IDŐJÁRÁS

QUARTERLY JOURNAL
OF THE HUNGARIAN METEOROLOGICAL SERVICE

CONTENTS

****

http://www.met.hu/firat/ido-e.html

VOL. 103 * NO. 4 * OCTOBER–DECEMBER 1999

IDŐJÁRÁS

Quarterly Journal of the Hungarian Meteorological Service

Editorial Office: P.O. Box 39, H-1675 Budapest, Hungary or
Gilice tér 39, H-1181 Budapest, Hungary
E-mail: prager@met.hu or *antal@met.hu*
Fax: (36-1) 290-7387

Subscription by

mail: IDŐJÁRÁS, P.O. Box 39, H-1675 Budapest, Hungary;
E-mail: prager@met.hu or *antal@met.hu*; *Fax: (36-1) 290-7387*

IDŐJÁRÁS

Quarterly Journal of the Hungarian Meteorological Service
Vol. 103, No. 4, October–December 1999, pp. 219–235

Arctic climate empirical diagnostics: a contribution to the climate change debate

V. N. Adamenko[1], **K. Ya. Kondratyev**[2] and **C. A. Varotsos**[3]

[1]*Polar Marine Academy, Butlerova Str., 8-227, St. Petersburg 195220, Russia*
[2]*Research Centre for Ecological Safety, Russian Academy of Sciences, Korpusnaya Str., 18, St. Petersburg 197110, Russia; e-mail: nansen@online.ru*
[3]*University of Athens, Panepistimioupolis, Build. PHYS-V, Athens, Greece, e-mail: kvarots@atlas.uoa.gr*

(Manuscript received 5 January 1999; in final form 17 September 1999)

Abstract—A hypothesis that global climate warming observed during the last century has been due to anthropogenically induced carbon dioxide concentration growth provoked controversial response. In this context, general considerations have been discussed supporting the viewpoint that the "greenhouse" global warming hypothesis is doubtful, although, of course, the greenhouse effect contribution should be taken into account. One of the strongest arguments in favor of the above hypothesis is a conclusion drawn from numerical climate modeling data that there must be an enhancement of the "greenhouse signal" with latitude. In this paper some results of surface air temperature (SAT) observations in the Arctic during the last 20–30 years have been discussed which demonstrate a reduction in SAT in a number of Arctic regions. Some dendroclimatic data relevant to tree growth near the northern forest boundary have also been considered. Analysis of these data (covering larger time periods) reveals that not only the conclusion about polar enhancement of climate warming is wrong but the warming itself could hardly be realistic. So it may be concluded that no noncontroversial information exists that can support the hypothesis of global "greenhouse" warming.

Key-words: global climate change, polar warming enhancement, dendrochronology data, Framework Convention on Climate Change, climate modeling, the Arctic.

1. Introduction

The problem of global climate change has attracted great attention during the recent decades (see *Adamenko,* 1985a; *Barnett,* 1999; *Bengtsson et al.,* 1999; *Brauch,* 1996; *Browning* and *Gurney,* 1999; *Emsley,* 1996; *Flower,* 1999; *Hansen et al.,* 1998; *Houghton et al.,* 1996; *Jain et al.,* 1999; *Kondratyev,* 1992, 1998, 1999; *Manabe,* 1998; *Mason,* 1995; *Mysak* and *Venegas,* 1998;

Postmentier et al., 1999; *Raschke,* 1996; *Schoenwiese,* 1996; *Scorer,* 1996; *Singer,* 1997; *Storch* and *Floeser,* 1999; *Warnecke,* 1997; *Watanabe* and *Nitta,* 1999; *Weber,* 1996; *Wigley,* 1998; *Wiin-Nielsen,* 1998; *Yao* and *Del Genio,* 1999, and others). The problem has mainly been discussed in the context of the "greenhouse stereotype", which proceeds from the assumption that global climate warming which took place in the course of the current century had been due to an enhancement of the atmospheric greenhouse effect caused by the growing concentration of carbon dioxide and other greenhouse gases (GHGs) in the atmosphere.

Even according to the assessment presented in the Report of the Intergovernmental Panel on Climate Change (IPCC), it is stated that "the balance of evidence suggests a discernible human influence on global climate" (*Houghton et al.,* 1996). The assessment of this kind of ideas, discussed in detail earlier (*Kondratyev,* 1992, 1996, 1997, 1998, 1999; *Kondratyev et al.,* 1996; *Kondratyev* and *Cracknell,* 1998, etc.), is not only of academic interest. It is in this context that the Framework Convention on Climate Change (FCCC) approved by the UN General Assembly recommends to reduce the amount of carbon dioxide emissions to the atmosphere by the year 2000 to the level of the year 1990, and this is a minimum demand. Later much stronger reductions have been recommended by the Third Conference of the Parties in Kyoto (*Schneider,* 1998) which, however, have not been quantitatively substantiated so far.

In this context, a non-biased evaluation of the justification of broadly spread estimates of anthropogenic impacts on climate acquires an exceptional importance. Evaluations, which are in discordance with the IPCC conclusions, can be found in quite a number of recent publications (see, for instance, *Ellsaesser,* 1992; *Emsley,* 1996; *Jastrow et al.,* 1990; *Kahl et al.,* 1993; *Kondratyev,* 1992, 1996, 1998; *Singer,* 1997; *Weber,* 1996, etc.). These evaluations, however, have not met adequate attention or have been ignored altogether. In the meanwhile, it is a matter of not minor remarks (concerning, for example, the IPCC reports) but of judgements of principal nature.

In this connection, *Singer* (1997) has been quite right to state that the science of climate is full of uncertainties of principal importance resulted from the fact that relevant observational data are insufficient and numerical climate models are far from being perfect. Here are some of the causes of these uncertainties.

- The problem of the global carbon cycle has not been solved so far, especially in the part relevant to the acquisition of anthropogenic carbon dioxide emissions by the ocean (the "biological pump" role) and the functioning of the land biosphere as a source or sink of carbon (the problem of the "missing" carbon sink). This creates great uncertainties in predicting the carbon dioxide concentration growth in the next century, especially if one takes into account the difficulty of prediction of time changes in using fossil fuels in the future.

- The quality of data on the surface air temperature for the recent century is not quite up to the mark.
- Discrepancies between the results of temperature change calculations made with different climate models sometimes reach 300%; many of the climate models do not take into account meso- and microscale processes in clouds or numerous processes of the interaction between the atmosphere and ocean which are of crucial importance.
- Climate models are incapable of adequately reproducing and accounting for climatic changes in the 20th century, such as a SAT rise from 1920 to 1940, a cooling before 1975 and the absence of warming in satellite data on the tropospheric climate, beginning with 1979 (*Ellsaesser,* 1992) (see also more recent publications, such as *Kondratyev,* 1998, 1999; *Postmentier et al.,* 1999).
- Climate models are incapable of explaining rapid paleovariations (on a decadal level) discovered from the data of the analysis of tree rings, ice cores, sea and lake sediments (*Fischer et al.,* 1999). Such significant events as El Niño/Southern Oscillation (ENSO), the North-Atlantic Oscillation and other rapid contemporary climatic changes have not been predicted from numerical modeling (although significant progress has been recently achieved in predictions of ENSO).
- Estimates of potential World Ocean Level (WOL) rise due to global warming have been broadly discussed but proved unreliable. One cannot exclude the possibility that enhanced evaporation from the sea surface may lead to a faster accumulation of polar glaciers, and consequently, to a drop in the ocean level. The suggestion can be supported by the presence of a negative correlation between the WOL rise and SAT in the tropics (see also recent papers published in *Annals of Glaciology*, 1998, Vol. 27).
- The repetition rate of strong storms and hurricanes has not increased during the recent 50 years, whereas under conditions of a global warming (following from the calculated decrease of the latitudinal temperature gradient) the opposite situation must prevail (see a recent paper by *Fu et al.,* 1999).
- Because the increase of carbon dioxide concentration stimulates photosynthesis, and the increase in SAT mostly observed in the nighttime and in winter leads to a longer duration of the vegetative season, this should be favorable for agriculture under conditions of a global warming and sufficient moistening. It is also important that agriculture has ample capacity for adaptation to climatic changes (*Kondratyev,* 1998).

Perhaps, the least expected and rather paradoxical aspect of contemporary research in climate and its variability is related to the conclusions of studies on the empirical diagnostics of observational data and indirect indicators of the state of the climatic system. The continuing analysis of observational data revealed new regular features of SAT variations and other climate characteristics. In particular, this is relevant to the high latitudes of the Northern Hemisphere (*"Are Human Activities...?"*, 1995; *Grotefendt et al.*, 1998; *Kahl et al.*, 1993; *Kondratyev et al.*, 1996; *Lovelius*, 1997; *Vaganov et al.*, 1996; *Report*, 1998, etc.).

2. Some results of the analysis of observational data and indirect indicators of the state of the climatic System as global climate change (CC) indicators

2.1 The "anthropogenic" CC signal

The discussion on the detection of the so-called "anthropogenic" signal is being continued (*Kondratyev*, 1998). Numerical climate models (CM) and their paleoclimatic analogs are inadequate to assess the reality: for example, predictions of a "polar enhancement" of warming have not been confirmed by empirical data (*Adamenko*, 1985a,b; *Adamenko et al.*, 1982; *Anisimov*, 1998; *Grotefendt et al.*, 1999; *Kahl et al.*, 1993; *Kondratyev*, 1998; *Vaganov et al.*, 1996; *Woodcock*, 1999; *Zakharov*, 1996). The numerical forecasting of precipitation does not reproduce the present-day climate either (*Anisimov*, 1998; *Vaganov et al.*, 1996; *Drozdov* and *Lugina*, 1998; *Zakharov*, 1996). This is doubtless in the inadequate results of the description of physical processes such as feedbacks due to cloudiness, sea ice dynamics, the halocline state in polar oceans, etc.

As it has been revealed by *Anisimov* (1998), the correlation between the summer temperatures over the continents and the carbon dioxide concentration variations predicted by means of paleoreconstructions and CM is negative. Variations in precipitation predicted by CM are often statistically unreliable. Most paleoreconstructions indicate an enhanced humidification of the continents during warming. A great uncertainty in the assessment of future precipitation makes it very difficult to assess many of CC consequences.

2.2 Mountain and sea ice dynamics as an indicator of CC

The frequently used conclusion that the state of mountain and sea ice dynamics is a reliable indicator of CC, is in fact controversial. The location of glacier edges, i.e., their retreat or advance, depends not only (and not so much) on climate as on the rheological state of glaciers: motion speed, bed friction, surface inclination, thermophysical parameters of the firn and ice thickness. Glaciology cannot offer a reliable explanation of the causes of the time-dependent motion of glaciers (*Adamenko*, 1985a). That is why the data on periods of the retreat or advance of mountain glaciers can only be used as very approximate indicators of anthropogenic or natural changes in the climatic system (CS) (*Zakharov*, 1996).

The use of "the environment-glaciers" models for the diagnostics and predictions is only possible in some particular cases, and only if the physical nature of the processes of the external mass-energy-exchange and of boundary and initial conditions is well known.

2.3 Sea ice cover dynamics

An equal degree of uncertainty is present in the characteristics of sea ice cover dynamics: the sea ice cover extent, thickness, age, motions and structure, in spite of the fact that the data of satellite remote sensing made it possible to obtain a realistic picture of the phenomenology of the processes—the boundaries dynamics and extent changes. However, the cause-and-effect features of the ice cover dynamics have not been adequately explained (*Kondratyev*, 1998; *McPhee et al.,* 1998; *Zhang et al.,* 1998, and others). According to Zakharov's concept (*Zakharov,* 1996), CC is not simply the cause of ice cover transformations; the sea ice cover dynamics at high latitudes, which is dependent upon the thickness and specific features of the three-dimensional structure of the halocline, the advection of water masses and ice and other factors, should be regarded as an interactive climate-forming factor (here the non-linearity of relevant dependences is important). When analyzing the sea ice dynamics, it is important to adequately consider the spatial-temporal variability of the processes of the ice accretion, ablation and motions. Of course, it is obvious that, in general, the interrelationships between sea ice dynamics and climate change are of interactive nature.

As an illustration, we examine the causes of the well-known reduction in the extention of sea ice cover in the Arctic seas during the 1920s–1930s, as well as that of the mountain and surface ice changes in the Arctic and Sub-Arctic and other mountain regions of the Northern Hemisphere. It is known that the climate change at that time mainly revealed itself as a warming of the cold season and an enhancement of precipitation. It was due to or accompanied by a certain transformation of macrocirculation conditions (*Adamenko,* 1985a,b; *Drozdov* and *Lugina,* 1998; *Vaganov et al.,* 1996; *Zakharov,* 1996)—a higher frequency of cyclonic circulations and a less frequent repetition of anticyclonic ones, a shift of cyclone trajectories to relatively higher latitudes. Considering these observational data, one cannot attribute the decrease of ice cover extent to the enhancement of ice ablation. The causes may be due to the following causes: (a) the advection of sea ice to lower latitudes; (b) the decrease of the ice formation intensity; (c) the increase of the duration of sea ice ablation, etc.

2.4 Possible causes for the retreat of mountain glaciers

During an Arctic warming, the retreat of mountain glaciers can hardly be explained by enhanced ablation (*Adamenko,* 1985a). Among possible causes of glaciation degradation in the mountains during the warming epoch, there are the following:

- The speed of motion of glaciers, and consequently, the advection of ice to the apron parts of glaciers can decrease as a result of the approaching "negative" component of the anomalies of the Nay-Shumsky kinematic wave (*Shumsky,* 1968). As a result, the weakening of ice advection from the firn glacier parts to the apron ones takes place. It is known that every glaciation centre, every glacier has its characteristic time of response to changes in the mass-energy exchange in time and space. This time depends on many causes, part of which influences non-linearly the ice advection and has not been adequately studied thus far. The weakening of the ice advection of mountain glaciers may be a response to the decrease of the accumulation of firn and ice during the minor glacial epoch (the 1870s–1880s).
- Decrease in the cooling of glaciers in the cold season which might be a result of wintertime warming and possible increase of cloud amount under conditions of the high cyclonic activity during the period climate warming in the Arctic.
- Longer duration of the ablation period in the warming periods at high latitudes (*Adamenko,* 1985a; *Anisimov,* 1998).

3. Empirical diagnostics of climate change

Observational data for the aquatic areas of the Northern Hemisphere indicate the existence of some ocean areas where, during the recent 3–4 decades, a decrease in air temperature and sea surface temperature (SST) occurred. Analysis of these data makes it possible to conclude that a uniform "polar enhancement" of climate warming does not actually exist.

Large regions, where inter-latitudinal temperature contrasts have enhanced, are clearly pronounced. Such regions have stably existed during the recent decades. It is essential that the appearance of these regions is connected with a well-known (and unpredicted by theory) phenomenon: increased moistening over the water catchment area of the Caspian Sea (*Adamenko,* 1985a). The phenomenon revealed itself as a substantial sea level rise and a considerable transformation of macrocirculation conditions over vast territories from the Atlantic to Western Siberia and Central Asia (*Adamenko,* 1980, 1985a,b; *Kondratyev,* 1992; *Vaganov et al.,* 1996, etc.).

These phenomena have not been predicted by numerical modeling and have been quite unexpected. Their causes should be sought in the manifestations of a whole number of factors that have not been adequately studied thus far, viz., autooscillations in the "ocean-atmosphere-polar ice" system, changing of the atmospheric optical transparency, which, in its turn, depends on quite a number of causes (volcanic eruptions, time-dependency of cloudiness fields, transport of aerosols from natural and anthropogenic sources, etc.).

Analysis of aerological data from high latitudes makes it possible to draw the following conclusions:

- The speed of motion of glaciers, and consequently, the advection of ice to the apron parts of glaciers can decrease as a result of the approaching "negative" component of the anomalies of the Nay-Shumsky kinematic wave (*Shumsky,* 1968). Instead of the expected warming, in a number of sectors of the Northern Hemisphere—from the equator to the high latitudes—the process of cooling took place during the periods 1961–1970 and 1981–1990 (*Drozdov* and *Lugina,* 1998).
- According to the data of the "North Pole" stations summarized for the entire period of their operation, the process of cooling was taking place in Central Arctic with a centre mainly in the American sector of the Arctic (*Zakharov,* 1996). This conclusion can be confirmed by independent data (*Kahl et al.,* 1993) which reveal the lack of evidence of anthropogenic warming predicted by numerical climate modeling. During the time period 1950–1990, seasons and regions of cooling near the surface and in the troposphere have been found out in the polar region of the Northern Hemisphere.
- It is important that, in connection with a cooling in the Arctic, in a number of its sectors regions have appeared where temperature gradients increased between the high and middle latitudes in the European sector of Eurasia during the recent 2–3 decades. This kind of increase is mostly characteristic for cold epochs observed in the past. The marked increase of temperature contrasts between the middle and low latitudes during the recent decades may be in correspondence with the discovered enhancement of cyclogenesis in the south-western part of the North Atlantic (*Adamenko,* 1985a; *Drozdov* and *Lugina,* 1998; *Radionov et al.,* 1996).
- Forecasts of increased dryness in the European Russia, which should follow from the anticipated warming at the end of the 20th century, have proved wrong; one of indicators of the above is the fact that the Caspian Sea level ceased to drop but started rising instead. It is important that similar phenomena have been discovered (from instrumental and paleoclimatic data) for cold epochs (*Adamenko,* 1985a).

It can therefore be concluded that the hypothesis of anthropogenic warming and its variability in time and space has not been confirmed by the empirical climate diagnostics. It is not confirmed either by the analysis of some indirect CC indicators which will be examined below.

4. The state of large lakes as an indicator of climate change

The liquid water and heat balance of water catchment regions and aquatic areas of large lakes are responsible, to a great extent, for their level regime, trophic status, natural and anthropogenic variability (*Adamenko*, 1985a). For shallow and relatively small lakes, their hypsometric and morphometric specific features may result in situations when the same changes of components of the heat and water balances due to CC can result from very different, non-linear response of the level regime. This means that it is not always and not for all closed waterbodies true that their level regimes and their variations may be considered to be indicators of climate change (in this respect, an analogy can be found with the above-considered state of glaciers).

