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CLIMATIC CHANGES IN THE AUSTRIAN ALPS DURING THE PERIOD 1775-1989

Abstract: SNEYERS R., BÖHM R. & VANNITSEM S., *Climatic changesin the Austrian Alps during the period 1775-1989.* (IT ISSN 0391-9838, 1992).

The homogenized series of regional averages of temperature observations made in the Austrian network (58 stations) during the period 1775-1989 are submitted to a trend analysis based jointly on the use of the non-parametric Pettitt's change-point determination and on the sequential application of the non parametric Mann's trend test. At the seasonal scale, an abrupt decrease of the means is evidenced round 1830 for the four seasons, followed by abrupt increases placed round 1910 for winter and spring, and round 1930 for summer and autumn. The relation with the Alpine glaciers evolution is discussed.

KEY WORDS: Climatic variations, Glacier fluctuations, Austrian Alps.

Riassunto: SNEYERS R., BÖHM R. & VANNITSEM S., *Variazioni climatiche nelle Alpi Austriache nel periodo 1775-1989.* (IT ISSN 0391-9838, 1992).

Le serie omogenee delle medie stagionali della temperatura, registrate dalla rete termometrica austriaca (58 stazioni) durante il periodo 1775-1989, sono state sottoposte ad analisi basate congiuntamente sulla determinazione del *change point* non parametrico di Pettitt e sull'applicazione sequenziale del test di tendenza non parametrico di Mann. Su scala stagionale è stata evidenziata una brusca diminuzione delle medie intorno al 1830, in tutte le stagioni, seguita da un rapido incremento collocabile intorno al 1910 per l'Inverno e la Primavera e intorno al 1930 per l'Estate e l'Autunno. Vengono discusse anche le relazioni con l'evoluzione dei ghiacciai alpini.

TERMINI CHIAVE: Variazioni climatiche, Fluttuazioni Glaciali, Alpi Austriache.

INTRODUCTION

The homogenization of the temperature observations recorded in the Austrian network at stations which started between 1775 and 1931 and were in operation until 1989 was undertaken. A first study of the results obtained for the annual regional averages of the deviations from the mean computed for the period 1951-1980 deduced from a set of 40 stations was made (BÖHM, 1990).

This study revealed that the recent increase of temperature had been preceded by a decrease which occurred round 1830 (fig. 1).

The work extended afterwards to a total of 58 stations and a similar computation for the seasonal averages gave new indications on the climate evolution in Austria during the period 1775-1989 (BÖHM, 1991). The graphical representation of the annual values at the seasonal scale corroborated that opposite abrupt changes occurred respectively round 1830 and at the beginning of this century. This engaged us to subject the series to a complete statistical analysis analogous to the one applied to the temperature series of Brussels-Uccle for the period 1833-1988 (SNEYERS & *alii*, 1990).

The purpose of this paper is to describe the metod and its results as well as to characterize and evaluate the two climatic changes. Moreover, the conclusions involve considerations concerning the consequences on the glaciological evolution in the Alps.

THE DATA

The chronology of the type of stations successively involved in the computation of the general average shows that during the whole period some variations occurred in the proportion of stations of each type. For what concerns especially the valley stations, to their absence in the average until 1850 succeeded a proportion growing up, from 1851 to 1854, from 25% to about 40% and subsequently to about 50% in 1896, this proportion remaining afterwards quasi constant.

Note that for computational convenience, winter has been attributed to the year of December.

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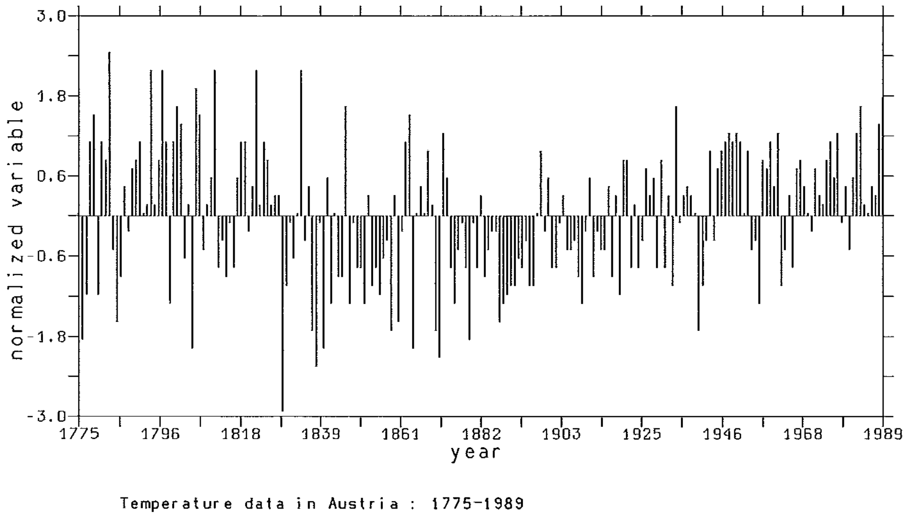

FIG. 1 - Annual averages of the temperature for the Austrian network from 1775 to 1989. Standardized deviations from the average.

