effects are much smaller than the observed differences between daily minimum and maximum temperature as discussed below. Since there are no sufficiently long data records from rural stations available to us a direct estimate of the urbanization effect could not be performed.

From the daily minimum and maximum values monthly means were computed and four seasonal means, winter (DJF), spring (MAM), summer (JJA) and fall (SON) formed for each year. Annual means were calculated as the arithmetic mean of all daily values of a year. At most 5 missing values were allowed for the monthly means and at most 10 missing values for the annual means. Only the station on Zugspitze has four missing monthly means in 1945 under these constraints.

Observed Changes of Mean Maximum and Minimum

The time series of annual mean minimum and maximum temperatures show a good coincidence within the group of mountain stations and within the group of midland stations, respectively, apart from the inhomogeneities mentioned in the previous Section. In Figure 1 the time series (centered around the 1901–1990 mean) of the two representative mountain stations are shown. The two time series agree very well, which led us to believe that they capture the essential features of the Alpine mountain region and are not much influenced by local effects. In Figure 2 the annual means of the two representative midland stations are plotted, showing that the two time series coincide well. Both the minimum and the maximum of the mountain stations increased during the observation period. At the midland stations on the other hand only the minimum increased, whereas the maximum shows no obvious increase. In *Weber* [1993] this behaviour was already noticed for the Swiss stations over the period 1901-1970. In order to roughly determine the amount of warming, the linear trends were calculated over the common observation period 1901–1990. The results are shown in Table 2. The two representative mountain stations and their average show a significant linear trend of the same size both in minimum and maximum temperature. The representative midland stations and the homogenized time series have a significant linear trend in the minimum but no significant, or a very small, linear trend in the maximum temperature. As the mountain stations and the midland stations are close together, the observed difference in the increase of minimum and maximum temperature is hardly caused by a longitudinal or latitudinal variability, but probably related to the different height of the two types of stations. This is in strong contrast to the results reported by *Bücher and Dessens* [1991] for the station on the Pic du Midi in the French Pyrenees, where the same diurnal asymmetry in warming was observed as for the midland stations.

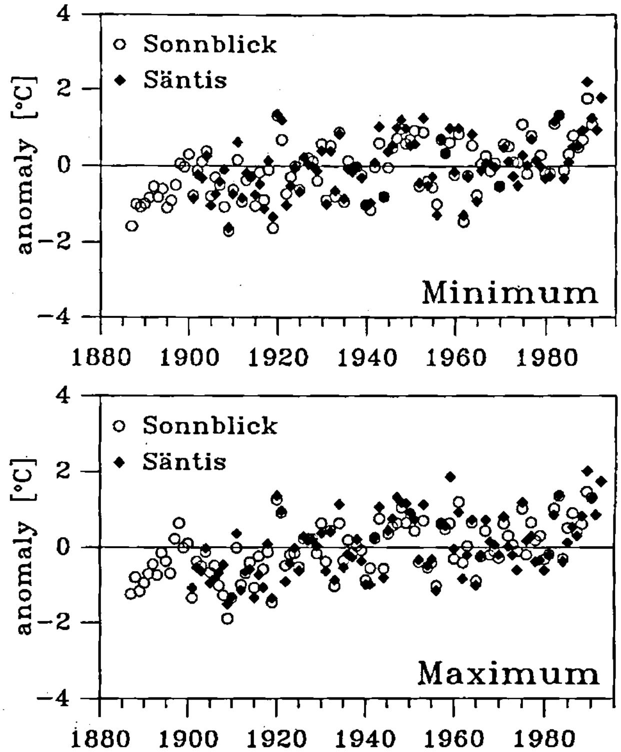

Figure 1. Anomalies from the 1901-1990 period of annual means of daily minimum (upper chart) and maximum (lower chart) temperature for the two representative mountain stations.

