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Changes in sunshine duration are correlated with changes in daily temperature range this century: An analysis of Swiss climatological data

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Abstract. Analyses of the relationship between trends in daily temperature range and those of sunshine duration in the Swiss Alps show a strong correlation at lower elevation sites. The decrease in daily temperature range is associated with a corresponding decrease in sunshine duration. At high elevations, however, this relationship is absent. The decrease in daily temperature range observed this century at lower elevation sites is inferred to be a consequence of an increase in low-level cloudiness. Higher elevation sites lie above the low-level cloud layers and the moisture-laden lower atmospheric boundary layer and as a result do not exhibit the same trends.

Introduction

In the context of the regional climate change that has occurred this century, a general decrease in daily temperature range (hereafter referred to as DTR) has been observed on all continents [*Karl et al.*, 1993; *Plummer*, 1996; *Lough*, 1997; *Zheng et al.*, 1997]. The Alpine region appears to be particularly sensitive to climatic changes [e.g., *Beniston et al.* 1994], and the density and quality of Swiss climatological data enable in-depth investigations of regional climate to be made. *Karl et al.* [1993] have shown that the Northern hemisphere minimum temperatures have risen by 0.84 K/century and their maximum counterparts by 0.28 K/century during the interval 1950 - 1990. There has thus been a corresponding decrease of 0.56 K/century in the DTR. Observational evidence from Swiss climatological stations [*Rebetez and Beniston*, 1998] for the same period exhibits a mean annual increase in minimum temperatures of 2.17 K/century and a decrease in maximum temperatures of 0.22 K/century. The decrease in DTR is thus 2.39 K/century, which represents a factor of four compared to the mean DTR decrease observed for the Northern Hemisphere. The decrease in DTR in Switzerland for the period 1901-1996 is somewhat lower than for the period 1950-1990, but nevertheless reaches 1.5 K/century. Strong seasonal differences have been observed, in particular for maximum temperatures which exhibit a strong decrease in May and June and a notable increase in winter. The decrease in DTR is particularly marked at lower elevations [*Rebetez and Beniston,* 1998]. As in *Karl et al.* [1993] concerning global observations, *Beniston et al.* [1994] suggest that the general lack of increasing trend in maximum temperatures at lower elevations in the Swiss Alps may be linked to an increase in cloudiness. For higher elevations, *Weber et al.* [1994] have not observed any decrease in DTR this century, whether it be in Switzerland (Santis, at 2500 m asl), Austria (Sonnblick, 3105 m asl) or Germany (Zugspitze, 2960 m asl).

Comprehensive theoretical explanations for the observed global decrease of DTR since the beginning of the industrial revolution have been published by *Hansen et al.* [1995, 1997a, 1997b]. These are based on analyses of the sensitivity of a climate model to a wide range of climate forcings. Part of the explanation is believed to lie in changes in cloudiness, possibly linked to the effects of anthropogenic aerosols. The large negative aerosol forcing may have substantially offset greenhouse warming since the industrial revolution in certain regions, by maintaining maximum temperatures lower.

Data

Five Swiss stations have been used for the present study, four of which have daily data spanning the period 1901 to 1996 and one, Jungfraujoch, from 1933 to 1996. The respective locations and altitudes of these climatological observing sites are illustrated in Figure 1. The climatological variables used for this investigation include minimum and maximum temperature as well as daily sunshine duration, which is an indirect measure of cloudiness. In all cases, daily observations have been used. DTR is defined here as the difference between maximum and minimum temperature.

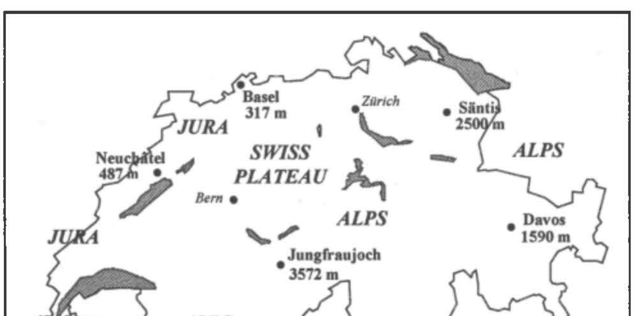

Figure 1. Map of Switzerland with selected sites in bold characters. All sites show data since 1901 except Jungfraujoch (1933).