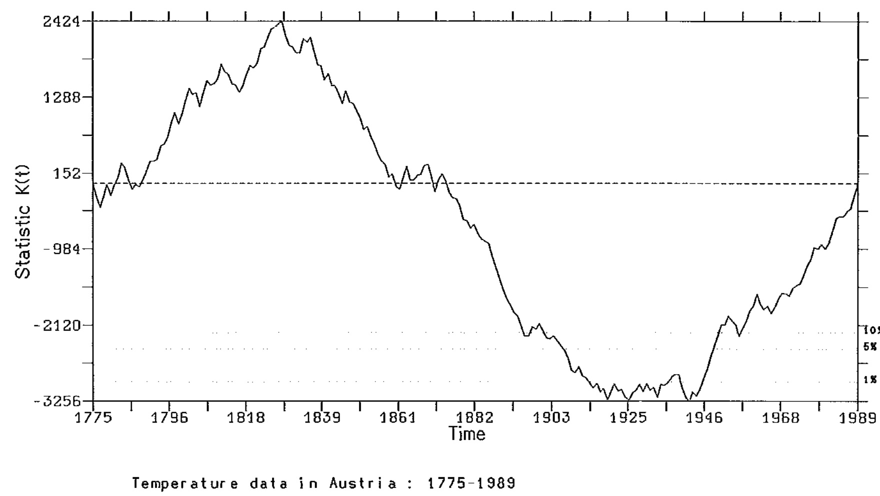

FIG. 2 - Annual averages of the temperature for the Austrian network from 1775 to 1989. Values of the statistic of Pettitt's change-point test.

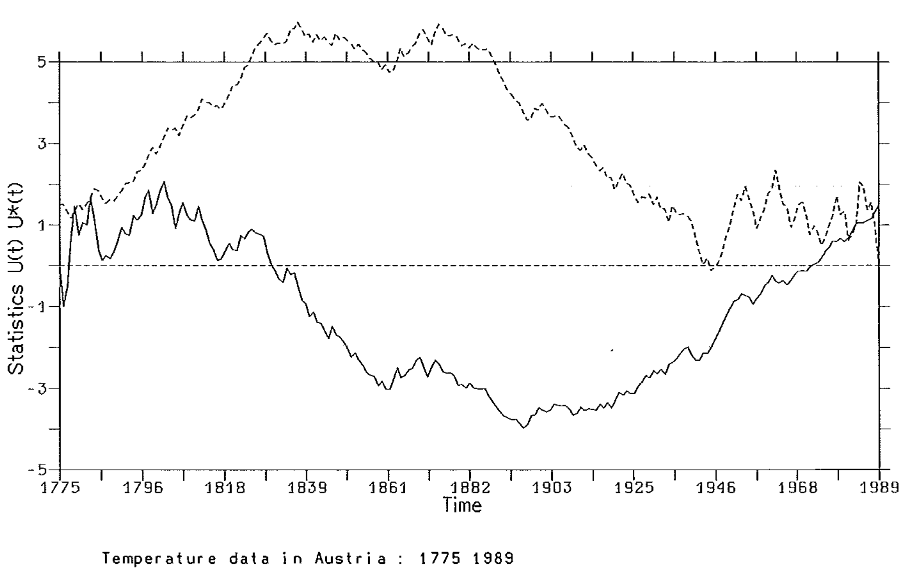

FIG. 3 - Annual averages of the temperature for the Austrian network from 1775 to 1989. Sequential onward (full line) and backward (dashed line) trend analysis. Standardized values of Mann's test statistic.

TABLE 1 - Standardized trend statistic u(t) and extreme $u(t)_{ext}$ for the periods 1775-1909 and 1828-1989. Change-points P_1, P_2 and P_3 inside the series 1775-1989. Corresponding temperature abrupt changes δ_1, δ_2 and δ_3. Standard errors s_m for the average and standardized serial correlation statistic u(r) for each subseries. Seasonal values for Winter (Wi), Spring (Sp), Summer (Su) and Autumn (Au).

