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Article

Thermal comfort trends and variability in the Croatian and Slovenian mountains

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Abstract

This paper deals with the climatic and bioclimatic conditions, trends and variability in the mountainous areas of Croatia and Slovenia. Two mountain meteorological observatories were chosen: Zavižan in the Croatian Dinaric Alps and Kredarica in the Slovenian Julian Alps. Both have the same monitoring protocol and similar instruments. The station's natural environment remained unchanged since 1955. Therefore, the data of both observatories are extremely valuable for studying changes in sensitive mountain ecosystems in Croatia and Slovenia. Data from the period 1955–2004 were used to assess mountain climatic and bioclimatic variability and trends in both countries. The analysis of the bioclimatic conditions has been carried out using the physiologically equivalent temperature (PET), which is based on the human energy balance models. The prevailing thermal sensation at both stations is very cold, varying from very cold winters to cold and cool summers. Results of the trend analysis indicate a significant increase in the thermal bioclimate index PET in both regions, mainly caused by rising air temperature, especially in spring and summer. The progressive trend test analysis indicated the beginning of positive PET trend in the 1980s – in 1981 on Zavižan and in 1988 on Kredarica. In spite of the considerable increase in thermal comfort in the last 50 years, the bioclimate conditions stayed within the range of the same class of thermal perception.

Zusammenfassung

Die vorliegende Untersuchung beschäftigt sich mit den klimatischen und bioklimatischen Bedingungen, Trends sowie der Variabilität in den Gebirgsregionen von Kroatien und Slowenien. Zwei meteorologische Observatorien wurden gewählt: Zavižan in den kroatischen Dinarischen Alpen und Kredarica in den slowenisch julianischen Alpen. Beide haben dasselbe Beobachtungs- und Datenerfassungsprotokoll sowie ähnliche Messgeräte. Die natürliche Umgebung der Stationen ist seit 1955 unverändert. Infolgedessen sind die Daten beider Observatorien für die Untersuchungen von Änderungen in den empfindlichen Gebirgsökosystemen in Kroatien und in Slowenien sehr wertvoll. Um gebirgsklimatische und bioklimatische Trends in beiden Ländern festzustellen, wurden Daten aus der Periode 1955–2004 verwendet. Die bioklimatischen Bedingungen sind auf der Grundlage der Physiologisch Äquivalenten Temperatur (PET) analysiert worden, welche auf der Energiebilanz des Menschen basiert. Das vorherrschende thermische Befinden an beiden Stationen ist sehr kalt und variiert von sehr kalt in den Wintern zu kalt bis kühl in den Sommern. Die Trendanalyse deutet auf einen signifikanten Anstieg des thermischen Index PET an beiden Stationen hin, hauptsächlich verursacht durch ansteigende Lufttemperaturen, insbesondere im Frühling und im Sommer. Die progressive Trend Test Analyse zeigt den Beginn des positiven PET Trends in den 1980er Jahren, in 1981 in Zavižan und 1988 in Kredarica. Trotz des beträchtlichen Anstiegs der thermischen Behaglichkeit in den letzten 50 Jahren bleibt das thermische Bioklima im Bereich der gleichen Bewertungsklasse des thermischen Befindens.

1 Introduction

Stations of low altitude are often under the direct influence of local anthropogenic factors such as urbanisation and its corresponding urban heat island. At stations of higher altitude, however, only large-scale anthropogenic factors may be present. That's why the detection of climate change at sites of higher altitude is of great importance for the analysis of global climate change.

Mountain meteorological stations played an extremely important role in weather forecasting in the past, as they were the only available data source on meteorological conditions several hundred meters above sea level. Nowadays these data are mainly used to estimate the climatic variations and the climate change trends in the environment that is not under the direct influence of the local anthropogenic factors. Mountains are characterised by enhanced variability of meteorological variables in time and space. To emphasize peculiarities of the mountain climate, it is necessary to include some biometeorological relevant variables (e.g. describing thermal comfort) to complement the usual meteorological information. For visitors living in lowland areas, unusual combinations of meteorological parameters can

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Table 1: Ranges of physiologically equivalent temperature (PET in °C) for different grades of thermal perception by human beings according to MATZARAKIS and MAYER (1996).

PET (°C)	**Thermal perception**
<4	Very cold
4–8	Cold
8–13	Cool
13–18	Slightly cool
18–23	Comfortable
23–29	Slightly warm
29–35	Warm
35–41	Hot
>41	Very hot

occur, that's why a physiological relevant description of climate is even more important.