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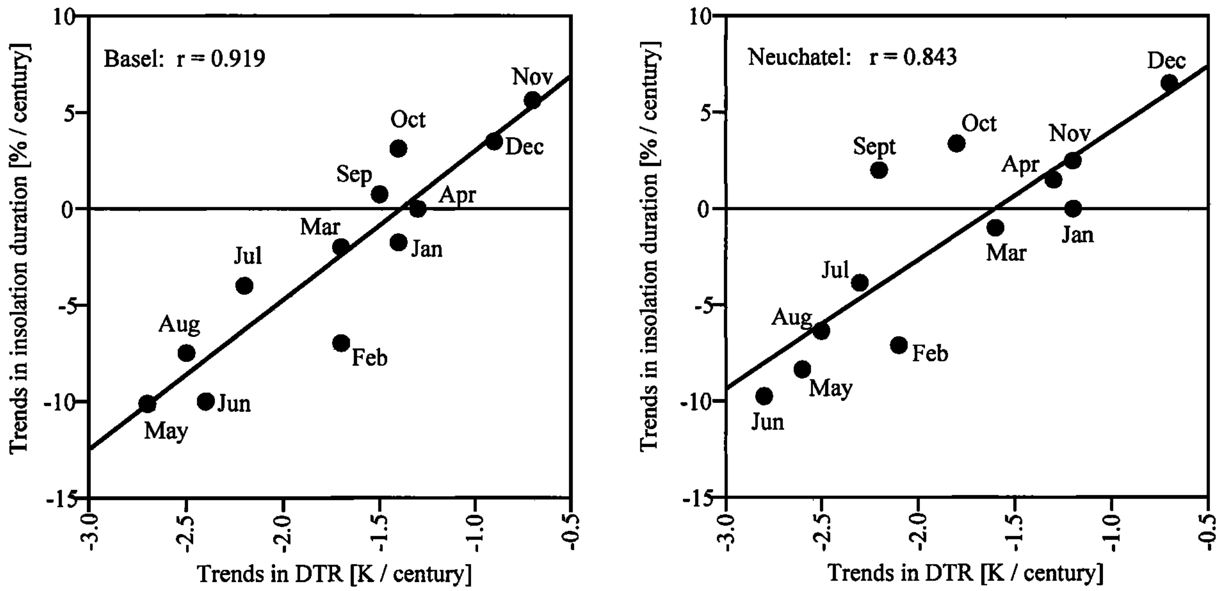

Figure 2. Monthly values for trends in DTR and trends in sunshine duration during the 20th century for Neuchatel (487 m) and Basel (317 m). At these low elevation sites, correlation is high between trends in DTR and those for sunshine duration.

Results

Figure 2 shows the relationship between monthly DTR trends and those for sunshine duration during the 20th century for two low-elevation sites, namely Basel and Neuchatel. In both cases the correlation is particularly high: r=0.919 and r=0.843 respectively, with F>99.99% (F=Fisher's significance test). DTR fall in the range -0.7 K / century to -2.8 K / century according to the month considered. For Neuchatel in June, for example, the DTR decreased by 25% between 1901 and 1996.

Figure 3 shows the same relationship as Figure 2, but for two mountain sites; Santis is a high elevation site while Davos is an intermediate altitude site. The very significant DTR-sunshine duration relationships observed at lower altitudes do not occur at Santis and are poor at Davos (F=90%). Contrary to lower altitude sites, DTR trends in Santis are very low and mostly positive. The lowest DTR trend in Santis (- 0.4 K / century in August) is still higher than the highest trend observed at lower elevations (-0.7 K / century in November in Basel or December in Neuchatel). An identical analysis for the Jungfraujoch site, located at 3572 m asl, confirms that at high elevations, the behavior of DTR this century is different from low altitude sites. The results are very similar to those of Santis, namely increasing DTR trends and no significant correlations with sunshine duration trends.