As has been noted above with regard to the Caspian Sea water catchment area, its response to CC should be considered taking account of the specific atmospheric conditions over the vast territory from the Atlantic to Western Siberia and Central Asia, from the Arctic to the subtropical latitudes (*Adamenko,* 1985a).

Analysis of the air temperature and precipitation anomalies in the water catchment area of the lake of Taimyr located at high latitudes has shown that the present epoch is rather characteristic of a cooling than a warming of climate in the region (*Adamenko,* 1985b). This is revealed by the higher frequency of negative temperature anomalies and precipitation during almost every month of the year; by the level regime and trophic state of the waterbody. The present-day decrease in the atmospheric moisture content and the cooling are very similar to the conditions of the end of the past and beginning of the present century.

5. Dendroclimatic indicators of climate change

5.1 Introductory remarks

Because the data of instrumental observations are limited in time, it is necessary to seek for and use indirect indicators of the state of the climatic system (CS) (see *Adamenko,* 1985a,b; *Anisimov,* 1998; *Brauch,* 1996; *Cheddadi et al.,* 1997; *Duursma* and *Carroll,* 1996; *Houghton et al.,* 1996; *Jaenicke* and *Weidner,* 1996; *Jastrow et al.,* 1990; *Kahl,* 1993; *Kondratyev,* 1998; *Report,* 1998; *Vaganov et al.,* 1996; *Warnecke,* 1997; *Weber,* 1996, etc.). Analysis of dendroclimatic indices makes it possible to assess long-term climate dynamics. Individual trees are known whose age is over 1000 years (in the Central Asian mountains, at the upper forest boundary), up to 600–800 years (in the forest-tundra, at the northern forest boundary): archa and larch, respectively; the gigantic sequoia in North America can be several thousand years old. The use of fossil and flooded wood makes it possible to obtain dendrochronological data for periods over 5 thousand years and more. Information obtained from tree rings allows to determine the temporal variation of various carbon isotopes, carbon dioxide, heavy metals penetrating the trees from the soil, as well as brought from the atmosphere due to dry and wet deposition (*Adamenko,* 1985a).

The main difficulty in reconstructing the climate signal from dendrochronological data is the necessity to filter out the contribution of other factors which influence the growth rate of tree rings. Such factors may be the photosynthetically active radiation, the state of the soils during the vegetation period, wintertime climatic conditions, the possible Markov type of tree growth processes (the dependence of subsequent conditions on the prehistory), the state of mineral and organic nutrition, photosynthesis conditions, etc.

Various methods have been developed in dendrochronology (*Lovelius,* 1997; *Vaganov et al.,* 1996) for taking into account the biological curve of growth. These methods make it possible to obtain the so-called dendrochronological growth rate indices I, which depend only on changing external conditions: the heat-to-moisture relationships, the photosynthetically active radiation (PAR), aeration, mineral nutrition, etc. Biologists assume (although this should be verified) that for trees which have reached the limit of growth conditions (or tolerance conditions), the value of index I is determined by a certain principal limiting factor. If $I > 1.00$, the external conditions determining the annual productivity are considered to be close to the average, and factors determining the annual production are considered to be favorable; if $I \leq 1.0$, a decrease in the annual productivity (inhibition) is considered to take place.

It is supposed that near the northern boundary of forest propagation the annual production is limited by the thermal regime, whereas at the southern boundary the decisive factor for the annual production is the moisture regime. In reality, analysis of the influence of the external environmental factors on forest productivity, and consequently, on tree ring width and other indicators of the state of trees in the sites of their growth, requires an individual and complex approach to the study of dendrochronological indices for the purpose of detecting different "signals", including those due to the effects of heat and moisture.

5.2 Observation data

Vaganov et al. (1996) and *Lovelius* (1997) discussed the indicative properties of dendrochronological indices. Their monographs contain information databases obtained from vast territories of the northern forest boundary in the Sub-Arctic and other regions. The initial data processing answered the following questions: (1) Is reconstruction of various CC indices from these data possible? (2) Are various CS indices, reconstructed from qualitative indicators, homogeneous in time and space? (3) What are present-day CC trends if one obtains them from qualitative CS indicators? (4) Can the so-called anthropogenic signal be detected from qualitative CC indicators? (5) Are variations in the qualitative CS indicators during the period of instrumental observations and in recent decades very different from the data for the last 5–6 centuries? Here are brief answers to these questions.

Analysis of the information considered (*Fig. 1*, regions 3 and 4), obtained from areas separated one from the other by thousands of kilometres, about the temporal variation of various indicators of biological productivity (*Figs. 2, 3*) near the northern boundary of forest propagation makes it possible to draw the following conclusions:

- Temporal variations of indices *I* during a nearly 70-year period are distinctly synchronous.
- Since the variations of the indices analyzed (Figs. 2, 3), as will be shown later, are in agreement with the summertime input of heat (*Adamenko,* 1985a,b), their temporal variations indicate that the changes have not been unidirectional.
- During the 1930s (the trend is shown in Fig. 2 corresponding to the data for the northern forest boundary at the Taimyr Peninsula) and the 1960s (the trends are in Fig. 2) and up to now, a trend towards the decrease of indices *I* reveals itself in the low-frequency variability range.
- Analysis of dendrochronological data shows, on the one hand, the lack of extraordinary features in the temporal variation of indices *I*; but, on the other hand, it reveals a long-term trend towards their decrease during the recent 30–60 years (the trends are in Fig. 2). As can be seen from a multifactor linear and nonlinear correlation analysis (see below), the temporal variation of indices *I* is 60–80%-determined by the conditions of heat input. Therefore, one can draw the conclusion about the presence of a clearly pronounced trend at the northern forest boundary (regions 3 and 4 in Fig. 1) towards cooling. This is revealed by the fact that the maximums of productivity (indices *I*) during the period from 1930s to 1990s were becoming lower and lower with time, and the minimums were becoming deeper (Fig. 2).

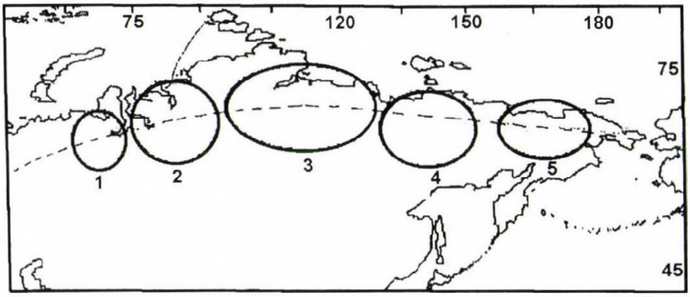

Fig. 1. Regions where samples of trees have been taken near the polar forest propagation boundary. 1 – Polar-Urals; 2 – West-Siberian; 3 – Taimyr-Putoran; 4 – East-Siberian; 5 – Chukotka

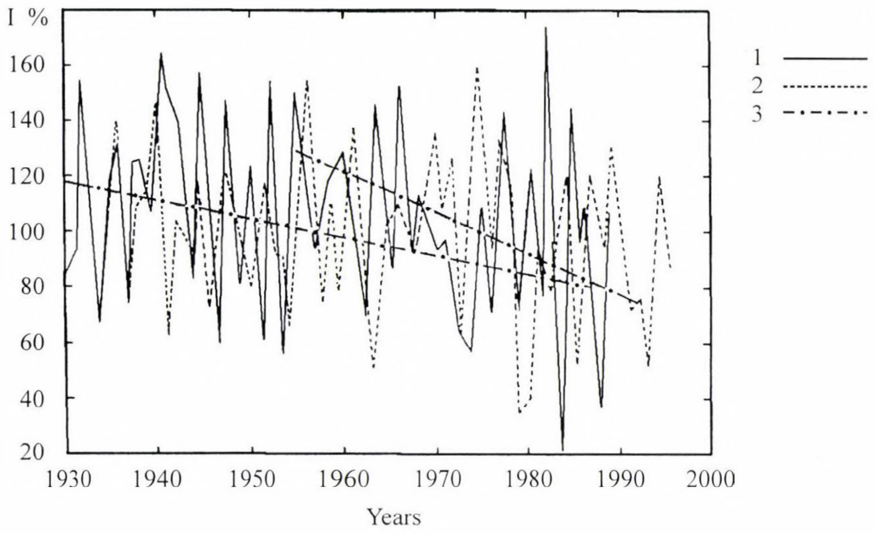

Fig. 2. Variations of dendrochronological index I (%) near the polar forest boundary. (Data of the Institute of Forests of the Siberian Branch of the Russian Academy of Sciences.) 1 – Ary-Mas; 2 – the Indigirka River basin; 3 – linear trend

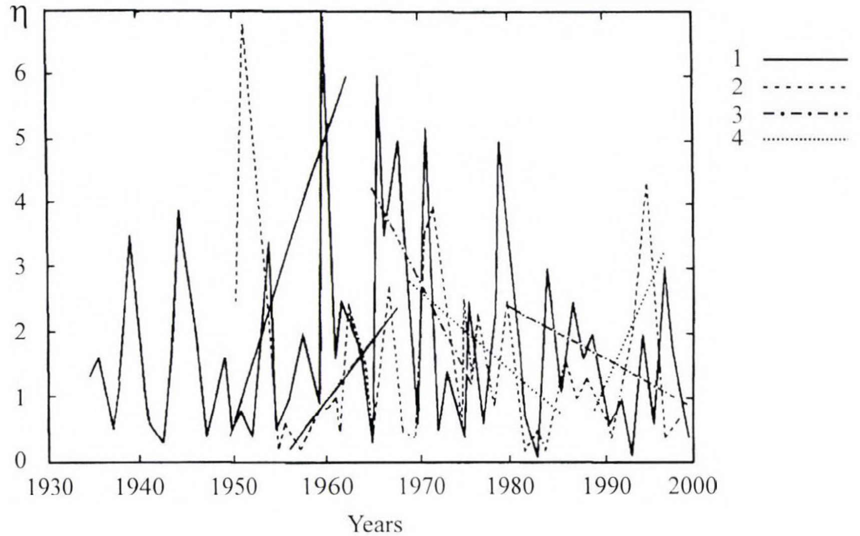

Fig. 3. Variation of the comfort index of bioproductivity η and its linear trends. 1 – the Novaya River (Taimyr); 2 – the Indigirka River (Eastern Siberia); 3, 4 – trends

5.3 Bioproductivity parameter

To more comprehensively characterize the variations of conditions favorable for forest productivity at the northern forest boundary during the last 5–6 centuries, analysis has been made of the temporal variation of the index of comfort for bioproductivity η determined by the ratio (Fig. 3):

$$\eta = \frac{I \geq 1.20}{I \leq 1.20}, \tag{1}$$

where $I \geq 1.20$ is the growth repetition rate which exceeds by 20% and more the average long-term norm calculated for running averages; $I \leq 1.20$ is the growth repetition rate which is 20% and more lower than the norm.

The values of the dimensionless parameter η determine, therefore, the ratio of the frequency of the years favorable for the biological productivity to that of the years unfavorable for it; thus, these values may be considered to be indices of the comfort for forest bioproductivity at its northern boundary.

An analysis performed earlier has revealed that index η depends on the summertime air temperature and the correlation coefficient exceeds 0.80 ± 0.03 (*Adamenko,* 1985a,b).

Analysis of the temporal variation of index η (Fig. 3) makes it possible to draw the following conclusions:

- Throughout the time period considered (5–6 centuries), there has not been any significant trend of a regular increase of index η with time, which could be comparable with the global air temperature variation or the independently recorded progressive increase of the carbon dioxide (or other greenhouse gases) concentration in the atmosphere.
- In contrary to the idea that global warming has been more pronounced at high latitudes, during nearly two centuries (the trend of decreasing η in Fig. 3) a significant tendency towards the decrease of η with time has revealed itself in the East-Siberian sector of the Sub-Arctic.
- During the late 1970s and early 1980s, a tendency towards the decrease of η took place also on the Taimyr Peninsula. The decrease of η reflects a reduction in the heat supply, i.e., the deterioration of conditions for biological productivity of forest at its northern boundary (region 3 in Fig. 1). This may be interpreted as some evidence in favor of a stronger cooling in the region considered in comparison with other ones (region 4 in Fig. 1). The variation of index η is in agreement with the results obtained by other investigators (*Anisimov,* 1998; *Lovelius,* 1997; *Vaganov et al.,* 1996, etc.), as well as with the above-mentioned decrease in heat and moisture reservoirs in the water catchment region of Lake Taimyr, the lowering of its level, the reduction of its area and changes in its biotic state.

- The variations of η during the 20th century are not exceptional (Fig. 3). The only specific feature of the changes is a greater intensity of the cooling processes. This fact is at variance with the well-known statement concerning universal anthropogenic warming and its enhancement at high latitudes.
- The climate warming of the 1930s at high latitudes has not clearly revealed itself in the variation of the η index: its relatively high values had also been observed in the past (Fig. 3). Comparison of the Arctic warming in the 20th century with the paleodata shows that the effect of the warming on biological productivity has been 2–5 times weaker than that in the past (see curve peaks in Fig. 3 relevant to the 16th and 17th centuries). This conclusion is in agreement with the data of a number of publications (*Vaganov et al.,* 1996; *Walland* and *Simmonds,* 1997; etc.).

5.4 Correlation analysis

In the context of the range of problems discussed, of interest is the analysis of the agreement between the variability in time for some CC indices used in the literature, which have been obtained from instrumental data on air temperature, assessments of the sea ice extent in the Arctic, and dendrochronological indices. Limiting ourselves to a very brief consideration, we present data on the correlation matrix of the 6th order in the truncated form (*Table 1*), with the level of confidence above 99.9%.

Not a single one of the *I* values of the time series presented by *Vaganov et al.,* (1996) has been in satisfactory agreement with the average air temperature variation in the Northern Hemisphere. This indicates that the values of *I* for each of over 60 points of observation within 5 regions considered (Fig. 1) cannot be regarded as indicators of global climate change but are connected with the regional-scale impacts. The averaging of the *I* values for certain sectors (Fig. 1, regions 1–5), performed by making use of the image recognition method developed by *Adamenko* (1985a), somewhat increased the values of correlation coefficients r with the averaged air temperature but did not make them statistically significant. No statistically significant correlation coefficients have either been discovered between the summarized index series presented by *Lovelius* (1997) and each of the 61 time series borrowed from the monograph by *Vaganov et al.* (1996). The values of the correlation coefficients between the *I* values for the series summarizing the growth rates of conifers at the northern forest boundary, obtained by *Lovelius* (1997), and all the other matrix parameters (Table 1) have proved to be statistically reliable and significant on a high level of confidence.

Hence it follows that the summarizing of *I* indices performed by *Vaganov et al.* (1996) or that of the results of measurements of the annual ring width of conifers near the northern forest boundary makes it possible to eliminate the influence of environmental conditions on the micro- and mesoscale levels, suppresses measurement noises and the effects of various artefacts, but singles out signals on a global or regional level. This conclusion is in accordance with the discovered by *Adamenko* (1985b) lack of a significant correlation of *I* indices for three regions on the Taimyr Peninsula with any indicators of heat and moisture regime on a local or mesoscale level, as well as a certain agreement between the *I* index anomalies and atmospheric circulation conditions which determine to a great extent the entire complex of conditions for biological productivity.

Table 1. Correlation matrix for growth rate indices of conifers near the northern boundary of forest propagation (I_{SA}, according to *Lovelius,* 1997), air temperature of the Northern Hemisphere (T_{NH} from the GRID data) and sea ice cover extent in the Arctic (S_{NE}, S_{EG}, S_{AA}, S_{BS}), according to *Zakharov* (1996)

		(1) T_{NH}	(2) I_{SA}	(3) S_{NE}	(4) S_{EG}	(5) S_{AA}	(6) S_{BS}
(1)	T_{NH}	1.00					
(2)	I_{SA}	0.55	1.00				
(3)	S_{NE}	-0.66	-0.58	1.00			
(4)	S_{EG}	-0.43	-0.34	0.79	1.00		
(5)	S_{AA}	-0.55	-0.44	0.93	0.84	1.00	
(6)	S_{BS}	-0.65	-0.57	0.91	0.47	0.79	1.00

Note: (1) T_{NH} is air temperature in the Northern Hemisphere during the 20th century; (2) I_{SA} values cover the latitude circle from the Kola Peninsula to Chukotka; (3)–(7) are data on sea ice cover extent in the Arctic; (3) S_{NE} - the North-European basin seas; (4) S_{EG} - the East-Greenland region seas; (5) S_{AA} - the Atlantic Arctic seas; (6) S_{BS} - the Barents Sea. The value of confidence of the correlation coefficient at the level of significance above 99.9% equals 0.31, by the module; correlation coefficient estimates have errors within the range from r $\pm$ 0.02 to r $\pm$ 0.05.

The accordance between some indirect climate indicators and data on surface air temperature, averaged over the Northern Hemisphere, may be considered a physical reality (*Adamenko,* 1985b). This statement is based on the fact that the correlation coefficient values between *I* and *T* are positive, and between *I* and *S* negative (see Table 1). Of interest is the fairly good agreement between various data on sea ice cover extent obtained independently for different Arctic seas (*Zakharov,* 1996), on the one hand, and between *I* and *S*, on the other hand.

6. Conclusions

The results considered above make it possible to draw the following general conclusions:

(1) The problem of the assessment of global climate change on the basis of the currently existing climate models is still far from being solved.

(2) The use of empirical diagnostics results shows that the anthropogenic climate warming signal has not revealed itself convincingly enough thus far either in the data of instrumental observations, or in indirect CC indicators (climate dynamics is far more complex than has ever been assumed).

(3) Analysis of the results of instrumental observations at high Northern latitudes indicates a considerable spatial-temporal inhomogeneity of temperature fields both during warming and cooling periods; the variations of humidity fields are even more complicated.