The analysis of climate change usually focussed on air temperature and precipitation. These parameters have been analysed for several locations in the European mountains: Sonnblick and Zugspitze (BÖHM and AUER, 1994), Säntis (STEFANICKI et al., 1994) and Pic de Midi (BÜCHER and DESSENS, 1991). Extensive studies of climate change in the European Alps were performed as the part of the joint EC- research project ALP-CLIM (Austria, France, Italy, Germany, Great Britain, Switzerland, Slovenia, Croatia and Hungary) (BÖHM et. al., 2001). GAJIĆ-ČAPKA and ZANINOVIĆ (1997) studied the changes in temperature for two high-altitude meteorological stations in Croatia from 1954 to 1995. The present article analyzes the climate change in the Slovenian and Croatian mountains from 1954 to 2004, while emphasizing the thermal perception of the human body.

Climate is a key factor for tourism. Pleasant climate conditions in the destination areas play a vital role in the tourists' decision making process. Mountain tourism is highly dependent on favorable climate and weather conditions (ABEGG, 1996). Accurate weather forecasts are important for the planning of hiking trips and other recreational activities. For tourism thermal perception is one of the dominant climate components of interest. In recent years, however, biometeorological studies have also focused on the changes in the thermal perception of the human body. KOCH et al. (1992) studied the long-term variations of thermal comfort in Vienna. ZANINOVIĆ (1998), and ZANINOVIĆ and MATZARAKIS (2004, 2005) analysed the changes in thermal sensation on the popular Croatian tourist destination island Hvar. Climatic conditions are clearly changing, creating new risks for tourism operators. The tourism sector is required to adapt to climate change in order to realize profit, to continue to generate economic benefits for the host communities, and to provide quality experiences for tourists.

The aim of this study is to quantify the thermal perception conditions and their changes in mountain areas of Croatia and Slovenia at the meteorological stations of Zavižan and Kredarica over a 50-year time period. The thermal perception will be quantified not only in terms of air temperature, but also with a human-biometeorological thermal index, which incorporates the effects of air temperature, air humidity, wind speed, and short- and long wave radiation fluxes. In addition, thermo-physiology (clothing and activity) is included. Although not permanently inhabited, both locations are very popular for hiking and alpine skiing. Constantly increasing number of visitors at both locations, along with a rapidly developing tourist industry in both countries overall, justifies the investigation of human bioclimatic trends in these two popular tourist destination areas.

2 Data and method

Zavižan (1594 m a.s.l., 44°49'N and 14°59'E) is the highest and most scenic place on Velebit, a mountain ridge, which extends in the direction northwest-southeast. Velebit is characterised by mountain climate and constitutes the dividing range between Mediterranean and continental climate. The meteorological observation on Zavižan commenced on October 1 in 1953 and has operated continuously since opening.

The highest mountain station in Slovenia is the observatory on Kredarica in the Julian Alps (2514 m a.s.l., 46° 22'N and 13° 51'E) (Fig. 2). It was established in 1954 by the Hydrometeorological Institute of Slovenia and, since then, observations and measurements have been performed continuously. The meteorological measurements on Kredarica are important with regards to alpinism, monitoring of climate variations and change. The meteorological data from the observatory Kredarica, located in a distance of about 500 m from Triglav glacier, are also suitable for studying the impact of climate variability and change on the glacier's melting rate.

Both meteorological stations operate strictly according to the WMO guidelines on climate monitoring. Political changes in the Balkan region had no impact on the observation protocol and data quality at both stations, as the meteorological network in former Yugoslavia was organized by republics, nowadays states. Since the establishment of both stations, professional observers carry out observations. The meteorological station on Kredarica is a reference climatological station in Slovenia. The meteorological station on Zavižan represents Croatia in the international monitoring programs and is included in the Global Atmosphere Watch Programme of the WMO (GAW) and the Mediterranean Air Pollution Monitoring and Research Program (MEDPOL).

The thermal effective complex deals with the influences of the thermal environment on the well-being and

Figure 1: The location of meteorological stations Zavižan and Kredarica.

health of human beings. The basis for this is the close relationship between the human thermoregulatory mechanism and the human circulatory system. For the physiologically significant assessment of the thermal environment, several thermal indices are available, which are derived from the human energy balance (MAYER, 1993; MATZARAKIS and MAYER, 1997; VDI, 1998; HÖPPE, 1999 and MATZARAKIS et al., 1999). Also the ongoing EU Commission COST 730 project in cooperation with WMO, WHO and as a commission of the International Society of Biometeorology is aiming to develop an universal thermal index (UTCI) based on human energy balance. Since UTCI is not determined yet, PET is one of the best currently available choices and it also fulfils the basic requirements for UTCI.