At lower elevations, changes in sunshine duration explain over 80% of the discrepancies in DTR trends between the different months. At higher elevations (above 2000 m asl), DTR trends are generally of opposite sign and bear little relationship to changes in sunshine duration. Contrary to lower

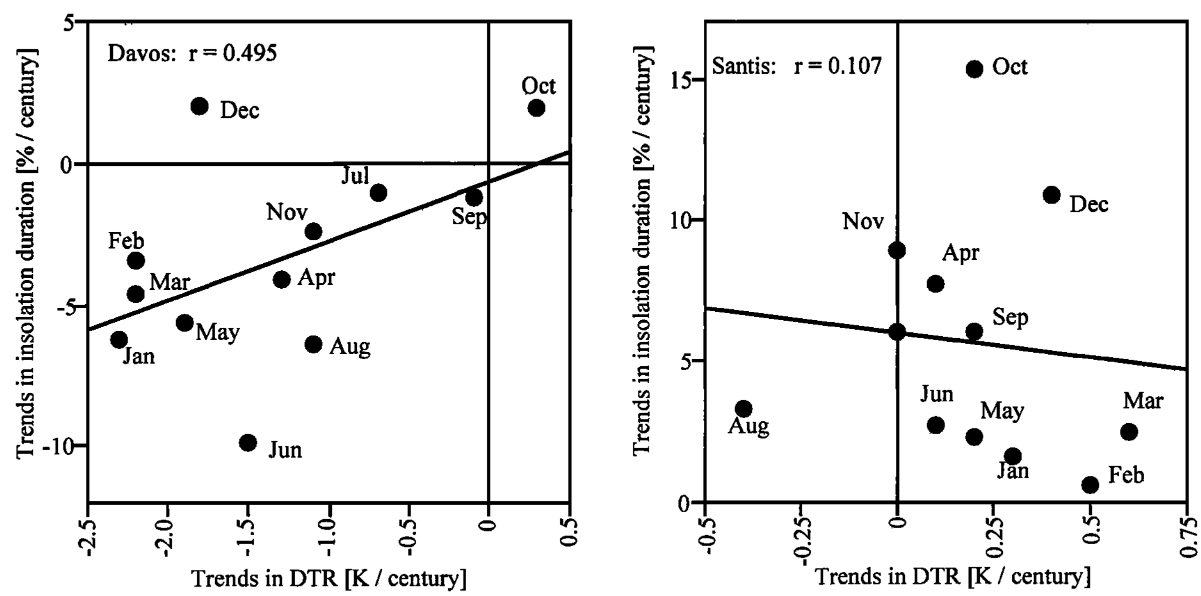

Figure 3. Same as figure 2, except for Santis (2500 m) and Davos (1590 m). Contrary to lower altitude sites, the high altitude site exhibits no relationship to changes in sunshine duration. At the intermediate elevation site, correlations between DTR and sunshine duration trends are significant, but not as high as at lower elevations.

altitude sites, not only minimum temperatures but also maximum temperatures exhibit increasing trends this century for all months. At intermediate elevation sites (1000 - 2000 m asl) correlations between DTR and sunshine duration trends are significant, but not as high as at lower elevations; these intermediate levels thus form a transition zone in which the DTR switches from one mode (decrease) to another (increase).

Discussion

The remarkably strong decrease in DTR at lower elevations in Switzerland, compared to mean values for the Northern Hemisphere, can be attributed to atmospheric processes linked to the particular topography of the Swiss Plateau, located between the Jura Mountains and the Alps. In these regions, cold air pools frequently occur with associated formation of low-level stratus-type clouds. These clouds tend to be persistent and have difficulty in clearing out of the Swiss Plateau because of the "dam effect" of the surrounding mountains.

Two possible factors may help explain the increase in cloud cover at lower elevations on the Swiss Plateau, namely the presence of anthropogenic aerosols or a greater atmospheric water vapor content. Although Switzerland is rather less polluted than its European neighbors (very little industry, strict emission standards for domestic heating, restrictions on truck transportation, etc.), it does suffer from various pollutants of both local and trans-boundary origin. In the particular topography of the Swiss Plateau, aerosols tend to stagnate between the Jura mountains on the western side and the Alps on the eastern side due to poor atmospheric ventilation. It could also be speculated that the observed warming this century has already enhanced the hydrological cycle, making more moisture available for stratus and low cloud formation, particularly over the Swiss Plateau.