(4) The present-day trends in the variations of the indirect indicators of the state of the climatic system—the levels and areas of lakes, the state of marine and mountain ice cover, dendrochronological indices, etc.—show that model climate predictions have not been adequate, and the anthropogenic signal in indirect CC indicators has not revealed itself clearly during the recent 2-3 decades. The temporal variation of indirect CC indicators reveals the lack of polar enhancement of climate change, as well as the presence of stable tendencies towards climate cooling in a number of regions of the high latitudes of the Northern Hemisphere. Variations of the latitudinal gradients in the thermal regime indices, the presence of a number of specific features in the variations of the state of large lakes are rather characteristic for the cooling than warming epochs (in the regions mentioned).

(5) Any global climate change is characteristic of the presence of vast regions of multidirectional transformation of the heat and moisture reservoirs on the land and in the ocean, and the interrelated conditions of the existence of the biota and humans. This conclusion may be drawn from both the consideration of numerical climate modeling results and the analysis of the instrumental observation data, as well as indirect CC indicators.

References

Adamenko, V.N., 1980: Barico-circulation conditions of the latest millennium over the territories of Western Siberia and Central Asia (the Middle Region). In *Contemporary Climate Formation Problems* (ed.: *P.S. Khromov*) (in Russian). Moscow Univ. Press, 130-143.

Adamenko, V.N., 1985a: *Climate and Lakes* (in Russian). Leningrad, Gidrometeoizdat, pp. 263.

Adamenko, V.N., 1985b: Dendrochronological indication of long-term variability of barico-circulation processes. In *The Geography of the Taimyr Lakes* (in Russian). Nauka Publ., 87-99

Adamenko, V.N., Masanova, M.D. and *Chetverikov, A.F.*, 1982: *Climate Change Indication. Methods of Analysis and Interpretation*. Leningrad, Gidrometeoizdat, pp. 112.

Anderson, D.L.T. and *Willebrand, J.* (eds.), 1996: *Decadal Climate Variability. Dynamics and Predictability*. Springer Verlag, Berlin e.a., pp. XIII/467.

Anisimov, O.A., 1998: Climate change in the region of the cryolithozone of the Northern Hemisphere and the assessment of its consequences. Abstract of *Ph.D. dissertation*, St. Petersburg State Univ.

Are Human Activities Causing Global Warming?, 1995. George C. Marshall Inst. Publ., Washington, DC, pp. 45.

Barnett, T.P., 1999: Comparison of near-surface air temperature variability in II coupled global climate model. *J. Climate 12*, 511-518.

Bengtsson, L., Roeckner E. and *Stendel, M.*, 1999: Why is the global warming proceeding much slower than expected? *J. Geophys. Res. 104*, 3865-3876.

Brauch, H.G. (ed.): 1996. *Klimapolitik*. Springer Verlag, Berlin e.a., pp. XXX+450.

Browning, K.A. and *Gurney, R.J.* (eds.), 1999: *Global Energy and Water Cycles*. Cambridge Univ. Press, pp. 292.

Cheddadi, R.Yu.G., Guiot, J., Harrison, S.P. and *Prentice, I.C.*, 1997: The climate of Europe 6000 years ago. *Climate Dynamics 13*, 1-9.

Drozdov, O.A. and *Lugina, K.M.*, 1998: The climatic system dynamics and geographic conditions. *In Ecologo-Geographic Assessment and Monitoring of the Environment*. St.Petersburg State Univ. Publ., 8-35.

Ellsaesser, H.W. (ed.), 1992: *Global 2000 Revisited. Mankind's Impact on Spaceship Earth*. Paragon House, New York, pp. 436.

Emsley, J. (ed.), 1996: *The Global Warming Debate*. The Report of the European Science and Environment Forum. Bourne Press Ltd., Bornemouth, pp. 288.

Fischer, H., Wahlen, M., Smith, S., Mastroianni, D. and *Deck, R.*, 1999: Ice core records of atmospheric CO_2 around the last three glacial terminations. *Science 283*, 1712-1714.

Flower, B.P., 1999: Warming without high CO_2? *Nature 399*, 313-314.

Fu, C., Diaz, H.F., Dong, D. and *Fletcher, J.O.*, 1999: Changes in atmospheric circulation over Northern Hemisphere oceans associated with the rapid warming of the 1920s. *Int. J. Climatol. 19*, 581-606.

Grotefendt, K., Lagemann, K., Quadfasel, D. and *Ronski, S.*, 1998: Is the Arctic warming? *J. Geophys. Res. 103*, 27679-27688.

Hansen, J.E., Sato, M., Ruedy, R., Lacis, A. and *Glascoe, J.*, 1998: Global climate data and models: a reconciliation. *Science 281*, 930-932.

Houghton, J.T., Meira-Filho, L.G., Callander, B.A., Harris, N., Kattenberg, A. and *Maskell, K.* (eds.) 1996: *Climate Change 1995. The Science of Climate Change*. Cambridge Univ. Press, pp. 572.

Jain, S., Lall, U. and *Mann, M.E.*, 1999: Seasonality and interannual variations of Northern Hemisphere temperature: Equator-to-pole and ocean-land contrasts. *J. Climate 12*, 1086-1100.

Jastrow, R., Nierenberg, W. and *Seitz, F.*, 1990: *Global Warming. What Does the Science Tell Us?* George C. Marshall Inst. Publ., Washington, DC, pp. 72.

Jones, P.D. and *Hegerl, G.C.*, 1998: Comparisons of two methods of removing anthropogenically related variability from the near-surface observational temperature field. *J. Geophys. Res. 103*, 13777-13786.

Kahl, J.S. et al., 1993: Absence of evidence for greenhouse warming over the Arctic Ocean in the past 40 years. *Nature 361*, 335-337.

Kondratyev, K.Ya., 1992: *Global Climate*. Nauka Publ., pp. 359.

Kondratyev, K.Ya., 1997: Global ecodynamics and sustainable development: the natural science aspects and the human dimension. *Izvestiya of Russian Geograph. Soc. 129*, No. 6, 1-12.

Kondratyev, K.Ya., 1998: *Multidimensional Global Change*. Wiley/Praxis, Chichester, U.K., pp. 761.

Kondratyev, K.Ya., 1999: *Climatic Effects of Aerosols and Clouds*. Springer/Praxis, Chichester, U.K., pp. 264.

Kondratyev, K.Ya., Johannessen, O.M. and *Melentyev, V.V.*, 1996: *High-Latitude Climate and Remote Sensing*. Wiley/Praxis, London, pp. 200.

Kondratyev, K.Ya. and *Cracknell, A.P.*, 1998: *Observing Global Climate Change*. Taylor & Francis, London, pp. 562.
Lovelius, N.V., 1997: *Dendroindication of Natural Processes and Anthropogenic Influences* (in Russian). St. Petersburg, *World & Family-95*, pp. 320.
Manabe, S., 1998: Study of global warming by GFDL climate models. *Ambio 27*, 182-186.
Mason, B.J., 1995: Predictions of climate changes caused by man-made emissions of greenhouse gases: a critical assessment. *Contemporary Physics 36*, 299-319.
McPhee, M.G., *Stanton, T.P.*, *Morison, J.H.* and *Martinson, D.G.*, 1998: Freshening of the upper ocean in the Arctic: Is perennial sea ice disappearing? *Geophys. Res. Lett 25*, 1729-1732.
Mysak, L.A. and *Venegas, S.A.*, 1998: Decadal climate oscillations in the Arctic: A new feedback loop for atmosphere-ice-ocean interactions.
Postmentier, E.S., *Soon, W.H.* and *Baliunas, S.L.*, 1999: *Natural Variability in an Ocean-atmosphere Climate Model*. Harvard-Smithsonian Center for Astrophysics, Cambridge, MA, No. 4802, pp. 16.
Radionov, V.F., *Briazgin, N.N.* and *Alexandrov, E.I.*, 1996: *Snow Cover in the Arctic Basin* (in Russian). Gidrometeoizdat, St. Petersburg, pp. 124.
Raschke, E. (ed.), 1996: *Radiation and Water in the Climate System. Remote Measurements*. Springer Verlag, Berlin e.a., pp. X+614.
Report on Study of the Arctic Change Workshop held November 10-12, 1997, 1998: Univ. of Washington, Seattle, Washington, Polar Science Center Publ. No. 8, pp. 63.
Schneider, S.H., 1998: Kyoto Protocol: The unfinished agenda. *Climatic Change 39*, 1-21.
Schoenwiese, C., 1996: *Klimaaenderungen. Daten, Analysen, Prognosen*. Springer Verlag, Berlin e.a., pp. XIII+224.
Scorer, R.S., 1996: *Dynamics of Meteorology and Climate*. J. Wiley & Sons, Ltd., Chichester, U.K., pp. 400.
Shumsky, P.A., 1968: *Dynamical Glaciology* (in Russian). VINITI Press, pp. 178.
Singer, F.S., 1997: *Hot Talk, Cold Science: Global Warming, Unfinished Debate*. Oakland, CA, Independent Inst., pp. 120.
Storch, H., von and *Floeser, G.*, 1999: *Anthropogenic Climate Change*. Springer, Berlin e.a., pp. XIV + 372.
Vaganov, E.A., *Shiyatov, S.G.* and *Mazepa, V.S.*, 1996: *Dendroclimatic Studies in the Urals-Siberian Sub-Arctic* (in Russian). Novosibirsk, Nauka Publ., pp. 246.
Walland, D.J. and *Simmonds, I.*, 1997: Modelled atmospheric response to changes in Northern Hemisphere snow cover. *Climate Dynamics 13*, 25-34.
Warnecke, G., 1997: *Meteorologie und Umwelt. Eine Einführung*. Springer Verlag, Berlin e.a., pp. XII + 266.
Watanabe, M. and *Nitta, T.*, 1999: Decadal changes in the atmospheric circulation and associated climate variations in the Northern Hemisphere winter. *J. Climate 12*, 494-510.
Weber, G.R., 1996: *Global Warming. The Rest of the Story*. Dr. Boettiger Verlags GmbH, Wiesbaden, pp. 188.
Wigley, T.M., 1998: The Kyoto Protocol: CO_2, CH_4 and climate implications. *Geophys. Res. Lett. 25*, 2285-2288.
Wiin-Nielsen, A., 1998: Limited predictability and the greenhouse effect—a scientific view. *Energy & Environm. 9*, 639-646.
Woodcock, A., 1999: Global warming—a natural event? *Weather 54*, No. 5, 162-163.
Yao, M.-S. and *Del Genio, A.D.*, 1999: Effects of cloud parameterization on the simulation of climate changes in the GISS GCM. *J. Climate 12*, 761-779.
Zakharov, V.F., 1996: *Sea Ice in the Climatic System* (in Russian). Gidrometeoizdat, St. Petersburg, pp. 213.
Zhang, J., *Rothrock, D.A.* and *Steele, M.*, 1998: Warming of the Arctic Ocean by a strengthened Atlantic inflow: Model results. *Geophys. Res. Lett. 25*, 1745-1748.
Zubov, N.N., 1945: *The Arctic Ice* (in Russian). The Arctic Sea Route Publ., Moscow, pp. 360.

IDŐJÁRÁS

Quarterly Journal of the Hungarian Meteorological Service
Vol. 103, No. 4, October-December 1999, pp. 237-247

Application of some statistical tests for detecting hidden periodicity in the Serbian annual precipitation sums

J. Mališić[1], **M. Unkašević**[2] and **I. Tošić**[2]

[1]*University of Belgrade, Faculty of Mathematics, Studentski trg 16, 11 000 Belgrade, Yugoslavia*

[2]*University of Belgrade, Faculty of Physics, Department of Meteorology, Dobračina 16, 11000 Belgrade, Yugoslavia; e-mail: itosic@afrodita.reub.bg.ac.yu*

(Manuscript received 9 November 1998; in final form 9 March 1999)

Abstract—Research on periodicity in the climatological time series has been receiving a lot of attention. It is important for studies of climatic fluctuations and changes. This paper deals with hidden periodicities in time series of annual precipitation sums of five stations in Serbia in the period 1925–1995. The Siegel's test is used to perform the analysis. This is an extension of the Fisher's test in the way that it may be able to detect even so-called compound periodicities hidden in random white noise. New critical values of test statistics from 5 to 100 years are calculated by using the Wei's approximation. Certain conditions, such as homogeneity and Gaussian distribution of the data have to be fulfilled to apply the test. Compound periodicity in the Serbian annual precipitation sums has not been found.

Key-words: hidden periodicity, climatological statistical tests, annual precipitation sums.

1. Introduction

Many time series in the natural sciences seem to exhibit periodical structures. In such a case, a series repeats more or less the same pattern over time. Two classical examples are the Wolf sunspots number and the annual number of Canadian Lynx. Some climatologic time series seem to have periodical structures as well.

Standard approaches to such time series are the fast Fourier transform method (*Cooley* and *Tukey*, 1965; *Mališić*, 1990), estimation of the spectrum and fitting of an autoregressive–moving average (ARMA) model or an autoregressive–integrated–moving average (ARIMA) model (*Kay*, 1980; *Thompson*, 1982).

Fitting of periodical phenomena by means of trigonometric functions has a long tradition in meteorology. Lots of different methods have been used for discovering hidden periods (*Blackman* and *Tukey*, 1959; *Anderson*, 1971; *Bloomfield*, 1976; *Siegel*, 1980; *Damsleth* and *Spjotvoll*, 1982; *Newton* and *Pagano*, 1983). However, during the last 20 years some new and non-traditional methods have been investigated: the maximum enthropy spectral estimation (*Andersen*, 1974; *Padmanabhan* and *Rao*, 1988; *Padmanabhan,* 1991), the maximum likelihood spectral estimation (*Friedlander*, 1982), etc.

This paper is inspired by the Fisher's and Siegel's tests (*Fisher*, 1929, 1939, 1940; *Siegel*, 1980) and presents an attempt of application of these tests to annual precipitation sums. Section 2 describes the used data and the results of the inhomogeneity tests. A short review of the Fisher's and Siegel's tests is given in Section 3. The new tests for periodicity containing the Fisher's test as a special case, and calculations of the test-statistics and its critical values are proposed in Section 4. Some conclusions about applicability of the *Fisher*'s (1940) and *Siegel*'s (1980) tests to examine periodicity in the annual precipitation sums during the period 1925–1995, and in the annual maximum precipitation sums during the period 1888–1994 are given in Section 5.

2. Data used

This paper takes into analysis the annual precipitation sums measured at the stations Belgrade-Observatory (44°48'N, 20°28'E, 132 m a.s.l.), Loznica (44°33'N, 19°14'E, 121 m a.s.l.), Vršac (45°08'N, 21°19'E, 85 m a.s.l.), Senta (45°56'N, 20°05'E, 80 m a.s.l.) and Sremska Mitrovica (44°58'N, 19°38'E, 81 m a.s.l.) in the period 1925–1995. These stations are located in the lowland of the northern part of Serbia (*Fig. 1*), which is spatially homogeneous.

Examination of homogeneity is necessary before any serious study of periodicity in climatological time series. In this paper the Kolmogoroff-Smirnoff's, the bivariate (*Maronna* and *Yohai*, 1978) and the *Alexandersson*'s (1986) tests for examination of inhomogeneity are used. The bivariate test is based on the assumptions of normality and independence. Assumption of normality is not rigorously met the by five annual precipitation series, as the coefficient of skewness shows, while the lag-one correlation coefficient is satisfied (*Table 1*). Namely, all series show positive skewness, indicating that the series are only approximately normal, while low values of lag-one correlation coefficients indicate that the series are independent.

The bivariate and Alexandersson's tests are based on second correlated series which are assumed to be unchanged and also give the maximum likelihood estimates of the time and amount of change. These tests allow to determine the year of inhomogeneity (T_1), the size of change and its statistical significance (level 0.05). The test statistics $T_0 = \max_{i<n}\{T_i\}$, ($n = 71$) is calculated and then compared to the critical value on the significance level 0.05 (*Potter*, 1981; *Alexandersson*, 1986). The statistics T_0 is used to test whether a shift in mean has occurred. The tests used indicated that there are no inhomogeneity in the annual precipitation series at the five stations.

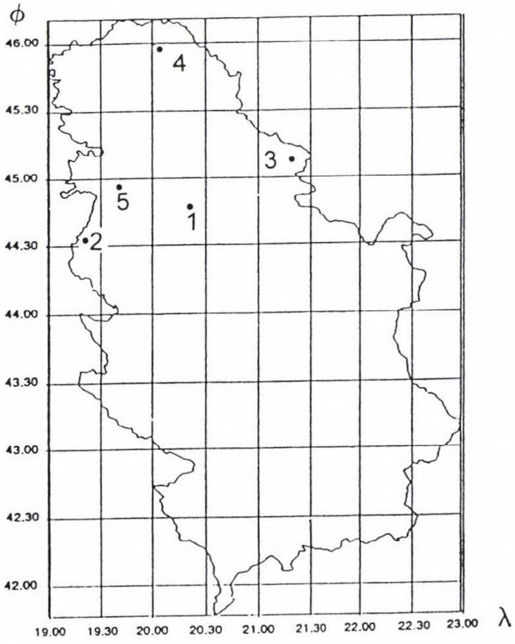

Fig. 1. Location map of the precipitation stations:
1. Belgrade-Observatory, 2. Loznica, 3. Vršac, 4. Senta, 5. Sremska Mitrovica.

Table 1. Statistics: A – coefficient of skewness, B – lag-one correlation coefficient

Stations	Belgrade-Obs.	Loznica	Vršac	Senta	Sr. Mitrovica
A	0.195507	0.442214	0.529956	0.122999	0.348323
B	0.210460	0.188676	0.087799	0.078852	0.063636

3. Review of the Fisher's and Siegel's tests

To examine periodicity in the time series of the annual precipitation sums (*Fig. 2*) we use the following analytical procedure.