In order to take into consideration the thermal environment of humans in a appropriate way, it is necessary to use evaluation methods that

- deal with the atmospheric environment as a whole and not with single meteorological parameters,
- have a thermo-physiological importance.

Therefore, *"simple" complex indices"* that have often been used in earlier publications, such as effective temperature or the equivalent temperature, do not meet the above-mentioned criteria (HAMMER et al., 1986; JENDRITZKY et al., 1990; SPAGNOLO and DE DEAR, 2003a; b). The VDI-guideline 3787, part 2 (VDI, 1998), recommends several methods for the assessment of the thermal component of the human climate, all of which are based on the human energy balance equation (HÖPPE, 1984, 1993, 1999). The thermal index applied in this study is called PET (Physiologically Equivalent Temperature), which is based on the model MEMI (Munich Energy-balance Model for Individuals). PET is one of the most used and recommended in the VDI-guideline (VDI, 1994 and 1998). Other existing thermal indices like PMV (Predicted Mean Vote) (FANGER, 1972; JENDRITZKY et al., 1990) and SET (Standard Effective Temperature), (GAGGE et al., 1986) or OUT _ SET* (Outdoor Standard Effective Temperature), (DE DEAR and PICKUP, 2000; SPAGNOLO and DE DEAR, 2003a; b) produce similar results. The calculations have been done by the use of the radiation and bioclimate RayMan model (MATZARAKIS et al., 2000) which is based on the VDI-guidelines 3787 and 3789 (VDI, 1994 and 1998). Solar radiation has been calculated by means of cloud amount, while the changes in output energy from the sun are assumed to be constant. The changes in sun radiation produce effects on the used global radiation. However, existing models and results of these changes can not be implemented in the present analysis because of the temporal resolution of the calculations.

The most important factors for modern thermal indices (PMV, PET or SET*) for sunny and warm conditions in the studied areas are in order of relevance: global radiation, air temperature, wind speed, and air humidity. For cold conditions and low global radiation, air temperature and wind speed are the most influencing para-