These two explanations are both plausible. Simulations undertaken by Hansen and colleagues [*Hansen et al.*, 1995, 1997a, 1997b] make the first hypothesis very likely, but a combination of the two is also possible.

At lower altitude sites, some months (April and September to December) exhibit an increase in insolation duration and nevertheless a decrease in DTR, although this is less marked than for months when there is a negative trend in insolation duration. We suspect that this small part of the decrease in DTR can be attributed to the fact that DTR is generally lower at sites with higher temperatures. This implies that the warming observed during the 20th century is generally expected to be correlated with a decrease in DTR, although not as strong as observed here. It should be emphasized that, even for these months, the smaller the increase in insolation duration, the greater the trend in DTR.

Conclusions

Maximum temperature increases during the last century have been observed to be generally lower than expected from greenhouse-gas forcing, particularly in spring and summer. The results described here show that there is a strong relationship between monthly DTR trends and sunshine duration trends this century. The decrease in DTR, observed to be particularly strong in spring and summer, is associated with a corresponding decrease in sunshine duration trends, i.e., an increase in cloudiness.

The present results show that the remarkably small increases or even decreases in maximum temperatures observed this century could be explained to a large extent by an increase in low-level cloudiness. This is supported by the fact that higher elevation sites, lying above the low-level cloud layers and the moisture-laden lower atmospheric boundary layer, do not exhibit the same trends, but rather opposite tendencies.

The analysis conducted here, by allowing a simultaneous analysis of DTR behavior at both low and high elevations, has enabled a confirmation of hypotheses related to the links between cloudiness and DTR trends for lowland sites elsewhere in the world. More work has to be done in order to help improve our understanding of these complex phenomena. The observations described here show that there is indeed a definite link between the decrease in insolation and the decrease in DTR, which is consistent with other studies on global warming.

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Reference list

Beniston, M. and M. Rebetez, F. Giorgi, M. R. Marinucci, An analysis of regional climate change in Switzerland, *Theor. Appl. Climatol.* 49, 135-159, 1994.

Karl, T. P. Jones, R. Knight, G. Kukla, N. Plummer, V. Razuvayev, K. Gallo, J. Lindseay, R. Charlon, and T. Peterson, A New Perspective on Recent Global Warming: Asymetric Trends of Daily Maximum and Minimum Temperature, *Bull. AMS*, 74/6 1007-1023, 1993.

Hansen, J. M. Sato, R. Ruedy, Long-term changes of the diurnal temperature cycle: implications about machanisms of global climate change, *J. Atmos. Res.* 37, 175-209, 1995.

Hansen, J. M. Sato, A. Lacis, R. Ruedy, The missing climate forcing, *Phil. Trans. R. Soc. Lond. B.* 352, 231-240, 1997a.

Hansen, J. M. Sato, R. Ruedy, Radiative forcing and climate response, *J. Geophys. Res.* 102/D6, 6831-6864, 1997b.

Lough J.M., Regional indices of climate variation: temperature and rainfall in Queensland, Australia. *Int.J. Climatology* 17(1): 55-66, 1997.

Plummer N., Temperature variability and extremes over Australia recent observed changes. *Austral. Meteorol. Mag.* 45(4): 233-250, 1996.

Rebetez, M. and M. Beniston, Changes in temperature variability in relation to shifts in mean temperatures in the Alpine region this century, in *Past, present and future climate variability and extremes: The impact on forests*, edited by M. Beniston and J. Innes, Springer-Verlag, Heidelberg/New York, 1998, in press.

Weber, R. P. Talkner, G. Stefanicki, Asymmetric diurnal temperature change in the Alpine region, *Geophys. Res. Lett.* 21, 673-676, 1994.

Zheng X.G., Basher R.E., Thompson C.S., Trend detection in regional mean temperature series: maximum, minimum, mean, diurnal range, and SST. *J. Climate* 10(2): 317-326, 1997.

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