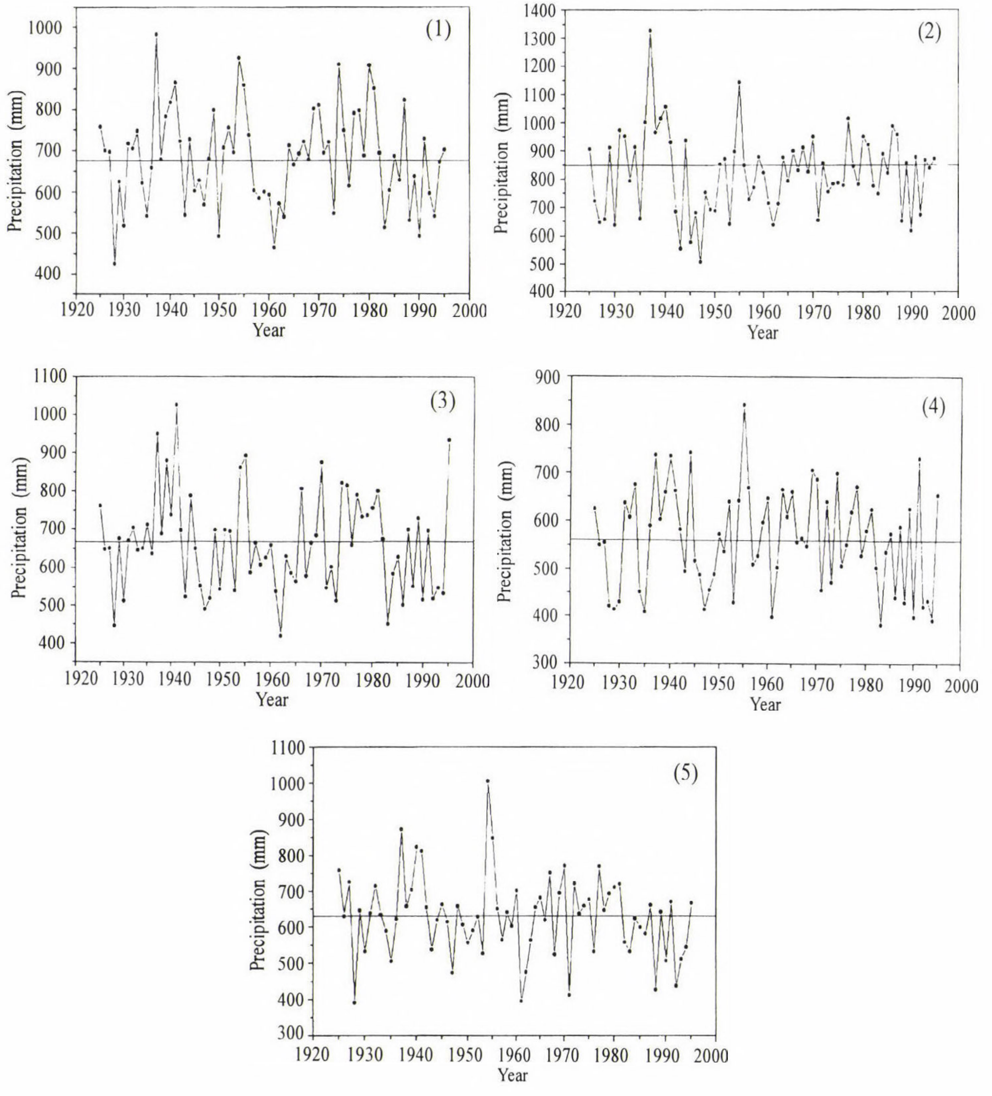

Fig. 2. Annual precipitation sums for the next stations:
1. Belgrade-Observatory, 2. Loznica, 3. Vršac, 4. Senta and 5. Sremska Mitrovica.

First, let $\{X_t,\ t = 1,2,\ldots,N\}$, $N = 2n + 1$, n is positive integer, be a series of observations taken at equally spaced time intervals and

$$X_t = \zeta_t + \varepsilon_t, \quad t = 1,\ldots,N, \tag{1}$$

where ζ_t represents the unobservable value of the annual precipitation at the moment t. The series $\{\varepsilon_t\}$ is assumed to be a strong Gaussian white noise, a sequence of independent, identically Gaussian-distributed random variables with zero mean and unknown variance σ^2. Let

$$a_0 = \bar{\zeta} = \frac{1}{N}\sum_{t=1}^{N}\zeta_t,\ a_j = \frac{2}{N}\sum_{t=1}^{N}\zeta_t \cos\left(\frac{2\pi jt}{N}\right),\ b_j = \frac{2}{N}\sum_{t=1}^{N}\zeta_t \sin\left(\frac{2\pi jt}{N}\right),\ j = 1,\ldots,n \tag{2}$$

be the Fourier coefficients of the decomposition

$$\zeta_t = a_0 + \sum_{j=1}^{n}\left[a_j \cos\left(\frac{2\pi jt}{N}\right) + b_j \sin\left(\frac{2\pi jt}{N}\right)\right]. \tag{3}$$

Further, we introduce the periodogram values

$$R_j^2 = A_j^2 + B_j^2 = \left[\frac{2}{N}\sum_{t=1}^{N}X_t \cos\left(\frac{2\pi jt}{N}\right)\right]^2 + \left[\frac{2}{N}\sum_{t=1}^{N}X_t \sin\left(\frac{2\pi jt}{N}\right)\right]^2,\ j = 1,\ldots,n. \tag{4}$$

and statistics

$$Y_j = \frac{R_j^2}{R_1^2 + R_2^2 + \ldots + R_n^2},\ j = 1,\ldots,n \tag{5}$$

Let the null hypothesis H_0 that there is no periodic activity, i.e.,

$$H_0\ (\zeta_1 = \zeta_2 = \ldots = \zeta_N), \tag{6}$$

and let the compound alternative hypothesis $H_{i_1,i_2,\ldots,i_m}$ means the periodicities at the frequencies $i_1/N,\ldots,i_m/N$. Then the Fisher's and Siegel's tests (*Fisher*, 1940; *Siegel*, 1980) are based on the statistics

$$G = \max_{1\le j<n} Y_j. \tag{7}$$

We reject H_0 if the statistics G exceeds the appropriate critical value $g_{F;\alpha}$, corresponding to the level of significance α (α = 0.01 or 0.05 for example). Thus, if the sample value g of the statistics G exceeds the critical value $g_{F;\alpha}$, we conclude that the series $\{X_t\}$ has the periodic component at the frequency i/N, i.e., N/i is the period.

It is clear that any increase in a smaller Y_j will tend to decrease their maximum G in Eq. (7). We remedy this case by choosing a threshold value $g_\alpha^* < g_{F;\alpha}$, i.e., we define a coefficient λ between 0 and 1 as

$$\lambda = \frac{g_\alpha^*}{g_{F;\alpha}}. \tag{8}$$

Then, the proposed statistics is

$$T_\lambda = \sum_{j=1}^{n} (Y_j - g_\alpha^*)_+ \equiv \sum_{j=1}^{n} (Y_j - \lambda g_{F;\alpha})_+ = \sum_{j=1}^{n} \varphi_+ , \tag{9}$$

where φ_+ is the positive-part of the function φ, defined as

$$\varphi_+ = \max\{\varphi, 0\} = \begin{cases} \varphi, & \text{if } \varphi \geq 0, \\ 0, & \text{if } \varphi < 0. \end{cases}$$

If λ = 1, we obtain the Fisher's test, because $T_1 > 0$ if and only if some value Y_j exceeds $g_{F;\alpha}$. A value of λ near 1 might be used when the simple periodicity is expected; smaller values of λ might be used when compound periodicities are expected.

4. Calculations of test-statistics and critical values

In the case of the compound alternative hypothesis $H_{i_1 i_2 \ldots i_m}$ we have

$$\frac{(N-1) - 2m}{2m} Z_{i_1, i_2, \ldots, i_m} = F_{2m;\, N-1-2m}, \tag{10}$$

where

$$Z_{i_1 i_2 \ldots i_m} = \frac{R_{i_1}^2 + R_{i_2}^2 + \ldots + R_{i_m}^2}{\sum_{j \notin \{i_1, i_2, \ldots, i_m\}} R_j^2} \tag{10'}$$

the denominator is the sum of all values R_j^2 except $R_{i_1}^2, R_{i_2}^2, \ldots, R_{i_m}^2$ and $F_{2m;N-1-2m}$ are Fisher's random variables with $2m;N$-1-$2m$ degree of freedom.

New critical values $g_{F;\alpha}$ were obtained by using the Wei's approximation (*Wei*, 1990):

$$P_{H_0}(G \geq g_{F;\alpha}) \approx n(1 - g_{F;\alpha})^{n-1}, \tag{11}$$

for significance levels $\alpha = 0.05$ and $\alpha = 0.01$, and for $n = 5, 6, \ldots, 100$ (*Table* 2). We use the Siegel's equation (*Siegel*, 1978, 1980) in the form

$$P_{H_0}(T_\lambda > t) = \sum_{l=1}^{n} \sum_{k=0}^{l-1} (-1)^{k+l+1} \binom{n}{l} \binom{l-1}{k} \binom{n-1}{k} t^k (1 - \lambda \lg_{F;\alpha} - t)_+^{n-k-1}, \tag{12}$$

Critical values of t_λ, calculated for T_λ, are listed in Table 2. The estimates have been performed for the same significance levels of α and the same values of n as for the critical values of $g_{F;\alpha}$. Note that calculated critical values coincided with critical values obtained by using the Siegel's test (*Siegel*, 1980) for $n = 5, \ldots, 50$.

5. Periodicity in the Serbian annual precipitation sums

The periodicity of the annual precipitation sums measured at the five stations during the period 1925–1995 is examined. After detrending, tapering and using the Hamming window (*Blackman* and *Tukey*, 1959), the values of the Fourier coefficients A_j and B_j, the periodogram values R_j^2 and the values of inferences Y_j are calculated. The same results are obtained by using other windows, for example, the Tukey and Parzen windows. The estimated values of Y_j for $n = 1, \ldots, 35$ are shown on *Fig. 3*.

Following the Siegel's suggestion (*Siegel*, 1980) for $\lambda = 0.6$ and on the significance level 0.05, we obtained $\lambda g_{F;\alpha} = 0.105$. For the Belgrade-Observatory annual precipitation sums T_λ is equal to 0.0361 (Eq. 9). This value is smaller than the critical value $t_{0.6} = 0.0792$ (Table 2a) which indicates that the compound periodicity does not exist. Also, we have not found compound periodicity for the stations Loznica ($T_\lambda = 0.0164$), Vršac ($T_\lambda = 0.0038$), Senta ($T_\lambda = 0$) and Sremska Mitrovica ($T_\lambda = 0$).

We examined the periodicity of the annual maximum precipitation sums measured at the Belgrade-Observatory station during the period from 1888 to 1994 (107 years). The estimated values of Y_j for $n = 1, \ldots, 53$ are shown in *Fig. 4*. For the annual maximum precipitation sums we have found $\lambda g_{F;\alpha} = 0.0752$

Table 2. Critical values $g_{F;\alpha}$ and t_λ for $\lambda = 0.8$, $\lambda = 0.6$ and $\lambda = 0.4$, when (*a*) $\alpha = 0.05$, (*b*) $\alpha = 0.01$

(a)

n	$g_{F;\alpha}$	$T_\lambda(0.8\ g_{F;\alpha})$	$T_\lambda(0.6\ g_{F;\alpha})$	$T_\lambda(0.4\ g_{F;\alpha})$
5	0.6837720	0.1365720	0.2733720	0.4101720
6	0.6161480	0.1260390	0.2465490	0.3808140
7	0.5611540	0.1123540	0.2249750	0.3556940
8	0.5156870	0.1028910	0.2074440	0.3340430
9	0.4774940	0.0959269	0.1937030	0.3160420
10	0.4449530	0.0890349	0.1812600	0.2995150
15	0.3346310	0.0669604	0.1398900	0.2460830
20	0.2704590	0.0549320	0.1162640	0.2137930
25	0.2281320	0.0462535	0.0997710	0.1905390
30	0.1979500	0.0400885	0.0878783	0.1732720
35	0.1752530	0.0358162	0.0792266	0.1603900
40	0.1575160	0.0324966	0.0724347	0.1500800
50	0.1314890	0.0268405	0.0614358	0.1329250
51	0.1293810	0.0264177	0.0605771	0.1315640
52	0.1273450	0.0260092	0.0597460	0.1302240
53	0.1253770	0.0256141	0.0589414	0.1289710
54	0.1234720	0.0252318	0.0581614	0.1277340
55	0.1216290	0.0248617	0.0574054	0.1265360
60	0.1132310	0.0231745	0.0539457	0.1209690
70	0.0996654	0.0204455	0.0482983	0.1114940
80	0.0891612	0.0183288	0.0438682	0.1039630
90	0.0807706	0.0166354	0.0402879	0.0977606
100	0.0739035	0.0152477	0.0373264	0.0925198

(b)

n	$g_{F;\alpha}$	$T_\lambda(0.6\ g_{F;\alpha})$	$T_\lambda(0.6\ g_{F;\alpha})$	$T_\lambda(0.4\ g_{F;\alpha})$
5	0.7885260	0.1573260	0.3151260	0.4729260
6	0.7217920	0.1441920	0.2885920	0.4335800
7	0.6644040	0.1332040	0.2660040	0.3992500
8	0.6151660	0.1231670	0.2461670	0.3716520
9	0.5727130	0.1143130	0.2289220	0.3486910
10	0.5358410	0.1070410	0.2143120	0.3293540
15	0.4068890	0.0813024	0.1636450	0.2620020
20	0.3297120	0.0657631	0.1335240	0.2215180
25	0.2781960	0.0558841	0.1138340	0.1943460
30	0.2412490	0.0485633	0.0994930	0.1742640
35	0.2133840	0.0431182	0.0887140	0.1587890
40	0.1915750	0.0381133	0.0795814	0.1457610
50	0.1595520	0.0317022	0.0669352	0.1269290
51	0.1569590	0.0315165	0.0662218	0.1258630
52	0.1544540	0.0314203	0.0656144	0.1247760
53	0.1520320	0.0305923	0.0643279	0.1234020
54	0.1496900	0.0298447	0.0631322	0.1215180
55	0.1474220	0.0299904	0.0628064	0.1210250
60	0.1370940	0.0276589	0.0584460	0.1142430
70	0.1204230	0.0245975	0.0520665	0.1044270
80	0.1075300	0.0212835	0.0461404	0.0959648
90	0.0972442	0.0198151	0.0426058	0.0894190
100	0.0888372	0.0177937	0.0388304	0.0843026

and $T_\lambda = 0.0417$, which is smaller than the critical value $t_{0.6} = 0.0589$ (Table 2a). Therefore the compound periodicity is not revealed in this case.

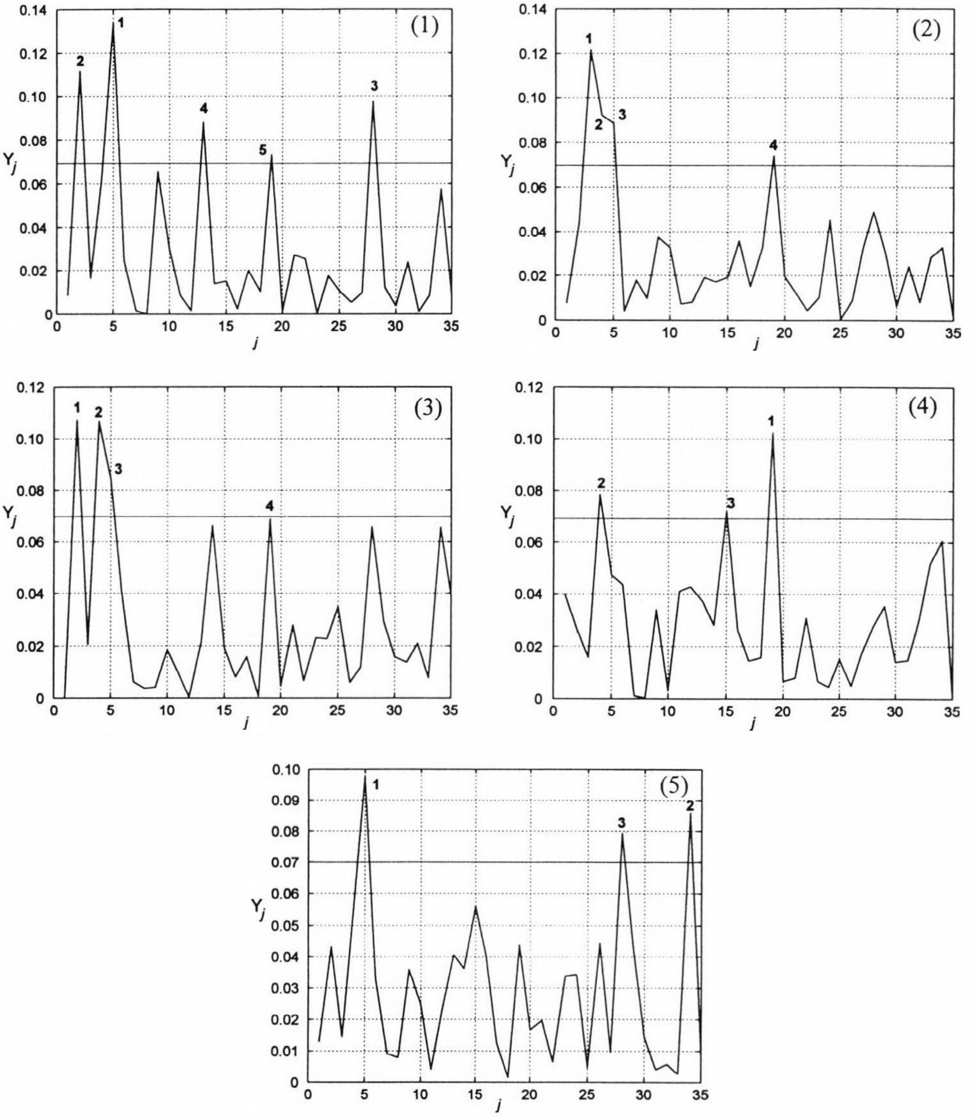

Fig. 3. Periodogram of the annual precipitation sums at 1. Belgrade-Observatory, 2. Loznica, 3. Vršac, 4. Senta and 5. Sremska Mitrovica stations, during 1925–1995. Horizontal lines represents the critical values Y_j.