	Wi	Sp	Su	Au
		1775-1909		
u(t)	−0.24	−3.00	−4.17	−2.16
$u(t)_{ext}$	−1.26 (1985)	−3.00 (1909)	−5.55 (1926)	−2.94 (1922)
		1829-1989		
u(t)	3.83	3.59	1.39	3.91
$u(t)_{ext}$	4.08 (1825)	4.33 (1837)	3.34 (1882)	4.51 (1874)
P_1		1836	1828	1827
P_2			1881	
P_3	1908	1911	1926	1925
δ_1	−0,41 °C	−0.87 °C	−0.62 °C	−0.47 °C
δ_2	0.15 °C	0.07 °C	−0.55 °C	−0.20 °C
δ_3	0.91 °C	0.62 °C	0.70 °C	0.94 °C
		1775-1829		
s_m	0.26 °C	0.18 °C	0.15 °C	0.14 °C
u(r)	−0.35	1.06	0.80	0.89
		1830-1910		
s_m	0.18 °C	0.11 °C	0.09 °C	0.10 °C
u(r)	−0.11	0.30	−0.89	−1.42
		1930-1989		
s_m	0.20 °C	0.14 °C	0.08 °C	0.11 °C
u(r)	2.60	−0.20	1.25	−1.03

THE STATISTICAL METHOD

To analyse the structure of the series of observations, use has been made of Mann's trend test (MANN, 1945), in a sequential onward and backward way (SNEYERS, 1958, 1975 and 1990), and of Pettitt's change-point test (PETTITT, 1979; SNEYERS & *alii*, 1990; DEMAREE, 1990), the two tests being non parametric, i.e. independent of any assumption concerning the form of the distribution of the data.

A change-point divides a chronological series into two independently distributed stable subseries with non homogeneous means. It follows that its existence is evidenced when the sequential analysis concludes to the stability of the series until and from such a point and when, at the same time, the total analysis concludes to a trend significant at the chosen level. The optimal estimation of the change point is then given by the extreme value of Pettitt's test statistic.

If several change-points exist, their existence may be found by applying Pettitt's test to the complete series and by pointing out the extreme values (maximum and minimum values) of the test statistic. Of course, in this case, the significant character of these extremes has to established and the analysis has to be extended to the subseries defined in this way.

RESULTS

The Annual Averages

Figure 2 gives the graph of Pettitt's test statistic for the general annual averages from 1775 to 1989. The main feature appearing from this graph is the existence of two extreme values, the first one occurring in 1828 and the second one placed approximately between 1910 and 1940.

Their significance is established by the fact that the sequential trend analysis (fig. 3) concludes for the series 1775-1910 to a decreasing trend significant at the $1.5 \cdot 10^{-4}$ level and for the series 1829-1989 to an increasing trend significant at a level smaller than $3 \cdot 10^{-7}$.

Moreover, the same analysis applied to the series 1830-1910 concludes to the stability of the series.

For what concerns the sequence 1829-1989, the sequential analysis shows that the standardized trend test statistic takes systematic positive values after 1910, but that after 1941, the series remains stable. Therefore, to evaluate the amplitude of the climate changes, the averages of the periods 1775-1828, 1829-1909 and 1942-1989 have been computed. The results being respectively in 0.1 °C : 0.61, −6.00 and 1.31, we may conclude that the progressive increase which occurred this century, of 0.7 °C, succeeded to an equivalent abrupt decrease placed in 1828.

The Seasonal Averages

For the significance of the trends at the seasonal level, the trend test has been applied to the seasonal averages of the periods 1775-1909 and 1829-1989.

The standardized values u(t) of the test statistic (table 1) are all indicative of decreasing trends in the first case and of increasing trends in the second one. Moreover, the sequential analysis shows, in the first case, for summer and autumn, larger absolute values $[u(t)_{ext}]$ for the test statistic beyond 1909, while in the second one, if such values are also found for the four seasons, the single one before 1829 concerns Winter.

For the significance of these values, taking into account that four independent tests are simultaneously applied, at the 5% level of significance, the probability for the critical value is $(0.95)^{1/4} = 0.98726$. For a normal standardized test statistic and for a one sided test, the corresponding value is: ± 2.23.

It follows that, except for the decrease of the winter temperature, all the trends are significant at the chosen level. In particular, even if we take account of the shorter lenght of the series 1882-1989, the increase for Summer is also significant at that level, due to the value 3.34 (1882).

The change-points P_1 and P_3 (tab. 1) have been estimated by applying Pettitt's test to the complete series, in the same manner as for the annual averages.

For what concerns the stability of the temperature during the periods separated by the ends of the total series and the change-points, all the subseries have been found to be stable, except Summer for which a secundary significant change-point P_2 has been detected in 1881.

The values δ_1, δ_2 and δ_3 of the corresponding temperature changes are also given in table 1, δ_1 and δ_2 being computed using 1828 and 1881 as change-points.