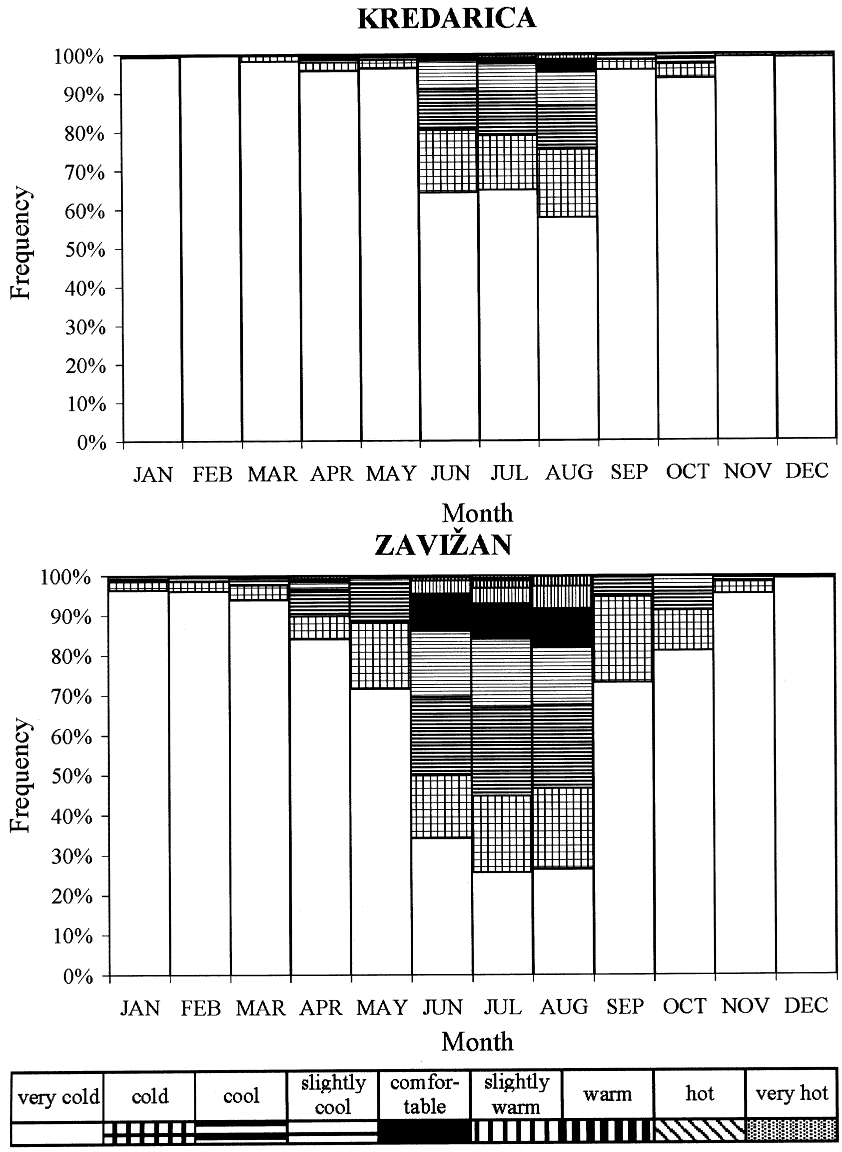

Figure 2: Probability of the occurrence of different thermal sensations according to the physiologically equivalent temperature, period 1996–2000.

Table 2: The mean differences between physiologically equivalent temperature and air temperature (PET-T) in °C at Zaviŭan and Kredarica, period 1955–2004.

Seasons	Spring	Summer	Autumn	Winter	Annual
Zavižan	–2.1	0.2	–3.3	–7.1	–3.7
Kredarica	–3.6	–1.1	-4.3	–6.8	–4.0

meters. Wind speed was not measured with a standard instrument for the first period, but was obtained by the wind force according to the Beaufort scale. The effect of wind speed on PET is not relevant in this study, due to the higher wind speeds in mountain areas.

The variability and trends of seasonal and annual values of the thermal comfort index physiologically equivalent temperature PET, as well as the meteorological parameters influencing thermal comfort (air temperature, relative humidity, wind speed and cloudiness) were determined. According to the recommendations of the cited VDI-guideline and the definition of PET, the clo is set for indoor condition (0.9 clo) and activity of light work (80 Watt). Clo describes the heat resistance of clothing, the value of 0.9 clo is equivalent to a business suit. The calculations have been carried out for each daily observation (07, 14 and 21 hours local time) separately. Variations and trends were analysed for the period 1955–2004. In order to eliminate short-term fluctuations, the noise was taken out of the data series by means of the weighted 11-year binomial moving average filter, which is often used for the analysis of climate variability (BÖHM et. al., 2001). The number of terms in the moving average has to be odd to enable the symmetry around the central value precluding the shift in phase. The 11-year is the average sunspot rhythm and the 11-

year moving average is used in order to study the related variations of terrestrial climate (MITCHELL et al., 1966).

The linear trend has been tested for significance with the Mann-Kendall rank statistics t (MITCHELL et al., 1966; SNEYERS, 1990). For each element x_i, or for each rank y_i which is given to them when they are arranged in increasing order of magnitude, the number n_i of elements y_j preceding it ($i > j$) is calculated so that $y_i > y_j$. The test statistic t is given by the equation:

$$t = \sum_i n_i$$

For the series, which showed the significant trend identified by the Mann-Kendall coefficient t, a progressive analysis of the time series by means of the statistic $u(t)$ was performed in order to determine the beginning of this phenomenon (SNEYERS, 1990). The t_i test values are normally distributed for a long series and their mean and variance are:

$$E(t) = \frac{n(n-1)}{4}$$

$$\mathrm{var}(t) = \frac{n(n-1)(2n+5)}{72}$$

They make possible the determination of standardized values:

$$u = \frac{t - E(t)}{\sqrt{\mathrm{var}(t)}}$$

The positive $u(t)$ points at an increasing trend, while the negative $u(t)$ points at a decreasing trend. In order to identify the beginning of the possible trend, $u(t)$ are calculated for all i's, from the first to the last datum, forming the progressive onward test series. The backward test series $u'(t)$ is formed in the same manner, calculating it from the last to the first term. If there is no trend the $u(t)$ and $u'(t)$ curves overlap several times, whereas in the case of a trend, the intersection point designates the beginning of the trend, becoming significant at 0.05 level in case the absolute $u(t)$ exceeds 1.96 value.