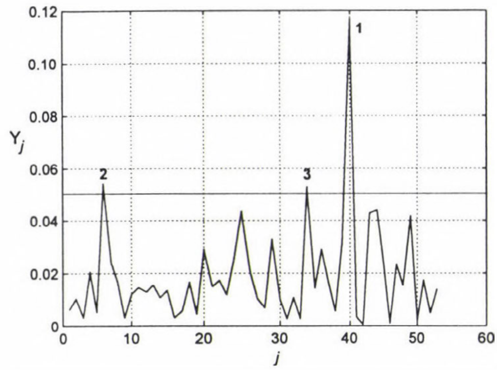

Fig. 4. Periodogram of the annual maximum precipitation sums at the Belgrade-Observatory station, during the period 1888–1994. Horizontal lines denotes the critical values Y_j.

6. Conclusion

We examined hidden periodicity in the annual precipitation sums measured at five stations in the northern part of Serbia, during the period 1925–1995 (71 years), using the Fisher's and Siegel's tests. The new critical values $g_{F;\alpha}$ and t_λ were obtained using the Siegel's test according to Wei's approximation for significance levels $\alpha = 0.05$ and $\alpha = 0.01$, for $n = 5,\dots,100$, and for $\lambda = 0.4$, $\lambda = 0.6$ and $\lambda = 0.8$. The annual precipitation sums as well as the annual maximum precipitation sums did not exhibit compound periodicity according to the Fisher's and Siegel's tests.

References

Alexandersson, A., 1986: A homogeneity test applied to precipitation data. *J. Climatol. 6*, 661-675.

Andersen, N. 1974: On the calculation of filter coefficients for maximum entropy spectral analysis. *Geophysics 39*, 69-72.

Anderson, T.W., 1971: *The Statistical Analysis of Time Series*. John Wiley & Sons, New York.

Blackman, R.B. and *Tukey, J.W.*, 1959: *The Measurement of Power Spectra from the Point of View of Communications Engineering*. Dover, New York.

Bloomfield, P., 1976: *Fourier Analysis of Time Series: An Introduction*. John Wiley & Sons. New York.

Cooley, J.W. and *Tukey, J.W.*, 1965: An algorithm for machine calculation of complex Fourier series. *Math. Comput. 19*, 297-301.

Damsleth, E. and *Spjotvoll, E.*, 1982: Estimation of trigonometric components in time series. *J. Amer. Statist. Assoc. 77*, 381-387.

Fisher, R.A., 1929: Tests of significance in harmonic analysis. *Proc. of the Royal Society*, *Ser. A, 125*, 54-59.

Fisher, R.A., 1939: The sampling distribution of some statistics obtained from non-linear equations. *Annals of Eugenics 9*, 238-249.

Fisher, R.A., 1940: On the similarity of the distributions found for the test of significance non harmonic analysis, and in Steven's problem in geometrical probability. *Annals of Eugenics 10*, 14-17.

Friedlander, B., 1982: A recursive maximum likelyhood algorithm for ARMA spectral estimation. *IEEE Trans. Inform. Theory*, IT-28, 639-646.

Kay, S.M., 1980: A new ARMA spectral estimator. *IEEE Trans. Acoustics, Speach. Signal Processing*, ASSP-28, 585-588.

Maronna, R. and *Yohai, V.J.*, 1978: A bivariate test for the detection of a systematic change in mean. *J. Amer. Statis. Assoc. 73* 640-645.

Mališić, J., 1990: Stochastic Processes: Theory and Applications (in Serbian). Gradjevinska knjiga, Belgrade.

Newton, H.J. and *Pagano, M.*, 1983: A method for determining periods in time series. *J. Amer. Statist. Assoc. 78*, 152-157.

Padmanabhan, G. and *Rao, A.R.*, 1988: Maximum entropy spectral analysis of hydrologic data, *Water Resour. Res. 24*, 1519-1533.

Padmanabhan, G., 1991: Non-harmonic spectral analysis to investigate periodicity in hydrologic and climatologic time series. *Theor. Appl. Climat 43*, 31-42.

Potter, K.W., 1981: Illustration of a new test for detecting a shift in mean in precipitation series. *Mon. Wea. Rev 109*, 2040-2045.

Siegel, A.F., 1978: Random areas on the circle. *J. Appl. Probab. 15*, 774-789.

Siegel, A.F., 1980: Testing for periodicity in a time series. *J. Amer. Statist. Assoc. 75*, 345-348.

Thompson, D.J., 1982: Spectrum estimation and harmonic analysis. *Proc. IEEE 70*, 1055-1096.

Wei, W.W.S., 1990: *Time Series Analysis: Univariate and Multivariate Methods*. Addison-Wesley Publ. Company, Redwood City.

IDŐJÁRÁS

Quarterly Journal of the Hungarian Meteorological Service
Vol. 103, No. 4, October–December 1999, pp. 249–260

Instrumental problems of UV and UV-B radiometers: regression models to derive UV and UV-B irradiance from global solar radiation data

I. Galindo, A. T. Elizalde and **J. Fonseca**

Centro Universitario de Investigaciones en Ciencias del Ambiente,
Universidad de Colima,
25 de Julio 965, Villas San Sebastián, Colima, Mexico
e-mail: galindo@volcan.ucol.mx

(Manuscript received 11 October 1998; in final form 5 July 1999)

Abstract—Direct evidence of increased ground level ultraviolet radiation is fragmentary mainly due to scarce measurements and instrumental problems such as calibration shifts. The problem is more critical at the tropics, therefore regression models are used to relate global solar radiation measurements made at Colima, Mexico with UV and UV-B irradiance under all sky conditions, thus expanding the UV-B data set from October 1995 to June 1999. Aging of total ultraviolet radiometer (TUVR) is also documented. Results show no trends in the synthetic UV-B time series. Remarkable calibration shifts occur in the total ultraviolet radiometer suggesting that the mean lifetime of these instruments under tropical conditions is about 4 years.

Key-words: UV and UV-B irradiance, global solar radiation, total UV radiometer, instrumental calibration.

1. Introduction

Stratospheric ozone depletion, which became evident in the 1970s, has produced a great concern in the scientific community in the last years. Ozone depletion trends are now well established in both hemispheres (*Gleason et al.*, 1993; *Jones* and *Shanklin*, 1995). Solar radiation that reaches the surface of the Earth´s contains approximately 5% ultraviolet, 55% infrared and 40% visible radiation. Stratospheric ozone absorbs essentially all the highest energy (i.e., 100–290 nm, UV-C, the shortest wavelength radiation), approximately three-quarters of the next highest energy band (i.e., 290–315 nm, UV-B) but only a small part of the lowest energy radiation (i.e., 315–385 nm, UV-A). Further ultraviolet radiation is absorbed in the troposphere via clouds, dust and gaseous and particulate air pollutants. In particular, in the vicinity of active volcanoes there is UV absorption due to volcanic sulphur dioxide and large silicate particles. As human-induced depletion of stratospheric ozone is much greater at higher latitudes, about 30–60°N (*McMichael et al.*, 1996), ozone measurements are scarce at the tropics, therefore ozone depletion trends at the tropics are not yet established even that ozone variability in these latitudes is very low.

Spectral measurements of ultraviolet-B radiation made at Toronto indicate that the intensity of light at wavelengths near 300 nm has increased by 35 percent per year in winter and 7 percent in summer. These trends indicate that the increase is caused by the downward trend in total ozone measured at Toronto during the same period (*Kerr* and *McElroy*, 1993).

Since UV measurements are difficult to made and scarce all over the world, indirect methods to determine UV-B irradiance have been attempted, either through radiative transfer modelling (*Box* and *Loughlin*, 1997; *Dave* and *Furukawa*, 1966, *Lemus-Deschamps et al.*, 1997, *Ruggaber et al.*, 1997) or using simple regression models (*Feister et al.*, 1996; *Nagaraja et al.*, 1984).

On the other hand, statistics of skin cancer incidence show percentage increases as a function of latitude for the period 1979–1994. The highest increases are reported on the middle and high latitudes (*UNEP*, 1994). The latitude span for Mexico shows skin cancer incidence increases of about 3% for that period. Though these figures are not yet verified, there are relevant skin cancer incidence figures for the Colima state located in the western part of Mexico (*Galindo* and *Loya*, 1998) which justify *per se* the need of reliable high quality systematic ground-level UV measurements.

Although most of Colima sites are free from anthropogenic aerosols, Volcán de Fuego de Colima (see *Fig. 1*), which is one of the most active volcanoes of Mexico, has a permanent plume delivering gases (mainly SO_2) and large silicate particles into the atmosphere. Sulphur dioxide is transformed through the gas-to-particle conversion mechanism into small sulphate particles and sulphuric acid drops. It is necessary to study the effects of volcanic aerosols on the UV radiation field.

In this study regression models are used to relate global solar radiation (290–2900 nm) to UV (290–385 nm) and UV-B (290–320 nm) irradiance measurements. The regression equation obtained let us expand the UV-B data set from October 1995 to June 1999 and the UV data set from June 1993 to June 1999. Unfortunately, at the time that these UV measurements were made no ozone measurements were made within this region. Therefore the stratospheric ozone depletion does not appear in the expanded data set here reported. The new UV-B data set will be used only to support medical statistics on increasing skin cancer incidence. Finally, the calibration shift of the instrument with the time of total ultraviolet radiometers (TUVR) is also presented.

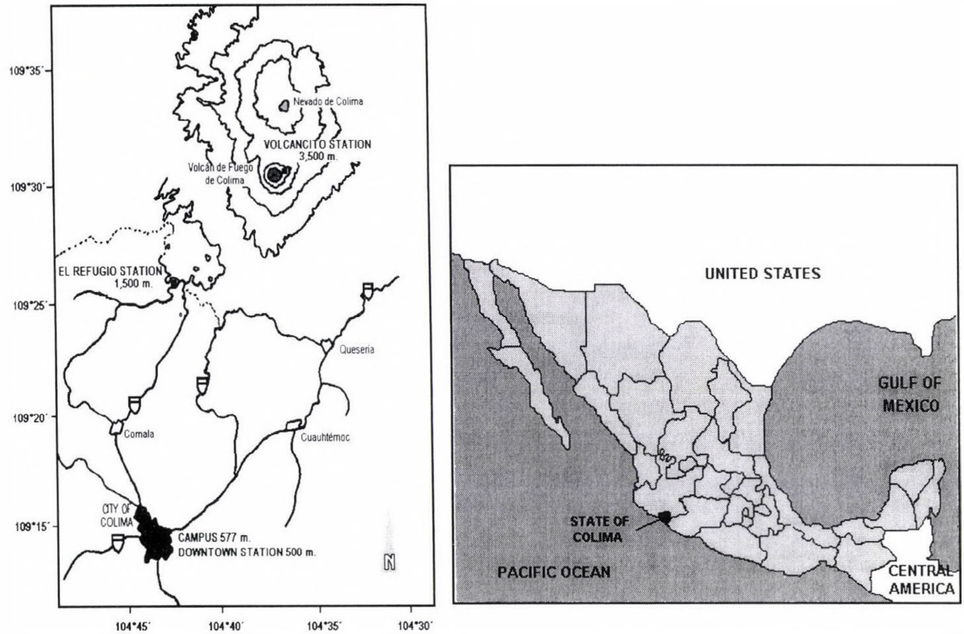

Fig. 1. Localization of the state of Colima in Mexico.
The two measurement sites are also depicted.

2. Methods

2.1 Measurement sites

2.1.1 University campus

A meteorological station was installed on the roof of a 4 m high building located at the University Campus (577 m a.s.l.) in April 1994. In June 1995 an Eppley precision spectral pyranometer (PSP) No. 29102F3 was added to measure global solar irradiance (290–2900 nm). From October 1995 to November 1996 a Solar Light Model 501 UV-Biometer S/N 1471 (290–320 nm) was operating. Finally, from November 1996 to January 1997 a UV-Biometer S/N 1458 was operating. All the instruments are coupled to a Campbell data logger sampling time in every 5 minutes. Unfortunately, the UV-Biometers are not protected electrically against shortcuts. Due to heavy storms, an electrical short circuit damaged very badly the UV-B sensors interrupting the measurements. Since the photodiode of these instruments were damaged, no attempts to repair and calibrate them were made. The data set of UV-B irradiance and global solar radiation measurements used for the regression analysis is from October 16, 1995 to December 31, 1996.

2.1.2 Rancho El Refugio

Our second station, installed in April 1994, is located in a rural zone at Rancho El Refugio (1,500 m a.s.l). The station operates two radiometers, Eppley Model TUVR S/N 27988 and 28928 (290–385 nm) to measure total and diffuse ultraviolet irradiance. Also there is an Eppley PSP No. 29102 that measures global solar radiation. All the instruments are coupled to a Campbell data logger sampling time in every 5 minutes. The data set for the year 1997 of total ultraviolet irradiance and global solar irradiance is used for the regression analysis.

A calibration program of all our pyranometers is regularly done against our Eppley H-F cavity radiometer No. 28965 which is one of the regional radiometer instruments of the Regional Radiation Center of Mexico for the Regional Association IV of the World Meteorological Organization (WRC, 1995). A conservative estimate of the accuracy of the measured global solar radiation is $\pm 2\%$. The observing site affords optimum exposure to the radiation sensors, with practically no obstructions extending beyond 3° above the plane of the sensors. The results are expressed in physical units (W m^{-2}).

The intensity of incoming solar radiation at the surface varies locally with the angle of incoming solar radiation and hence with the day, season, latitude and cloudiness (*Kuik* and *Kelder*, 1994), therefore local natural conditions are better represented performing regression analyses using measurements under all-sky conditions. Data sets of UV-B, UV and G were matched on time forming $n \times 2$ matrices (G_i, $UV\text{-}B_i$) and (G_j, UV_j), where i,j is the sampling time. The regression analyses were made using the MATLAB interactive system.

3. Calibration shift UV radiometers

The Eppley ultraviolet pyranometer (TUVR) sensor is a Weston selenium barrier-layer photoelectric cell (*Coulson*, 1975). The value of the original instrumental constant of these instruments is quite similar to the values shown in *Table 1*.

The instrument used as reference (TUVR S/N 28656) was received in January 1993, since then it has been on storage most of the time. In order to check irradiance levels of the other UV radiometers in operation, the instrument was exposed under high irradiance conditions only for several days. The other three radiometers were exposed under all sky conditions most of the time.

The photocell loses sensitivity with time. To study this effect, known as aging effect, a comparison was made under clear conditions. All the instruments were simultaneously exposed to the sun and coupled to a datalogger with five minutes sampling time.

Table 1. Original instrument constants of total ultraviolet radiometers (TUVR)

TUVR Nr.	k [mW cm^{-2} mV^{-1}]	Date
27831	0.518	09.18.1989
27988	0.469	11.09.1990
28656*	0.538	11.02.1992
28928	0.559	04.14.1992

* Reference instrument

4. Results

4.1 Ultraviolet-B irradiance

The degree of correspondence that exists between *UV-B* irradiance and global solar radiation *G* under all weather conditions is given by a polynomial of degree 2, which is the best fit for such regression models. Regression equation for UV-B irradiance from global solar radiation measurements made at campus Colima from October 16, 1995 to December 31, 1996 is as follows (see *Fig. 2a*):

$$UV\text{-}B = 1.28 \cdot 10^{-7} G^2 + 7.42 \cdot 10^{-5} G - 1.01 \cdot 10^{-3} \qquad (1)$$
$$c = 0.999, \quad e = +7.6\%,$$

where c is the correlation coefficient, e is the determination error.

The comparison of measured UV-B irradiance and that obtained using the regression equation for a particular day (January 10, 1996) is shown in *Fig. 2b*. The agreement is quite good around noon (10:30–14:30), however, for low solar height the estimated UV-B is relatively higher than the measured. The differences between modelled and measured UV-B are shown in *Fig. 2c*. The largest differences ($\sim$12 mW m^{-2}) are observed in the afternoon, whereas in the morning the difference is not larger than 9 mW m^{-2}. At noon there is a negative difference ($\sim$5 mW m^{-2}).

Synthetic time series were constructed for the time period from October 1995 up to present (June 1999). No trends were observed during this period.

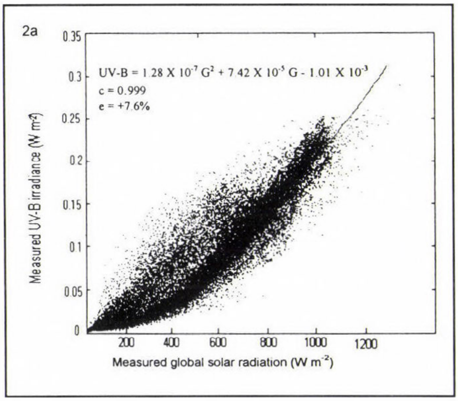

Fig. 2a. Regression equation for UV-B irradiance from global solar radiation measurements made at campus Colima from October 16, 1995 to December 31, 1996.

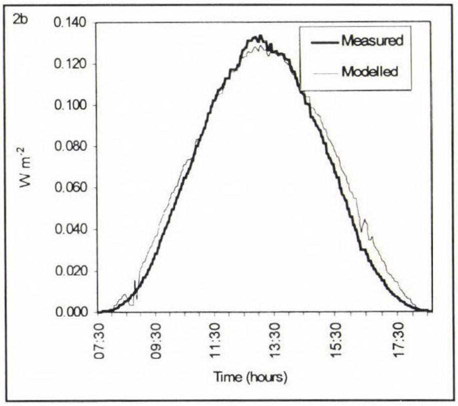

Fig. 2b. Comparison of UV-B measurements with calculated values of the regression equation for a particular day, January 10, 1996.