Finally, the standard errors on the mean and the standardized statistic of WALD & WOLFOWITZ' serial correlation test (1943) have been computed for common periods of stability for the four seasons.

From the standard errors (tab. 1), it appears that the estimation of the temperature changes has a standard error of about 0.14 °C, except for winter for which this error amounts twice this value.

For the serial correlation statistic, at the 5% level of significance, account being taken that we have a set of 12 independent tests, the winter series 1930-1989 is the single one which is nearly significant. This significance may be related to the succession of three mild winters at the end of the series and allows to accept the assumption of independence for the subseries defined by the change-points.

CONCLUSIONS

The abrupt changes found at the seasonal scale for the Alps are in good accordance with the ones discovered for Brussels and for Paris (SNEYERS, 1958) and confirmed each time in subsequent studies (SNEYERS, 1971, 1990).

For what concerns the seasonal variability of δ_1 and δ_3, it should be noted that a chi-square test applied to the deviations with their annual average leads to a non significant value of the test statistic at the 5% level. We may thus conclude to the homogeneity of both changes at the seasonal level.

This result allows an interesting remark relative to the influence of these changes on the glaciological evolution in the Alps during the considered period of observation.

In this respect, note that PELFINI & SMIRAGLIA (1988, fig. 2) have shown that the percentage of glaciers in recession after 1930 remained larger than 50%, which is the equilibrium percentage, until 1965, which means more than 50 years after the beginning of the warming during this century.

Moreover, remembering that we assume that spring and autumn play the main role in the glaciers evolution (SNEYERS, 1971), it seems that the temperature decrease of 1828, which is practically compensated by the recent increase, might have had an opposite effect with an equivalent persistence, the maximum of the glaciation having then probably occurred after 1880. However, this assumption has to be accepted with some caution, the present state of the Alpine glaciers being apparently not the same as the one existing before the cooling of 1828 (OROMBELLI & PORTER, 1982).

Finally, let us mention that the point of the abrupt change of 1881 entails further investigations, even if replacing the summer sample of 1827-1926 in the set of 4 samples of 100 years taken from a total sample of 215 years, this change is only scarcely significant at the 5% level.

REFERENCES

BÖHM R. (1990) - *Temperature Trends of High Stations in the Austrian Alps.* Veröffenntlichungen der Schweizerischen Meteorologischen Anstalt, Tagungsbericht, ITAM-90, 21. Internationale Tagung für Alpine Meteorologie, 322.

BÖHM R. (1991) - *A Mesoscale Investigation of Longtime Temperature Variations in Austria.* Ann. Geophysicae, European Geophys. Soc., IV General Assembly, Wiesbaden, Suppl. Vol. 9, 128.

DEMAREE G. (1990) - *Did an Abrupt Global Climate Warming occur in the 1920s?.* In: Contributions à l'étude des changements de climat. Inst. R. Météor. Belgique, Pub. A, *124*, 32-37.

MANN H.B. (1945) - *Non parametric test against trend.* Econometrika, 13.
OROMBELLI G. & PORTER C. (1982) - *Late Holocene Fluctuations of Brenva Glacier.* Geogr. Fis. Dinam. Quat., *5*, 14-37.
PELFINI M. & SMIRAGLIA C. (1988) - *L'evoluzione recente del glacialismo sulle Alpi italiane*, Boll. Soc. Geogr. Ital., ser. XI, *5* (1-3), 127-154.
PETTITT A.N. (1979) - *A non-parametric Approach to the Change-point Problem.* Appl. Statis., *28* (2), 126-135.
SNEYERS R. (1958) - *Connexions thèrmiques entre saisons consécutives à Bruxelles-Uccle.* Inst. R. Météor. Belgique, Pub. B, *23*, 24 pp.
SNEYERS R. (1971) - *La détermination de la stabilité du climat par l'analyse statistique des séries d'observations; un exemple: la température de l'air et l'eau recueillie à Bruxelles-Uccle de 1833 à 1969.* Ann. Météor., N.F., *5*, 205-208.
SNEYERS R. (1975, 1990) - *Sur l'analyse statistique des séries d'observations.* Note technique N. 143. Organisation Météor. mondiale, Genève, 192 pp. (French and English versions).
SNEYERS R., VANDIEPENBEECK M., VANLIERDE R. & DEMAREE G. (1990) - *Climatic changes as appearing from the homogenized series of observations made in Brussels-Uccle (1833-1988).* In: Brazdil, R. Ed., *Climate Change in the historical and industrial Periods.* Masaryk University, Brno, 170-174.
WALD A. & WOLFOWITZ J. (1943) - *An exact test for randomness in the non-parametric case based on serial correlation.* Ann. Math. Statis., *14*, 378-388.