3 Results

3.1 Bioclimatic conditions

According to the mean annual and seasonal PET values, the mean annual thermal sensation at Zavižan and Kredarica during the period 1955–2004 was very cold (0.6°C and –5.4°C respectively), varying from very cold winters (–10.8°C and –14.3°C) to cold summers at Kredarica (4.2°C) and cool summers at Zavižan (11.9°C). Spring and autumn were very cold, but because of the maritime influence, autumn was warmer than spring at both locations.

Table 3: Seasonal and annual trends (per 10 years) of mean physiologically equivalent temperature (PET in °C), temperature (t in °C), vapour pressure (VP in hPa), wind speed (v in m/s) and cloudiness C (in tenths) at Zavižan and Kredarica, period 1955–2004. Shading denotes trends significant at the 0.05 level according to Mann-Kendall rank statistics.

ZAVIŽAN

Seasons	PET	t	VP	v	C
Spring	0.34	0.23	0.01	–0.20	–0.05
Summer	0.49	0.30	–0.08	–0.20	–0.05
Autumn	0.12	0.00	–0.04	–0.24	0.04
Winter	0.15	0.11	–0.07	–0.20	–0.13
Annual	0.27	0.14	–0.06	–0.21	–0.05

KREDARICA

Seasons	PET	t	VP	v	C
Spring	0.21	0.37	0.06	0.12	0.05
Summer	0.28	0.52	0.08	0.09	–0.08
Autumn	–0.03	0.12	0.03	0.05	0.11
Winter	0.36	0.35	-0.00	0.09	–0.10
Annual	0.18	0.27	0.04	0.07	–0.00

The sensation of very cold prevails at both locations for the mean daily values, with very cold being more frequent at Kredarica due to its higher elevation (Fig. 2). Very cold is the most frequent sensation at Kredarica even during summer, while the daily means rarely show comfortable or warm conditions. At the same time, cool and slightly cool prevail at Zavižan during summer. Approximately ten per cent of summer days are comfortable and sometimes, although not very frequent, it is warm.

When comparing air temperature and PET, one can conclude that at higher altitude the thermal regime is lower than air temperature (Fig. 3 and Tab. 2). The differences are the greatest during winter, due to wind, which intensifies the sensation of coldness. The differences are lowest in summer and are mainly the result of the presence of convective clouds at high altitudes during summer.

3.2 Variations

At the beginning of the observing period the PET values at Zavižan and Kredarica do not show similar trends (Fig 4). At Zavižan there was a warming period from the beginning of the reading period until the mid 1960s, followed by a cooling period until the mid 1970s, while at Kredarica the decreasing air temperatures are evident from 1955 until the early 1980s. Both locations showed rising temperatures until the end of the 1980s. As the temperatures at both stations decreased from the beginning of the period until 1980, the main reason for the increase in PET at Zavižan at the very beginning of the period is the simultaneous decrease in wind speed. While