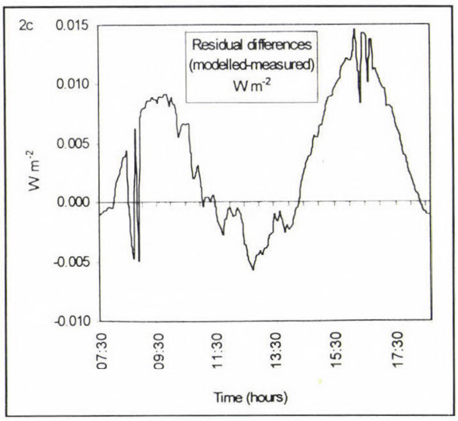

Fig. 2c. Difference between modelled and measured UV-B for January 10, 1996.

4.2 *Ultraviolet irradiance*

The degree of correspondence that exists between *UV* irradiance and global solar radiation (*G*) is given by a linear regression equation which is the best fit for such regression models. Regression equation for UV irradiance from global solar radiation measurements made at rancho El Refugio from January 1 to December 31, 1997 (see *Fig. 3a*) is as follows:

$$UV = 0.0741\ G + 1.8471 \qquad (2)$$
$$c = 0.962,\ e = +8.4\%.$$

The comparison of measured UV irradiance and that obtained using the regression equations for a particular day is shown in *Fig. 3b*. The agreement is relatively good, however the model produces systematically higher values. The differences between modelled UV and measured UV are shown in *Fig. 3c*. The largest differences (~ 7 W m^{-2}) are observed in the early morning, whereas during the rest of the day the differences rank between 4 and 1 W m^{-2}. At noon the fit lies around 2 W m^{-2}.

4.3 *Calibration shifts*

Fig. 4a shows the mean hourly voltage output of each instrument, and *Fig. 4b* shows the records in physical units. It is noticed that one of the instruments (S/N 28928) shows significantly higher values of incoming UV radiation, whereas the rest of the instruments respond quite similarly but with much lower signals. It is remarkable how the rest of the radiometers have degraded, between 40–50%, including the reference instrument (TUVR S/N 28656). Comparing the actual recorded values with previous records for the same time and place, one observes a significant loss of sensitivity (-14%) for the instrument S/N 28928, which shows, that this instrument was less degraded than the others. The above results suggest that the TUVR instrument mean lifetime under tropical conditions is about 4 years.

The instrument TUVR S/N 27988 was send to the manufacturer for photocell replacement and calibration against their standards. The new instrumental constant enables us to assume that the measured UV intensity with the reference instrument is proportional to the measured signals of the other radiometers:

$$K_N L_N \approx K_i L_i, \qquad (3)$$

where the *K* is the instrumental constants and the *L* is the measured voltage. *N* stands for the new instrument S/N 27988, *i* stands for the test instruments.

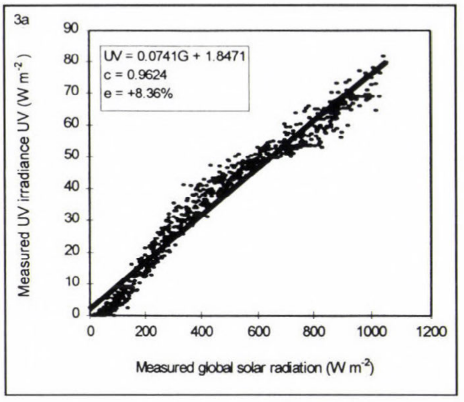

Fig. 3a. Regression equation for UV irradiance from global solar radiation measurements made at rancho El Refugio from January 1 to December 31, 1997.

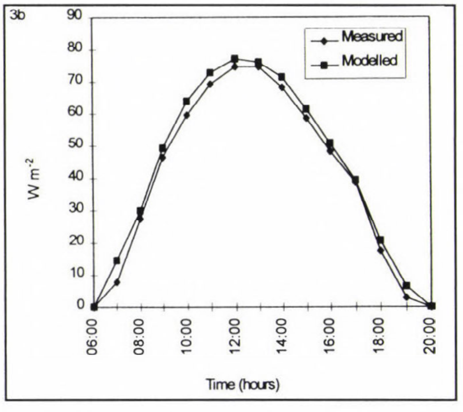

Fig. 3b. Comparison of UV measurements with calculated values of the regression equation for a particular day, May 1, 1998.

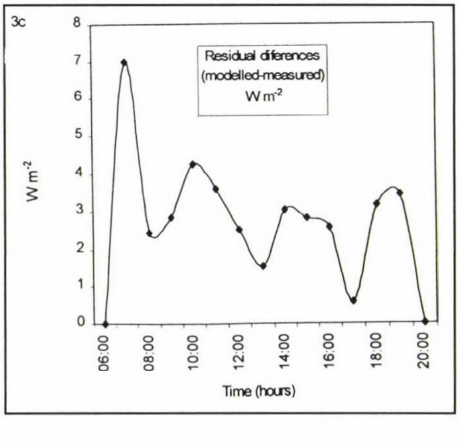

Fig. 3c. Difference between modelled and measured UV for May 1, 1998.

Using the proportionality constant one can raise the sensitivity of the test instrument in reference to the new instrumental constant:

$$K_i = K_N \, (L_N / L_i). \tag{4}$$

Using the above expressions, new calibration constants were obtained for the operational radiometers. A new comparison between all the instruments was made. We have selected one particular day (July 24, 1998) to show the new instruments response. *Fig. 5a* depicts the measured UV values with the TUVR S/N 27831, whereas *Fig. 5b* is for TUVR S/N 28656 and *Fig. 5c* is for TUVR S/N 28928. All of them were compared to the new reference instrument (S/N 27988). It is observed that there is still a response difference between the different radiometers.

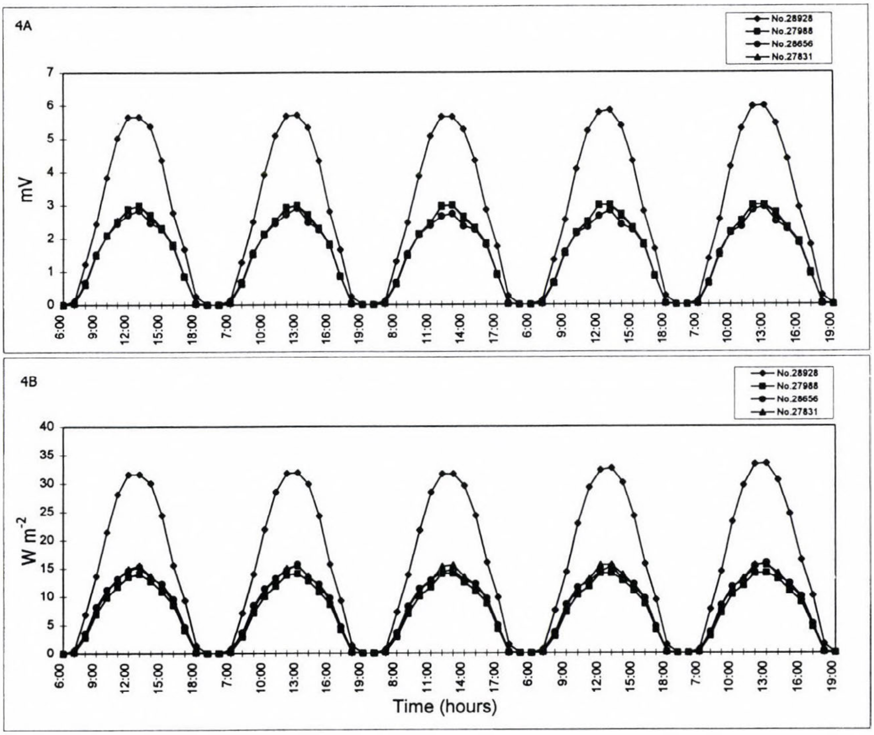

Fig. 4. Comparison of TUVR radiometers under clear sky conditions (15–19 February, 1998): (*a*) Mean hourly voltage output, (*b*) mean hourly UV irradiance (W m^{-2}).

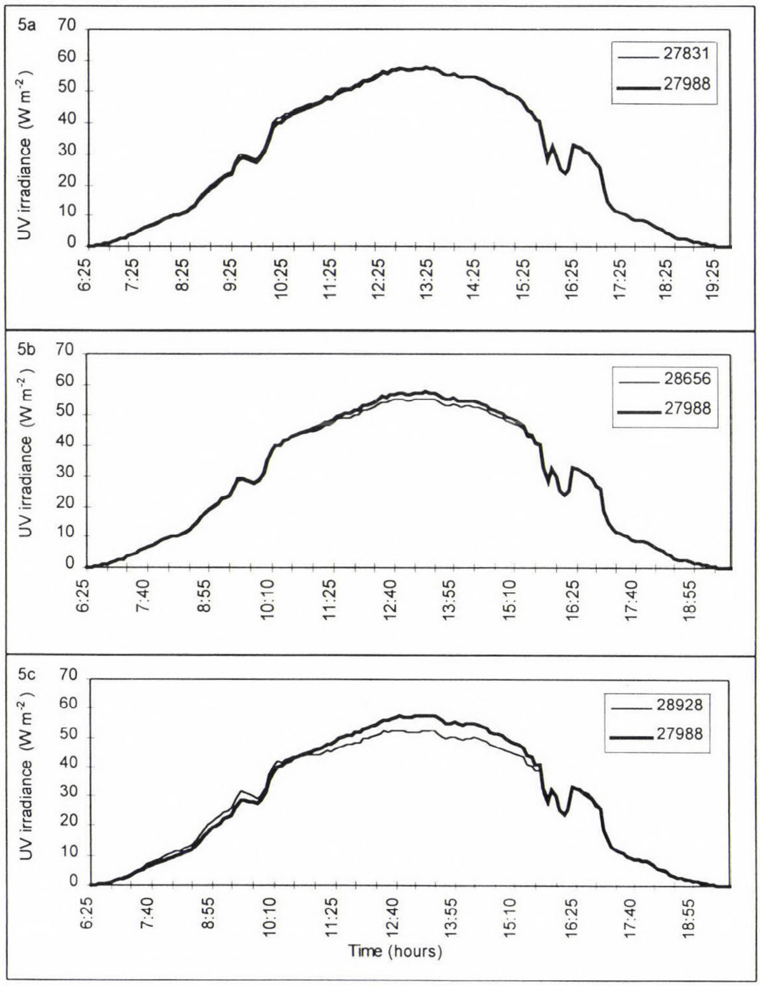

Fig. 5. Comparison of TUVR instruments: (*a*) S/N 27831; (*b*) S/N 28656; (*c*) S/N 28928 for a particular day (July 24, 1998).

Let us take the ratios of the measured values to UV ≥ 40 W m^{-2}, i.e., for high UV intensities which obviously occur around noon. The results are shown in *Table 2*.

The above results show that it is not enough to refer the instrumental response to a new instrumental constant since sensitivity loss of the photocell does not reach the actual incoming high UV intensities. The TUVR S/N 28928 instrument obviously needs a new photocell.

Table 2. Ratio of the measured values to UV ≥ 40 W m^{-2}, referred to a new instrumental constant

TUVR S/N	Ratio (%)
27831	1.06
28656	2.42
28928	5.81

5. Conclusions

Regression methods for global solar radiation and ultraviolet irradiance data permit to extend UV records which, in turn, may be used to analyze time variations of incoming UV-irradiance.

The analysis of synthetic UV-B series obtained shows no trends for the period 1995 up to present (June, 1999).

The best fit is obtained between global solar radiation (290–2900 nm) and ultraviolet irradiance-B (290–320 nm) through a second order polynomial. Whereas the best fit obtained between global solar radiation and UV irradiance (290–385 nm) obeys a linear regression.

Significant calibration shifts occur in the total ultraviolet radiometers. Therefore frequent instrumental comparisons and calibrations should be made. It is found that the mean lifetime of this kind of instruments is about 4 years at the tropics.

References

Box, M. and *Loughlin, P.*, 1997: Efficient calculation of UV indices using radiative perturbation theory. In *Proc. of the First Sparc General Assembly*. Melbourne, Australia, 2-6 December 1996 Vol. II, WCRP-99, WMO/TD-NO. 814, 525-528.

Coulson, K.I., 1975: *Solar and Terrestrial Radiation. Methods and Measurements*. Academic Press, New York, 322 pp.

Dave, J.V. and *Furukawa, P.M.*, 1966: Scattered radiation in the ozone absorption bands at selected levels of a terrestrial Rayleigh Atmosphere. *Meteorol. Monogr. 7*, 1-353.

Feister, U., Nöthlich, A. and *Grewe, R.*, 1996: Short-term forecasts of biologically effective UV radiation; comparison between modelled and measured irradiation. *Meteorol. Appl. 3*, 75-89.

Galindo, I. and *Loya, L.*, 1998: Ground level ultraviolet irradiance (UV-B), ozone and incidence of skin cancer at the tropics. Submitted to *Int. J. Epidemiol.*

Gleason, J.F., Bhartia, P.K., Herman, J.R., McPeters, R., Newman, P., Stolarski, R.S., Flynn, L., Labow, G., Larko, D., Seftor, C., Wellemeyer, C., Komhyr, W.D., Miller, A.J. and *Planet, W.*, 1993: Record low global ozone in 1992. *Science 260*, 523-524.

Jones, A.E. and *Shanklin, J.D.*, 1995: Continued decline of total ozone over Halley, Antarctica since 1985. *Nature 376*, 409-411.

Kerr, J.B. and *McElroy, C.T.*, 1993: Evidence for large upward trends of ultraviolet-B radiation linked to ozone depletion. *Science 262*, 1032-1034.

Kuik, F. and *Kelder, H.*, 1994: Spectral ultraviolet radiation measurements and correlation with atmospheric parameters. *Final Report NOP Project 852088*, Koninklij Netherlands Meteorologisch Institut. Scientific Report WR-94-05, 38 pp.

Lemus-Deschamps, L., *Rikus, L.*, *Atkinson, R.*, *Grainger, S.* and *Paevere, J.*, 1997: Ultraviolet index analyses and forecasts. In *Proc. of the First Sparc General Assembly*. Melbourne, Australia 2-6 December 1996 Vol. II, WCRP-99, WMO/TD-NO. 814, 549-552.

McMichael, A.J., *Haines, A.*, *Slooff, R.* and *Kovats, S.* (eds.), 1996: *Climate and Human Health*. World Health Organization, Geneva, 297 pp.

Nagaraja Rao, C.R., *Takashima, T.*, *Bradley, A.W.* and *Lee, Y.T.*, 1984: Near ultraviolet radiation at the earth´s surface; measurements and model comparisons. *Tellus 36B*, 286-293.

Ruggaber, A., *Schwander, H.* and *Nakajima, T.*, 1997: Modelling of UV radiation. In *Proc. of the First Sparc General Assembly*. Melbourne, Australia 2-6 December 1996, Vol. II, WCRP-99, WMO/TD-NO. 814, 553-556.

United Nations Environmental Programme, 1994: Environmental effects of ozone depletion: 1994 assessment. Nairobi, UNEP.

IDŐJÁRÁS

Quarterly Journal of the Hungarian Meteorological Service
Vol. 103, No. 4, October-December 1999, pp. 261-273

Source characterisation of airborne particles in Seville (Spain) by multivariate statistical analyses

A. J. Fernández Espinosa[1], **M. Ternero Rodríguez**, **F. J. Barragán de la Rosa** and **J. C. Jiménez Sánchez**

Department of Analytical Chemistry, University of Seville, E-41012 Seville, Spain; e-mail: anjose@cica.es

(Manuscript received 10 August 1998; in final form 19 July 1999)

Abstract—Metal contamination (Al, Cr, Mn, Fe, Co, Ni, Cu, Zn, Cd and Pb) in suspended particles was studied at twelve monitoring stations in Seville. The metal concentrations in cellulose filter samples were analyzed by FAAS (flame atomic absorption spectrophotometric) and GFAAS (graphite furnace atomic absorption spectrophotometry). We found that the sum and the percentages of metals analyzed with respect to the Total Suspended Particles (TSP) were low. The study shows that Al and Fe are the major metal elements with concentrations of around 860 ng m^{-3} which together represent 90.6% of the sum of metals. Three statistical groups of metals were found by factor analysis and cluster analysis: Fe, Al and Mn; Zn, Cd and Cr; and Pb and Cu. These techniques, applied in the 1monitoring stations, were effective at associating the groupings obtained with the different environmental locations of the city and with the origin of the metals in different areas of the same city. Areas of the city influenced by traffic and industry were distinguished, especially those influenced by metal foundry industries (Camas, Puerto Este, Pinomontano and La Liebre). A second group comprises areas influenced by traffic alone (Los Remedios, Laraña, Resolana, Recaredo and Luis Montoto). The remaining sites correspond to areas influenced by emission sources (Reina Mercedes, Bellavista and Torreblanca).

Key-words: heavy metals, factorial analysis, particulate matter, air pollution.

1. Introduction

The presence of harmful substances in the atmosphere is particularly worrying because of the number of people that can be affected. Also, air pollution can have significant negative effects on a wide range of living organisms and on the rocky materials of monumental buildings. The danger depends on the nature of

---

[1] Corresponding author

the pollutants and on its content in the atmosphere. Although there are considerable amount of data on gaseous pollutants (CO, SO_2, NO_x and O_3) this is not the case for heavy metals. Heavy metals have an important effect on biochemical mechanisms especially because they accumulate in the biomass.

In large urban areas, the considerable amount of particulate matter in the air is an important problem. The main sources of airborne particulate matter are: agriculture, industry, fuels for domestic use and motor traffic. Particles in suspension comprise the most representative variable, and determination of heavy metals in unsedimentable particles is also of great value. Because of their small size, these particles have a direct incidence on health by affecting respiration. On the other hand, they are easily transported large distances and can stay in the air for some time depending on meteorological conditions.