In Table 3 the linear trends for three-months seasons are presented for the representative averages of the moun-

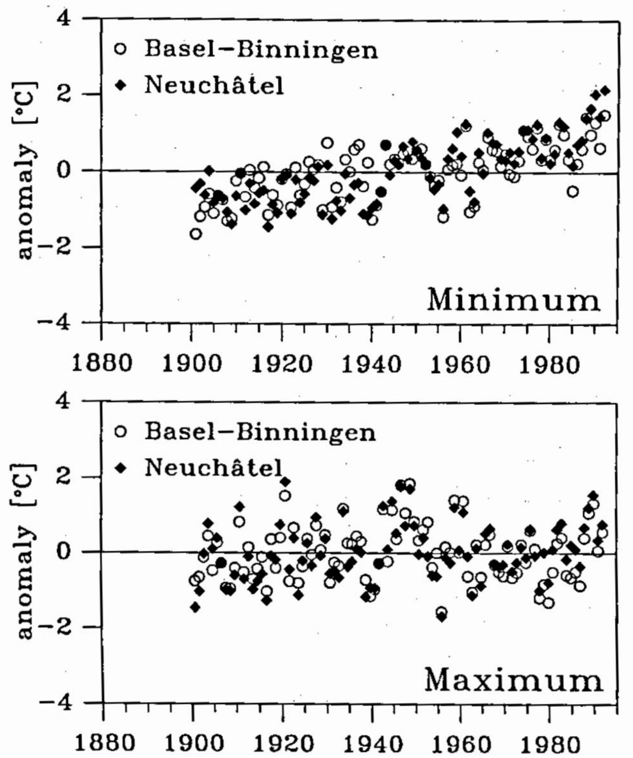

Figure 2. Anomalies from the 1901-1990 period of annual means of daily minimum (upper chart) and maximum (lower chart) temperature for the two representative midland stations.

tain and midland regions. At all representative stations the largest warming occurred during fall. A multiple testing, based on the binomial distribution of independent trials [*Sneyers*, 1990], shows that the largest seasonal increase is

Table 2. Trends [°C/100 yr] of the annual means of daily minimum (MIN) and maximum (MAX) temperature

Station or region	MIN	MAX
Mountain Stations		
Säntis	1.12	1.36
Sonnblick	1.23	1.43
Zugspitze	†*0.44*	0.74
Zugspitze homogenized	0.99	0.74
Mountain average	0.93	1.18
Mountain average homog.	1.11	1.18
Representative average	1.17	1.40
Midland stations		
Basel	1.77	*0.11*
Neuchâtel	2.24	*0.59*
Zürich	1.82	†*-0.24*
Bern	†1.22	†0.59
Zürich homogenized	1.82	*0.52*
Bern homogenized	1.96	1.12
Midland average	1.76	*0.26*
Midland average homog.	1.95	0.59
Representative average	2.01	*0.35*

Linear trends which are not significant at the two–tailed 5% level are printed in italics. A † marks time series with an obvious inhomogeneity. The representative average of a region is the arithmetic mean of the two representative stations as described in text.

Table 3. Trends [°C/100 yr] of seasonal means of daily minimum (MIN) and maximum (MAX) temperature

Region	Season	MIN	MAX	Mean
Mountain				
representative average	Winter	*0.95*	*1.06*	*1.01*
	Spring	*0.71*	*0.90*	*0.81*
	Summer	1.04	1.23	1.13
	Fall	1.90	2.30	1.21
	Annual	1.15	1.37	1.26
Midland				
representative average	Winter	1.77	*0.46*	1.11
	Spring	1.70	*-0.11*	0.79
	Summer	2.16	*-0.24*	0.96
	Fall	2.26	1.17	1.72
	Annual	1.97	*0.32*	1.15

Linear trends which are not significant at the two–tailed 5% level are printed in italics. The representative average of a region is the arithmetic mean of the two representative stations as described in text. In this table, the annual mean is defined as the arithmetic mean of the four seasons.

significant at the 5% level and can be localized within the year. A trend analysis of the monthly means confirms that most of the significant warming took place in fall, especially in September and October.

Conclusions

Long records of daily minimum and maximum temperature from three stations at high altitude in the Alps and four nearby midland stations at lower altitude were taken, and monthly, seasonal and annual means of the daily extreme values were formed. The resulting time series show a good coincidence between the stations within each group. The midland stations have the same diurnal asymmetry in their temperature increase as is observed over large parts of the continents. Only a small part of this asymmetry is caused by urbanization. The mountain stations, on the other hand, show an almost equal increase of minimum and maximum temperature. We believe that these findings may indicate that the cause of the diurnal asymmetry in temperature increase is confined to the lowest part of the troposphere. For example, an increase in low level cloud cover could account for the observed behavior of daily minimum and maximum temperature. However, the question whether the extension of low level clouds changed during this century could not be investigated as no data have been available to us.

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