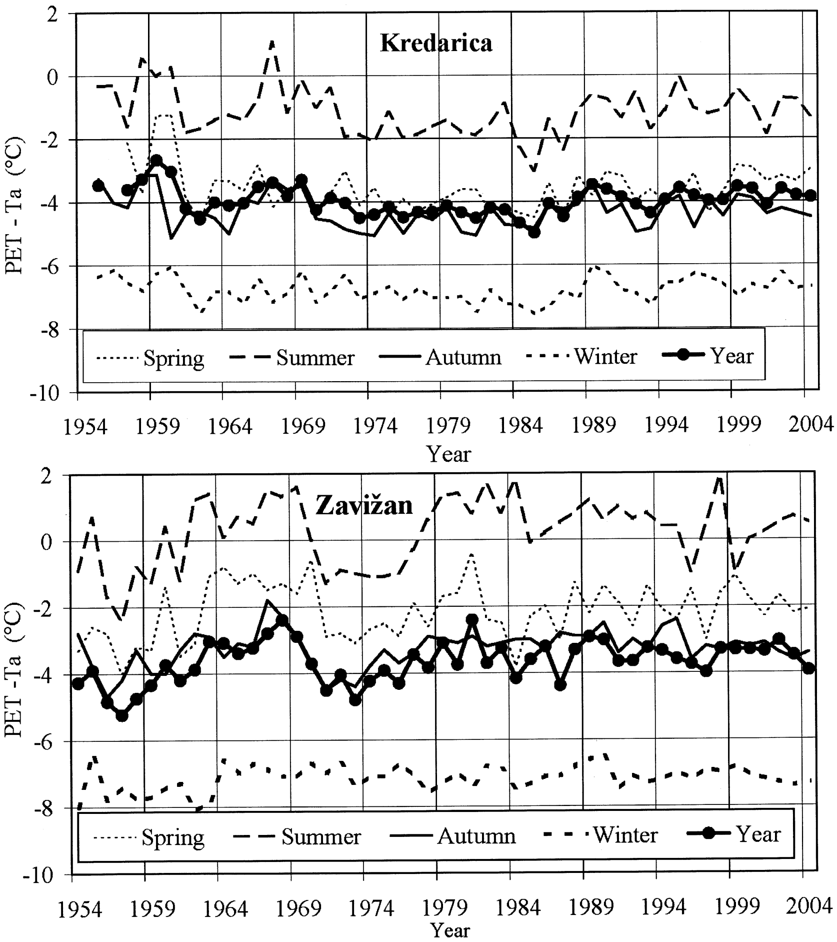

Figure 3: The differences between physiologically equivalent temperature and air temperature at Zavižan and Kredarica.

the minimum in PET occurring at Kredarica at the beginning of 1980s coincides with the minimum in the air temperature, the lowest PET at Zavižan in the mid-1970s is a consequence of increased wind speed. On the other hand, the maximum in air temperature accompanied by the minimum in cloudiness and lower wind speed resulted in the highest PET in the early 1990s at both locations. It has to be mentioned that the influence of wind speed on PET has to be considered carefully because of the subjective observations of the wind speed.

3.3 Trend analysis

At both locations the PET showed a positive trend in annual values (0.3°C/10 years at Zavižan and 0.2°C/10 years at Kredarica) and in all seasons (except autumn at Kredarica). The highest changes of PET were observed at Zavižan in summer (0.5°C/10 years) and at Kredarica in winter (0.4°C/10 years), the smallest in autumn at both stations (Tab. 2). However, the trends were significant for annual values at both stations and for spring and summer at Zavižan. These positive trends were primarily the result of increasing temperatures over time, significant for spring, summer and the yearly average at both locations. Due to negative trends in wind speed in all seasons, although not significant, the increase in PET values at Zavižan was higher than the increase of mean temperature. On the other hand, the increasing wind speed trends at Kredarica (not significant) resulted in a lower increase in PET than in air temperature. Finally, in spite of the smaller increase in temperature, Zavižan showed greater changes in PET than Kredarica. The influence of other parameters that are significant for thermal comfort on the positive PET trends was less important.

The progressive trend test was applied to the annual values of PET and air temperature (Fig. 5). The graphical presentation of the forward (u) and backward (u') test series of PET demonstrates that the PET began to increase in 1980 at both stations, the same trend was also evident in the variation analysis. The intersection point between u and u', indicating the beginning of trend, occurred at Zavižan in 1981, while u exceeded the 1.96 limit value in 1989, suggesting the beginning of a significant positive trend. At Kredarica the positive trend began in 1988, but it did not reach the significance limit yet. The progressive trend test for temperature, with a dominant effect on the positive trend in PET, showed that the increasing trend began almost simultaneously