The aim of the present work was to determine the metal content of suspended particulate matter in Seville, which is the most densely populated city of southern Spain. It presents an extension of 142 km^2 and is situated only 10 meters above the sea level on an extensive plain crossed by the Guadalquivir River. In 1993 it had a population of 716,937 inhabitants, but on workdays the effective population increases to one million mainly with commuters from nearby towns. Seville has a Mediterranean climate with an annual average temperature of 19°C and rainfall of 580 mm. Other climatological conditions (poor winds, thermal investments) do not favour pollutant dispersion. Industry as a source of metal pollutants is rather scarce and represents about 5% of the city's economic activities. Metallic products represent only 15% of this industry.

Several studies on contamination by particulate matter in the city of Seville have been carried out in order to determine metals in sedimentable particles (*Usero et al.,* 1983a, b) and in suspended particles (*Melgarejo et al.,* 1986; *Usero et al.,* 1988; *Luis-Simón et al.,* 1995). Consequently, one of the main goals of this work was to study the evolution of the situation after the economic and urban changes experienced in the city after 1992, when the World Fair of Seville (EXPO 92) was celebrated.

2. Experimental

2.1 Sampling

Sampling network with twelve monitoring stations was elaborated (*Fig. 1*). It is designed to encompass practically all urban areas and some peripheral zones of Seville. In this network stations are located near to focuses of emission (industries and zones of high traffic density) as well as to others with cleaner air.

The stations can be classified into three categories according to the nearest and most significant possible pollution sources:

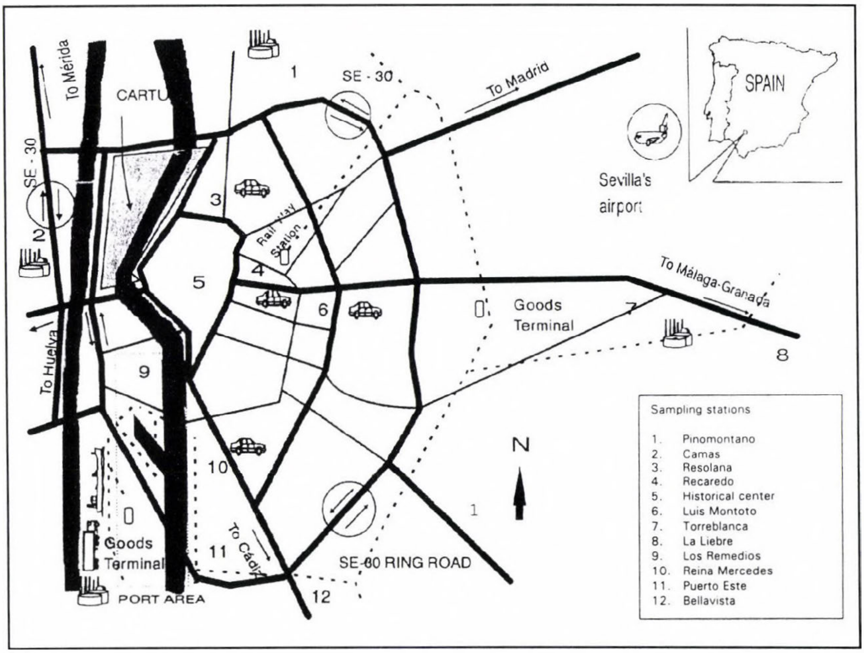

Fig. 1. Sampling network in Seville with the location of the twelve sampling.

(i) *Stations under the influence of industrial emissions.* Camas (station 1) is 6 kilometres far from the city centre, near to two foundries of iron and aluminium. Puerto Este (station 3) is near to Seville Harbour in the estuary of the Guadalquivir, in which important loading and unloading activities take place. There is a certain amount of industry nearby (fertilisers, oils, cement and construction materials, small metallurgy and shipyards). Pinomontano (station 10) is near to fertiliser and building material production plants. La Liebre (station 12) is 15 kilometres far from the city. It is next to an important cement factory, and there is a glass factory and metal foundries nearby.

(ii) *Stations under the influence of vehicle emissions.* Los Remedios (station 2), Larańa (station 5) in the historic centre, Resolana (station 6), Recaredo (station 7) and Luis Montoto (station 9). The last three sites are next to important communication routes inside the city.

(iii) *Peripheral stations with few sources of industrial emissions or traffic.* Reina Mercedes (station 4), Bellavista (station 8), near to a factory of fiber-cement and Torreblanca (station 11).

In this study, 48 samples were collected (four samples in each monitoring station on different days of the week) from February to October, 1993.

Atmospheric suspended particles were collected on 20.3 × 25.4 cm cellulose filters (Whatman-41) using a Quimisur-SMAV high volume sampler on the top roof of buildings at 4–6 m high. Approximately 1500 m^3 air was collected in each 48 hour sampling period with a nominal aspiration flow of 40 m^3 h^{-1}.

In order to obtain a sufficient quantity of sample and absolute concentration of metals, the relationship between the duration of the sampling and results of subsequent analytical determinations was studied. Because of the low levels of metals and the small amounts of particles collected, a sampling period of 48 hours was chosen.

Beforehand, a preliminary assay was done to select the most suitable filter. Although some authors prefer to use glass-fiber filters (*Obiols et al.,* 1986; *Clevenger et al.,* 1991), in our experience cellulose ones were preferable for the analyzed parameters (*Usero et al.* 1988; *Luis-Simón et al.,* 1995), because of the chemical stability, low concentration of blanks and low cost. These filters can easily break down, and values corresponding to blanks are lower than glass-fiber values. These showed high levels of impurities of iron, aluminium and especially zinc (*Berg et al.,* 1993), and reactivity with metals (*Zatka et al.,* (1992). In addition, several experiments were done to improve the method for chemical attack of samples in teflon vessels. The proportions and types of acids used in the digestion mixture, temperature, time and other variables were noted in order to optimise the blanks and efficacy of attacks. Other mixtures and heating procedures (*Obiols et al.,* 1986; *Frenzel*, 1991), have been studied, but we obtained the best results in the method recorded below.

2.2 Apparatus and reagents

Samples were analyzed by flame atomic absorption spectrophotometry (FAAS Perkin-Elmer 3100) for the majority metals Fe, Al, Zn, Cu and Pb, and by graphite furnace atomic absorption spectrophotometry (GFAAS Perkin-Elmer 2380 with HGA Programmer Perkin-Elmer 300) for the trace metals Cd, Co, Ni, Mn and Cr.

All the reagents employed were of analytical grade, and Milli-Q water was used.

2.3 Methodology for the chemical analysis

A quarter of cellulose filter was finely divided into 1 cm^2 pieces prior to chemical treatment, consisting of acid digestion by heating in a closed teflon vessel under pressure.

First, the sample was treated in an open vessel with 20 mℓ of concentrated nitric acid and then it was evaporated to half of the volume in a sandbath at 180°C. Afterwards, 20 mℓ of water plus 2 mℓ of perchloric acid were added. The closed vessel was introduced into a stove at 120°C for six hours. The treated sample solution was decanted from the washed silica-carbonaceous residue, placed in a 50-mℓ standard flask and diluted to the mark with Milli-Q water. Treated samples were then analyzed by FAAS or GFAAS.

Blanks were determined for all metals. The previously described procedure was repeated with four unused filters and the average value of the blanks was subtracted from samples.

2.4 Multivariate analyses

To draw conclusions from the data, multivariate analyses were applied to the average of the four concentrations obtained for each metal in each monitoring station. Statistical models of parameter correlation, factor analysis and cluster analysis of variables and cases were applied using the CSS:STATISTICA (StatSoft) software package. The data matrix represents the total contents for the 10 metals and the 12 monitoring stations. Another matrix with an additional column corresponding to values of total suspended particles (TSP) was also studied.

3. Results and discussion

To interpret the data, in addition to plots and basic statistics of the results, other models of multivariate statistics, called pattern recognition, were also applied. These models can handle a large amount of numerical data reducing the variables to a few factors, which allow us to evaluate their combined effect and to classify metals by emission sources.

3.1 Heavy metal composition

Concentration values for total particles in suspension (TSP) and metal concentrations appear in *Table 1* (expressed in nanogram of the element per cubic meter of sampled air).

Values for TSP, the sum of metals (S) and their relative percentages in the TSP (S/TSP%) for each sample are recorded in *Fig. 2*. Regarding these data globally, the following considerations can be made:

The sites with the highest levels of TSP are 5 and 1, and these, therefore, have low S/TSP% values. Stations 8 and 2 behave similarly, due to the even lower absolute amounts of metals.

The sites with the lowest levels of TSP (stations 9, 10 and 4) coincided with the areas of the city with the highest relative metal percentages.

These observations can be explained as follows: Evolution of S/TSP% in the graph follows the same profile as the total sum of metals (Fig. 2), because the largest variation among the different stations is given for this variable. If the TSP value is low and the sum of metals is medium or high, the metallic richness is high (sites 9, 10, 4), but if the TSP value is high and the sum of

Table 1. Average metals concentrations (ng m^{-3}) and total suspended particles (TSP) in Seville from February to October, 1993

Station	Al	Fe	Zn	Pb	Cu	Mn	Ni	Co	Cr	Cd	TSP $\times 10^{-3}$
Nº 1	895.3	1131.2	74.1	16.4	9.3	11.6	4.7	1.8	0.9	0.9	176.8
Nº 2	467.1	421.0	53.5	43.6	19.0	8.3	3.1	1.2	0.8	0.4	155.1
Nº 3	1179.4	1491.6	158.4	48.5	24.4	23.0	24.5	9.3	3.9	1.3	140.6
Nº 4	445.9	621.3	79.1	91.5	38.8	8.5	4.9	2.0	1.2	0.8	75.3
Nº 5	859.5	818.8	70.3	74.5	39.6	10.2	6.7	2.6	2.1	0.6	186.1
Nº 6	1299.2	1217.2	75.7	76.3	53.7	18.2	5.6	4.0	2.7	0.4	139.2
Nº 7	694.2	938.1	111.5	198.1	80.9	12.2	3.3	5.9	1.1	1.1	123.9
Nº 8	276.1	213.5	143.9	26.1	27.0	3.3	3.9	2.7	2.5	1.4	146.8
Nº 9	1192.4	1058.2	52.0	66.5	51.1	15.8	4.4	3.5	1.2	0.3	94.3
Nº 10	1036.8	636.1	64.3	35.9	39.1	9.6	4.6	1.8	0.9	0.5	80.7
Nº 11	1268.0	876.8	134.4	34.3	21.4	18.8	17.8	3.7	1.5	0.5	138.8
Nº 12	708.0	893.8	73.7	18.0	45.6	17.5	4.7	5.2	0.3	0.5	143.1
Mean	860.2	859.8	90.9	60.8	37.5	13.1	7.4	3.6	1.6	0.7	133.4
Range	276-1299	214-1492	52-158	16-198	9-81	3-23	3-25	1.2-9.3	0.3-3.9	0.3-1.4	75-186

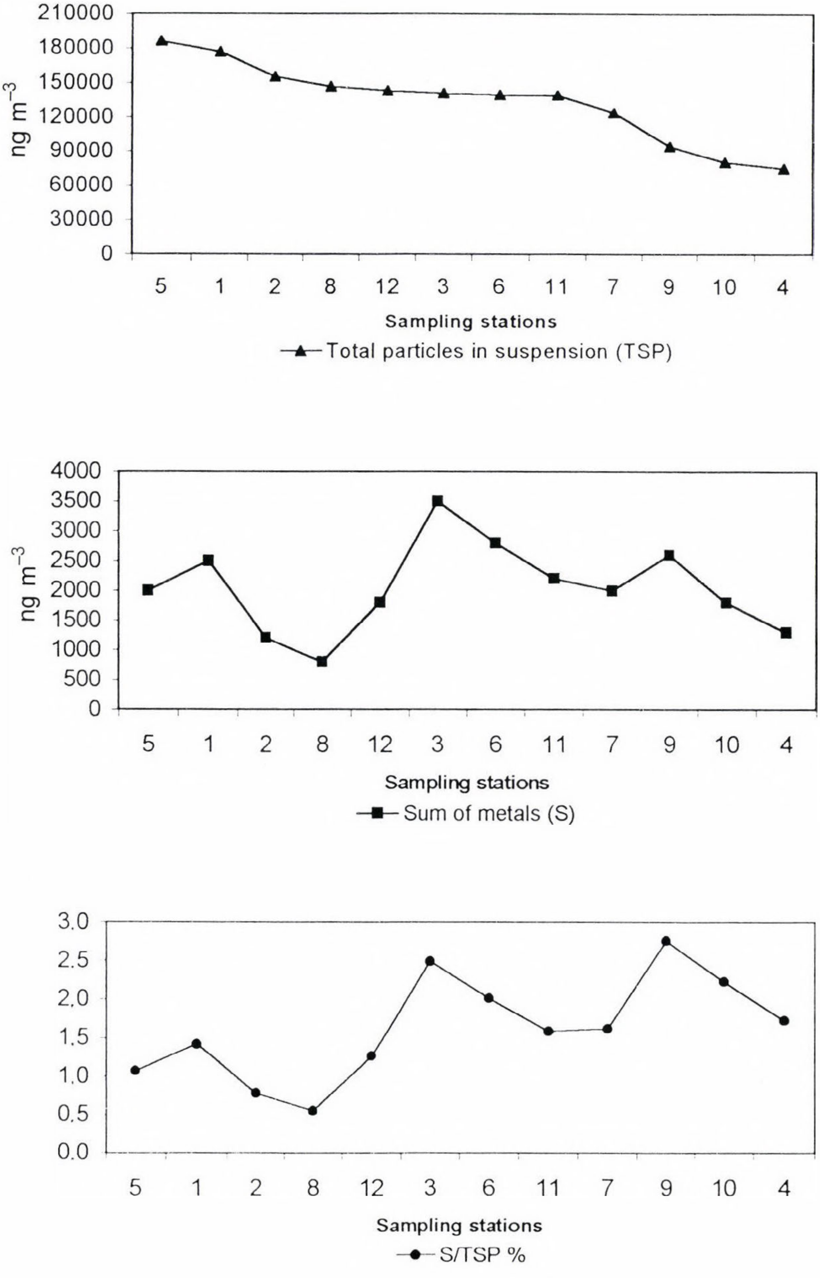

Fig. 2. Average of total particles in suspension (TSP), sum of metals (S) and their relative percentages in the TSP (S/TSP%) parameters at the twelve sampling stations of Seville.

metals is low, the metallic richness is low (sites 2, 8). Therefore, the values of S/TSP% reflect the metallic richness of particles, although the parameter that measures the degree of metal pollution is the total sum of all the metals (S). However, the parameter S/TSP% is useful to assess the level of metal contamination in conditions in which, mainly due to the rains, TSP and S levels diminish considerably. Therefore, in spite of varying meteorological conditions, metal concentrations on different days or in different seasons would give some indication of the degree of metal contamination of the particles.

Values of metal pollution (S) (Fig. 2) reflect that the highest levels are found in Puerto Este (3), Resolana (6), Luis Montoto (9) and Torreblanca (11). The least contaminated sites are Bellavista (8), Los Remedios (2) and Reina Mercedes (4).

Regarding individual heavy metal contents (Table 1) we observed the highest average concentrations for Al and Fe with 860 ng m^{-3} for both elements. The metals Zn, Pb and Cu presented concentrations an order of magnitude below the above value (91–38 ng m^{-3}), and finally, Mn, Ni, Co, Cr and Cd showed even lower amounts (13–0.7 ng m^{-3}).

Table 2 presents the results of two experiments: the average individual metal content (C), the metallic fractions (C/TSP%) and the relative metallic composition (C/S%) obtained in 1985 (*Usero et al.,* 1988) and 1993. The comparison reveals a reduction in metal concentrations (C) from 1985 to the present day. They are four times lower for Al, Fe, Zn, Ni and Cd and even ten times lower for Pb and Cr. On the other hand, these parameters remained more or less constant for Mn and Co. Similar values of relative composition (C/S%) show that the same contamination sources remained in Seville. However, lead and chrome are notable exceptions, since their concentrations suffered a greater decrease. The metallic fraction on particulate matter (C/TSP%) was also diminished since TSP levels were only reduced from 210,000 to 133,400 ng m^{-3}.

3.2 Correlation of metals

Table 3 includes the correlation matrix of the studied parameters. Tabulated values show that Mn significantly correlates with Fe, Al and Co ($r > 0.73$) and to a lesser extent with Ni ($r = 0.69$). These elements are presumably of soil or agricultural origin. A good correlation between elements mainly from vehicular emissions such as Pb and Cu ($r = 0.81$) is also observed. Zn correlates with Cd and Cr moderately well ($r > 0.64$) and to a lesser extent with Co and Ni (r coefficients of 0.62 and 0.69). All these elements are from waste stored in uncontrolled dumps, where burning and incineration often take place. Also, in the case of Ni and Co the significant correlation with earth metals marks a mixed origin. In the following factor and cluster analysis, TSP was ignored because of its low correlation with the remaining parameters.

Table 2. Comparative study of 1985 and 1993 in Seville

	1985*			1993**		
TSP		210.000 ng m^{-3}			133.400 ng m^{-3}	
Metal	C	C/TSP%	C/S%	C	C/TSP%	C/S%
Al	3070.0	1.462	39.72	860.2	0.645	45.32
Fe	3570.0	1.700	46.18	859.8	0.644	45.30
Zn	340.0	0.162	4.40	90.9	0.068	4.79
Pb	680.0	0.324	8.80	60.8	0.046	3.20
Cu***				(37.5)	(0.028)	
Mn	19.6	0.009	0.25	13.1	0.010	0.69
Ni	26.0	0.012	0.34	7.4	0.006	0.39
Co	4.6	0.002	0.06	3.6	0.003	0.19
Cr	16.0	0.008	0.21	1.6	0.001	0.08
Cd	3.3	0.002	0.04	0.7	0.001	0.04
Sum	7729.5	3.681	100.00	1898.1	1.424	100.00

C: total contents in ng m^{-3}
C/TSP%: metallic fraction
S: sum of total contents in ng m^{-3}
C/S%: relative composition
* see *Usero et al.*, 1988
** present work
*** the metal not was analyzed in 1985

3.3 Factor analysis of the metals

The previous correlations were confirmed by factor analysis of the variables revealing three factors which together explained 87% of the variance. The factors that contributed to less than 5% of the variance were rejected. Percentages and loadings explained in each case are included in *Table 4*. The variables obtained in each factor are the following:

Factor 1. This is formed by Al, Fe, Mn, Co and Ni (it is noteworthy that these last two elements can also be found in Factor 2). This factor explains 43% of the variance and it prevails in stations Puerto Este (11), Resolana (3), Torreblanca (7) and Luis Montoto (6) (see *Fig. 3*). These elements contribute to almost 90% of metal content in the atmosphere of Seville. Factor 1 shows the presence of elements (*Usero,* 1988) of earth crustal origin.