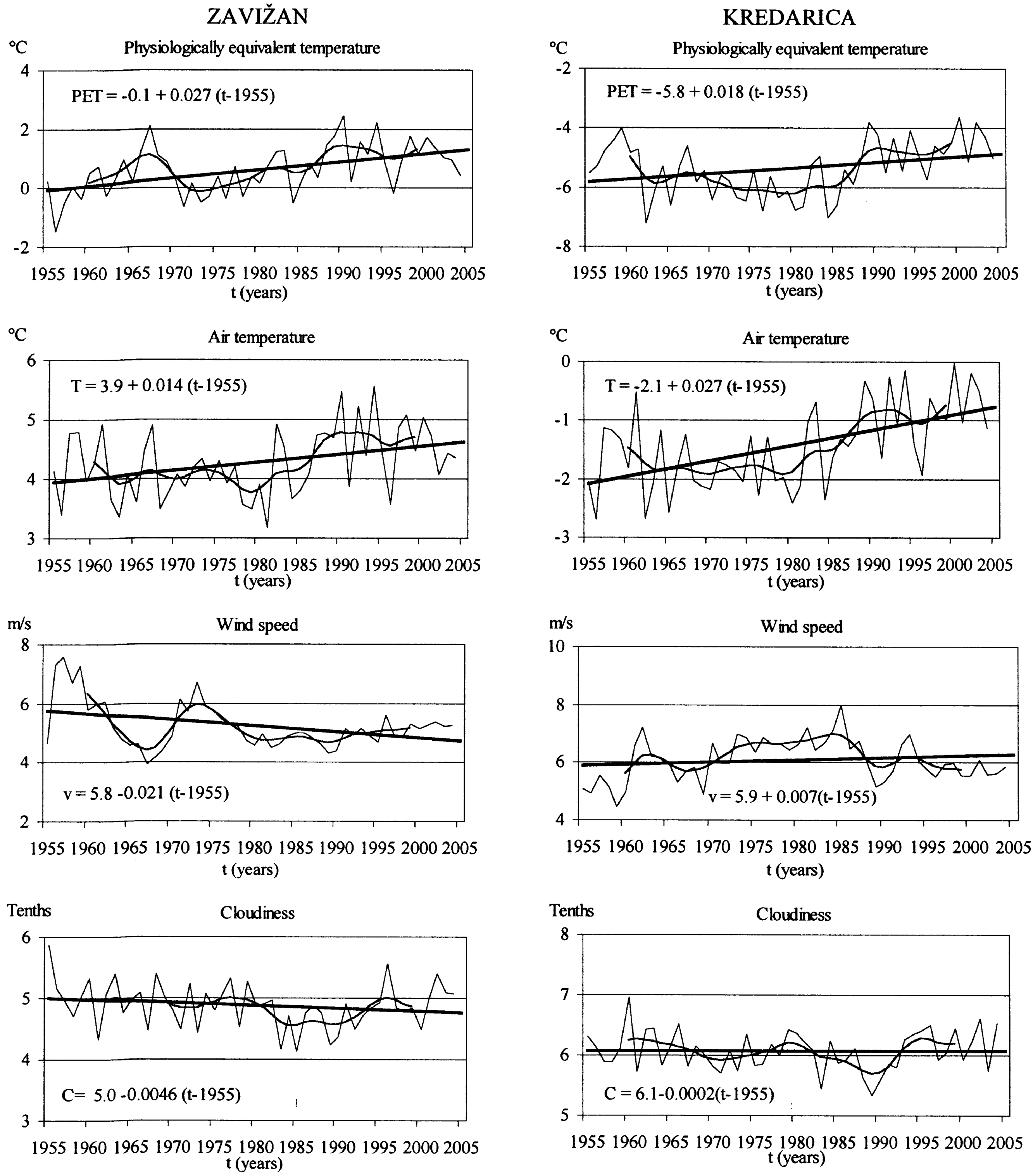

Figure 4: Annual variations of the physiologically equivalent temperature (PET in °C), air temperature (T in °C), wind speed (v in m/s) and cloudiness (C in tenths), weighted 11-year binomial moving average series, and linear trends during the period of 1955–2004 at Zavižan (left) and Kredarica (right).

at both locations – in 1988 at Zavižan and in 1989 at Kredarica, becoming significant a few years later (1999 at Zavižan and 1994 at Kredarica). Analysing by seasons, the positive trends in PET at Zavižan began between 1982 (summer) and 1987 (winter) and at Kredarica between 1988 (winter) and 1998 (spring and summer).

The physiologically most important factors of a high mountain climate are the increased UV radiation and wind speed, as well as reduced oxygen partial pres-

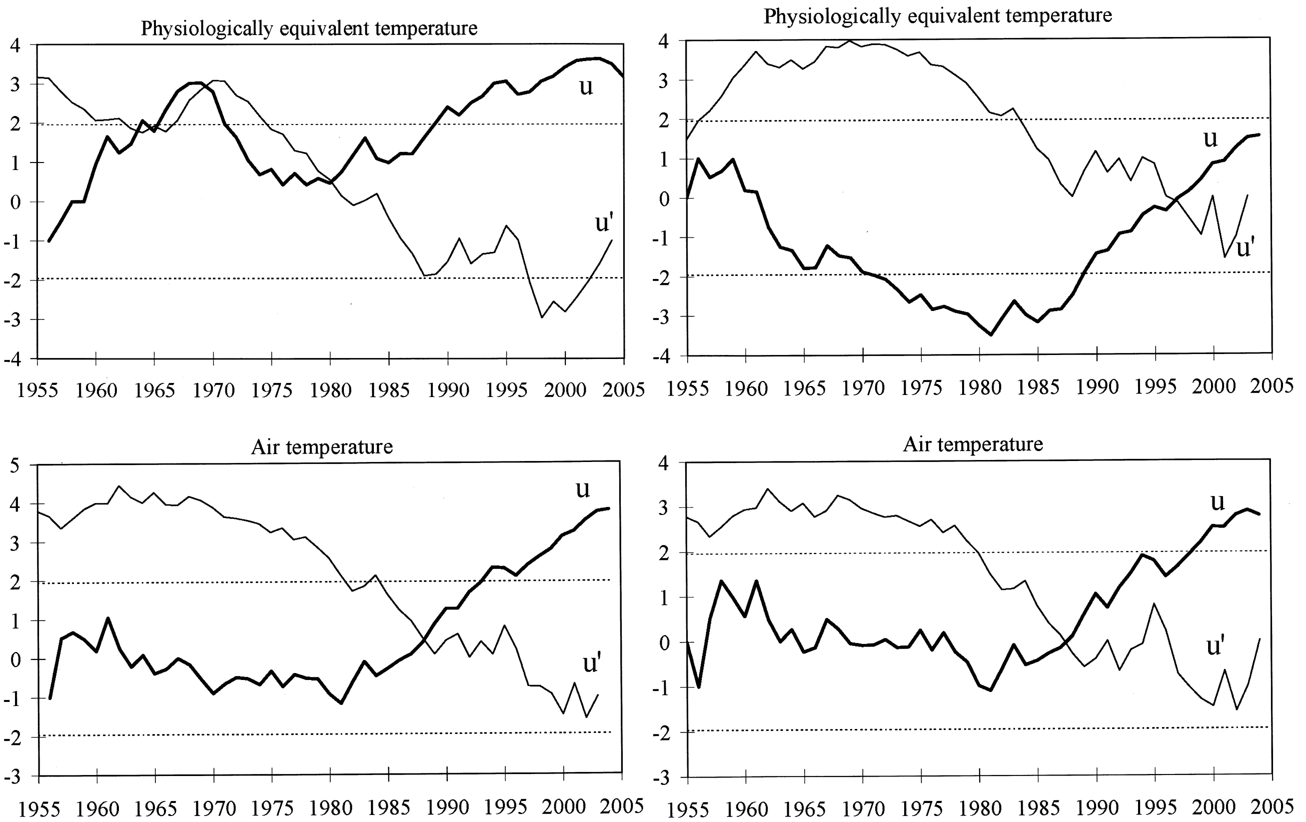

Figure 5: Progressive trend test: forward series u (bold) and backward series u' (thin line) for annual values of mean physiologically equivalent temperature and air temperature during the period of 1955–2004 at Zavižan (left) and Kredarica (right).

sure, lower air temperature, air humidity, and air pollution. Nevertheless, the most important difference between alpine and lowland climate is the absence of heat load, mainly because of the altitude, but also due to the presence of valley and slope breezes, and presence of forests with their characteristic microclimate. In a warm environment the body has to increase its circulation to allow heat exchange between the body and the environment, but evaporation is automatically limited by high air humidity. That's why a warm and humid environment is an additional strain and should be avoided. Since the local sources of air pollution are limited to those related to household heating, the clear, non-polluted air is another very important feature of the alpine climate.

4 Conclusion

The highest meteorological stations in Croatia and Slovenia showed a positive trend in thermal comfort and air temperature. The findings coincide with earlier studies on the trends in mean minimum and maximum air temperatures at Zavižan (GAJIĆ-ČAPKA and ZANINOVIĆ, 1997) undertaken for the period 1954–1995. Similar results for minimum and maximum temperatures gained BÖHM and AUER (1994) for Sonnblick and Zugspitze, STEFANICKI et al. (1994) for Säntis and BÖHM et. al (2001) for the European Alps until 1998. Opposite results of temperature changes showed BÜCHER and DESSENS (1991) for Pic de Midi. In spite of a considerable increase in thermal comfort in the last 50 years, the bioclimatic and thermo-physiological impact of the bioclimate conditions stayed within the range of the same class of thermal perception. There is a growing market for guided tours and other recreational activities in the pleasant climate and scenic environment of the Velebit. Kredarica will remain one of the most popular mountain destinations in the Slovenian Julian Alps. Climate change and increasing heat stress in areas of low altitude, but also the rapid development of eco-tourism, will make these mountain areas even more attractive for tourism, leisure and sporting activities.

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