Factor 2. This consists of elements such as Zn, Cd and Cr. This factor explains 24% of the variance and this grouping is significant at stations of

Puerto Este (11) and Bellavista (12) (Fig. 3). This factor is associated mainly with waste combustion (*Usero,* 1988) and represents 5% of all the metals.

Table 3. Correlation coefficients (r) for the ten analyzed metals and TSP

Al	1										
Cd	-0.39	1									
Co	0.36	0.41	1								
Cr	0.29	**0.51**	**0.55**	1							
Cu	0.06	-0.11	0.29	-0.11	1						
Fe	**0.77**	-0.04	**0.67**	0.37	0.14	1					
Mn	**0.79**	-0.20	**0.73**	0.32	0.10	**0.86**	1				
Ni	**0.52**	0.30	**0.67**	**0.64**	-0.34	**0.54**	**0.69**	1			
Pb	-0.07	0.16	0.26	0.00	**0.81**	0.12	-0.03	-0.19	1		
Zn	0.02	**0.78**	**0.62**	**0.64**	-0.14	0.13	0.23	**0.69**	0.03	1	
TSP	-0.04	0.14	0.05	0.21	-0.38	0.12	0.03	0.12	-0.24	0.14	1
	Al	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	TSP

Factor 3. This is formed by Cu and Pb corresponding to 5% of the metal content. This factor explains 20% of the variance and its highest influence is observed at the Recaredo (4) station (Fig. 3). This reflects the effect of vehicle emissions.

Table 4. Factor loadings for the varimax rotation

Variable	Factor 1	Factor 2	Factor 3	Communality (%)
Al	**0.91**	0.16	-0.06	86
Cd	-0.27	**-0.91**	0.07	91
Co	**0.63**	**-0.61**	0.31	87
Cr	0.36	**-0.73**	-0.09	66
Cu	0.09	0.13	**0.95**	93
Fe	**0.90**	-0.10	0.14	85
Mn	**0.97**	-0.09	0.02	94
Ni	**0.66**	**-0.60**	-0.32	89
Pb	-0.03	-0.11	**0.93**	88
Zn	0.13	**-0.93**	-0.06	89
% of total variance	43.2	23.8	19.9	

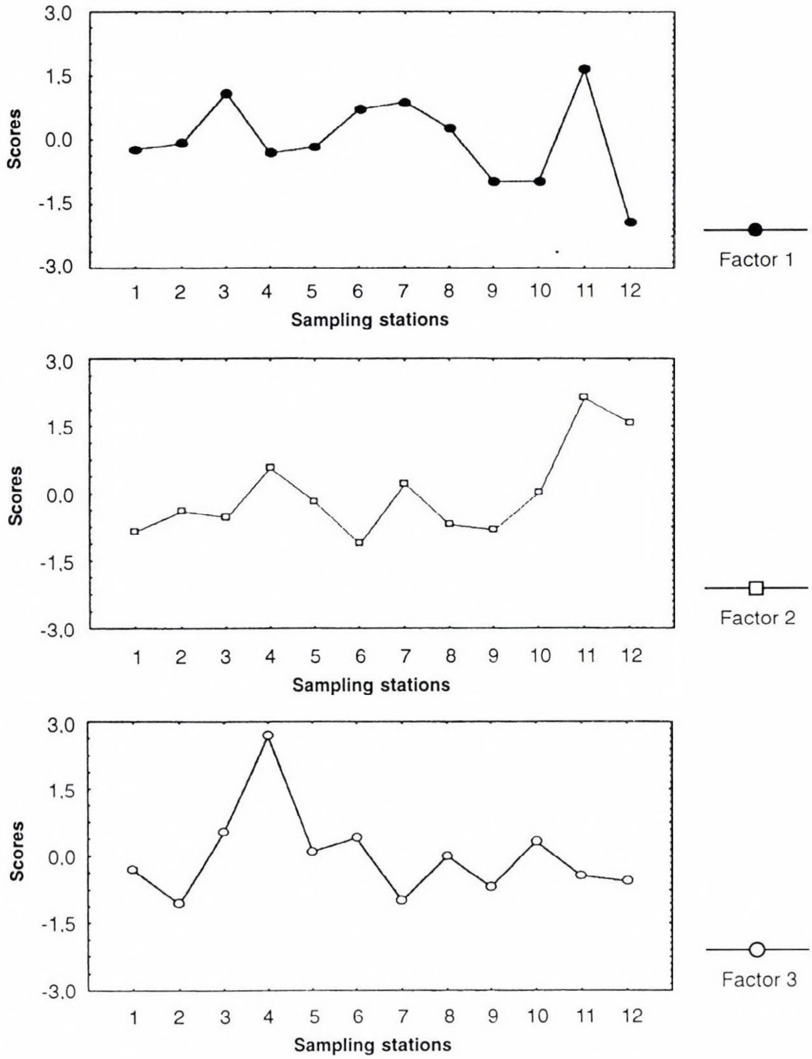

Fig. 3. Graphical representation of the three factors in the twelve sampling stations of Seville.

3.4 Cluster analysis

Cluster analysis of variables with the standardised matrix (*Fig. 4*) was also carried out. This analysis groups together Al, Fe and Mn, the other cluster is formed by Cd, Zn, Co, Ni and Cr, and the last cluster consists of Cu and Pb.

Metals are practically classified in the same groups obtained by factor analysis, while Co and Ni show a mixed behavior between Factor 1 and Factor 2.

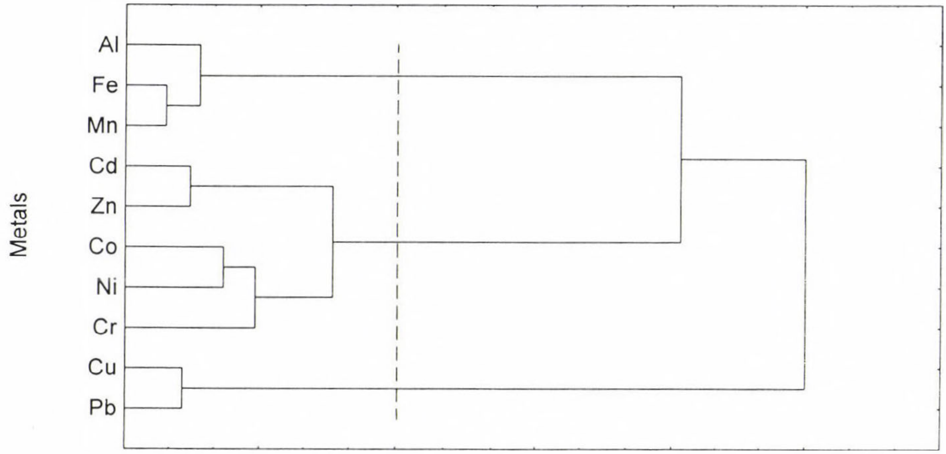

Fig. 4. Dendrogram of the cluster analysis of the ten metals.

4. Conclusions

From our results we can conclude that, in general, atmosphere of Seville is cleaner now than several years ago. This is indicated by the average value of TSP that has reduced from 210,000 to 133,400 ng m^{-3}. On the other hand, the metal fraction in TSP has diminished considerably, i.e., suspended particles now contain smaller amounts of metals. The decrease observed for lead and chromium is especially significant. In the first case, this is due to the new underground network of railways and ring roads constructed in 1992 for the World Fair. The latter has certainly alleviated dense inner city traffic. The continual increase of the proportion of vehicles with unleaded fuel also plays an important role. The decrease in chromium is especially pronounced because of the conversion of many former uncontrolled garbage dump sites into large controlled urban waste installations far from the city center also as a consequence of urban and environmental restructurization.

The absolute metal content has also decreased. Similarly to above, this is also partially due to improvement in traffic and waste management. However, the relative concentration of the ten heavy metals studied has not changed. Metals which present with the highest concentrations are still iron and aluminium, clearly derived from soil or building activities. Zinc, lead and copper present in lower levels, manganese, nickel, cobalt, chromium and cadmium in still smaller amounts. Unexpectedly, the percentages of each metal with respect to the sum (the metal fraction) also remained constant in the last few years (Table 2). This suggests that the pollutant sources have not experienced substantial changes with time, although absolute levels have decreased. Lead and chromium are two clear exceptions to this behavior since, because of the aforementioned reasons, they are now present in much lower percentages.

Factor analysis of variables detects the principal metal sources for atmospheric particles. The main one is the land, due to agricultural works on the periphery. Thus, the metals included in this group are iron, aluminium, manganese, nickel and cobalt. Other important sources are urban wastes and traffic. Thus, Zn, Cd and Cr are components of different waste sources, while Cu and Pb are grouped as components of vehicle emissions. The soil and waste components in particles come from the city's outskirts, whereas the components of traffic origin are emitted in city centre. In this way, zones predominantly affected by the different metal sources in the city have been identified.

Acknowledgements—We would like to thank the "Consejería de Medio Ambiente de la Junta de Andalucía" for their financial assistance to carry out a research project in our Department.

References

Berg, T., Royset, O. and *Steinnes, E.*, 1993: Blank values of trace elements in aerosol filters determined by ICP-MS. *Atmos. Environ.* 27A, 2435-2439.

Clevenger, T.E., Saiwan, C. and *Koirtyohann, S.R.*, 1991: Lead speciation of particles on air filters collected in the vicinity of a lead smelter. *Environ. Sci. Technol. 25*, 1128-1133.

Frenzel, W., 1991: Microanalytical concept for multicomponent analysis of airborne particulate matter. *Fresenius J. Anal. Chem. 340*, 525-533.

Luis-Simón, F.J., Gómez-Camacho, J. and *Respaldiza, M.A.*, 1995: Study of the elemental composition of the air pollution in Seville. *Int. J. PIXE, 5*(1), 43-56.

Melgarejo, P.L., Ternero, M. and *Gracia, I.*, 1986: A study of the atmospheric lead pollution in Seville, Spain. Influence of meteorology and traffic, and relationship with other traffic-generated pollutants. *Intern. J. Environ. Anal. 24,* 283-296.

Obiols, J., Devesa, R. and *Sol, A.*, 1986: Speciation of heavy metals in suspended particulates in urban air. *Toxicol. Environ. Chem. 13*, 121-128.

Usero, J., Ternero, M. and *Gracia, I.*, 1983a: Estudio de la contaminación atmosférica de la ciudad de Sevilla por partículas sedimentables. I. Fracción insoluble. *Ingeniería Química.* 176, 149-153.

Usero, J., Ternero, M. and *Gracia, I.*, 1983b: Estudio de la contaminación atmosférica de la ciudad de Seville por partículas sedimentables. II. Fracción soluble. *Ingeniería Química. 189*, 57-62.

Usero, J., Rosa, F., Ternero, M. and *Gracia, I.*, 1988: A determination of the sources in the Seville urban aerosol. *Intern. J. Environ. Anal. Chem.* 33, 233-244.

Zatka, V.J., Warner, J.S. and *Maskery, D.*, 1992: Chemical speciation of Nickel in airborne dusts: Analytical methods and results of an interlaboratory test program. *Environ. Sci. Technol.* 26, 138-144.

BOOK REVIEWS

Rudolf Czelnai: **The World Ocean** (in Hungarian; A világóceán. Modern fizikai oceanográfia). Vince Kiadó, Budapest, 1999, 182 pages. Price: 1295 HUF.

Hungary has neither sea, nor ocean. Therefore the Hungarian experts of earth sciences had learned only the very basic knowledge about the oceans, that is better to say the world ocean, since the "geographic" oceans are not isolated from each other, so they form one complet system. Now, we have a book, written in Hungarian, about the modern physical oceanography! The author thinks that each nation and each person has relations to the ocean, since it has defining role in the future of the humankind. He hopes that in the future Hungarian scientists might take part in exploring of the oceanic secrets, since the science becomes more and more international.

The book consists of a foreword and seven chapters. The different chapters present different parts of the scientific knowledge about the ocean but in each case in a "easy to read easy to understand" way. The author has the remarkable ability to describe very complicated things in a simple way, however the reader always feels that the reality is much more complex, but he or she receives the essence of it. The other general feature of the book is that the reader sees the fast increase of our knowledge about the ocean (or the whole Earth system), but he or she learns the limits of this knowledge and understands the we must make all efforts to learn much more since we are responsible for our environment and for the future of our children.

I am sure: each reader of this book will learn a lot and, at the same time, enjoy this learning!

G. Major

Wilfried Schröder: **Aurora in Time** (in German; Das Polarlicht). Science Edition, D-28777 Bremen, 1999, 156+10 pages. Price: $20.

This book is a reprint edition of the book "Das Phaenomen des Polarlichts", besides it contains a 10 page English introduction/summary titled: "Some Aspects of the History of Auroral Research". Not only the introduction, but the whole text deals with the history of observations and understanding of aurora from the Ancient Age till the end of the last century. (Developments in the 1900's are supposed to be known.) Besides the European history, the Arabic and Far-Eastern (Korean, Chinese and Japanese) historical observations and their descriptions are mentioned. Until the 18th century the aurora was regarded as miracle or astrological sign. Then the connection between the appearance of aurora and the irregular variations of the terrestrial magnetic field was recognised. It was also observed, that auroras are more frequently seen in those years when the sunspot number is high. More detailed investigations were made when auroras could be recorded on photos.

The history of any field of science is interesting. This is specially true for auroral research, since its development was driven only by the human curiosity until the last decades.

G. Major

ATMOSPHERIC ENVIRONMENT

an international journal

To promote the distribution of Atmospheric Environment *Időjárás* publishes regularly the contents of this important journal. For further information the interested reader is asked to contact *Prof. P. Brimblecombe*, School for Environmental Sciences, University of East Anglia, Norwich NR4 7TJ, U.K.; e-mail: atmos_env@uea.ac.uk

Volume 33 Number 16 1999

Volume 33 Number 17 1999

Carbonaceous Particles in the Atmosphere

The 6th International Conference, Vienna, Austria, 22–24 September 1997

Volume 33 Number 18 1999

IDŐJÁRÁS

VOLUME 103 * 1999

BUDAPEST, HUNGARY

AUTHOR INDEX

TABLE OF CONTENTS
I. Papers

Book review

III. News

Contents of journal Atmospheric Environment, 1999

IV. SUBJECT INDEX

The asterisk denotes book reviews

A

NOTES TO CONTRIBUTORS OF *IDŐJÁRÁS*

The purpose of the journal is to publish papers in any field of meteorology and atmosphere related scientific areas. These may be

- reports on new results of scientific investigations,
- critical review articles summarizing current state of art of a certain topic,
- shorter contributions dealing with a particular question.

Each issue contains "News" and "Book review" sections.

Authors may be of any nationality, but the official language of the journal is English. Papers will be reviewed by unidentified referees.

Manuscripts should be sent to
Editor-in-Chief of IDŐJÁRÁS
P.O. Box 39
H-1675 Budapest, Hungary

in three copies including all illustrations. One set of illustrations has to be of camera ready quality, the other two might be lower quality.

Title part of the paper should contain the concise title, the name(s) of the author(s), the affiliation(s) including postal and E-mail address(es). In case of multiple authors, the cover letter should indicate the corresponding author.

Abstract should follow the title, it contains the purpose, the data and methods as well as the basic conclusion.

Key-words are necessary to help to classify the topic.

The text has to be typed in double spacing with wide margins. Word-processor printing is preferred. The use of SI units are expected. The negative exponent is preferred to solidus. Figures and tables should be consecutively numbered and referred to in the text.

Mathematical formulas are expected to be as simple as possible and numbered in parentheses at the right margin. Non-Latin letters and hand-written symbols should be indicated and explained by making marginal notes in pencil.

Tables should be marked by Arabic numbers and printed in separate sheets together with their captions. Avoid too lengthy or complicated tables.

Figures should be drawn or printed in black and white, without legends, on separate sheets. The legends of figures should be printed as separate list. Good quality laser printings are preferred as master copies.

References: The text citation should contain the name(s) of the author(s) in Italic letter and the year of publication. In case of one author: *Miller* (1989), or if the name of the author cannot be fitted into the text: *(Miller,* 1989); in the case of two authors: *Gamov* and *Cleveland* (1973); if there are more than two authors: *Smith et al.* (1990). When referring to several papers published in the same year by the same author, the year of publication should be followed by letters a,b etc. At the end of the paper the list of references should be arranged alphabetically. For an article: the name(s) of author(s) in Italics, year, title of article, name of journal, volume number (the latter two in Italics) and pages. E.g. *Nathan, K.K.,* 1986: A note on the relationship between photosynthetically active radiation and cloud amount. *Időjárás 90,* 10-13. For a book: the name(s) of author(s), year, title of the book (all in Italics except the year), publisher and place of publication. E.g. *Junge, C. E.,* 1963: *Air Chemistry and Radioactivity.* Academic Press, New York and London.

The final version should be submitted on diskette altogether with one hard copy. Use standard 3.5" or 5.25" DOS formatted diskettes. The preferred word-processors are WordPerfect 5.1 and MS Word 6.0.

Reprints: authors receive 30 reprints free of charge. Additional reprints may be ordered at the authors' expense when sending back the proofs to the Editorial Office.

More information: gmajor@met.hu
Information on the last issues:
http://www.met.hu/firat/ido-e.html

Published by the Hungarian Meteorological Service

Budapest, Hungary

INDEX: 26 361

HU ISSN 0324-6329