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Analysis of Zagreb climatological data series using empirically decomposed intrinsic mode functions

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The empirical mode decomposition method (EMD) (Huang, 1998) is applied to the series of annual and seasonal averages of temperature, cloudiness, air pressure and annual and seasonal sums of global radiation and precipitation, all observed in Zagreb-Grič in the period 1862–2002. The method itself decomposes the original series into so called intrincic mode functions (IMF), each being characterized by its own, intrinsic time scale.

Sums of the low-frequency IMFs for the single element revealed present climatic fluctuations on the decade-to-century scale. It is confirmed that climatic fluctuations of every single element, particularly temperature and cloudiness, are the results of variations in the global atmospheric circulation above the whole Europe. Trend and long-term variations of Zagreb temperature fits to globally observed increase of temperature but also to variations of zonal circulation index. Exchange of Hadley's zonal and Rossby's wave regime of the general atmospheric circulation at the beginning of the 20th century is observed in the long-term variations of almost every element. Linear correlation coefficients between annual and seasonal long-term variations are calculated. It is shown that spring and winter variations mostly influenced annual fluctuations that is due to internal feed-back processes. Also, correlation coefficients for every pair of climatic element are calculated, enabling conclusions about interaction between elements on long-term scales.

Keywords: empirical mode decomposition, intrinsic mode functions, climatological series, climatic fluctuations, Zagreb

1. Introduction

Climatological series have been, for a long time, a subject of interest in research of climatic fluctuations and the long-term predictions of future climate regimes. Climate as a complex system still challenges our knowledge, leaving us with the problems that deal with sparse data, insufficient methods, limited models and unexplained physical processes.

Studies that rely on historical instrumentally measured data can apply various statistical techniques to analyse climate on regional-to-global scale for the time no longer than one to few centuries. Following this approach, the present paper deals with Zagreb data series of temperature, cloudiness, global radiation, air pressure and precipitation, all obtained at the observatory located on Grič Hill (φ = 45° 49' N, λ = 15° 59' E) in the period 1862–2002. Several previous analyses of these data have applied methods as linear regression for estimating the trends (Gajić-Čapka, 1993), moving average for revealing long-term variations (Šinik, 1985), Fourier and singular spectrum in searching for periodicity (Gajić-Čapka, 1993; Belušić, 2001). These analyses confirmed a significant climatic fluctuation of air temperature, solar radiation and cloudiness (Šinik, 1985), revealed quasi-periodic oscillations in precipitation data (Gajić-Čapka, 1993) and tracked down the connections between seasonal and annual variations (Belušić, 2001). Although useful, the methods, being linear themselves, are not completely suitable for the nonlinear and non-stationary climatological data. In order to cross the borders of such disabilities Huang (1998) invented a method called empirical mode decomposition (EMD). The method extracts energy that is associated with various intrinsic time scales, generating a collection of intrinsic mode functions (IMF). IMFs derived from the data correspond to different physical time scales which characterize various dynamical oscillations present in the time series.

In this paper the EMD method, which was already shown to be a powerful tool for dealing with nonlinear and non-stationary data (Huang, 1998), will be used for the analysis of annual and seasonal averages of climatic elements.

The paper is organized as follows: in section 2 a brief explanation of the method is given. In section 3 the fluctuations of recent Zagreb climate are revealed using the EMD and discussed in terms of the general atmospheric circulation (GAC). The correlations between climatic elements are analysed too. The conclusions are summarized in section 4.

2. Method and data

Huang (1998, 1999) invented the empirical mode decomposition method (EMD) that decomposes the original signal into functions that will produce realistic instantaneous frequencies. These functions are called intrinsic mode functions (IMFs) and are defined as functions which (1) have the same numbers of zero crossings and extrema; and (2) are symmetric with respect to the local mean.

The procedure of computing IMFs from the original data series $x(t)$ is as follows:

1) identify all extrema of $x(t)$,
2) interpolate between minima (maxima), ending up with 'envelope' $e_{min}(t)$ ($e_{max}(t)$),
3) compute the average of envelopes $m_1(t)=(e_{min}(t)+e_{max}(t))/2$,
4) calculate the difference between the data $x(t)$ and the mean $m_1(t)$ and designate it as $h_{11}(t)$; $h_{11} = x(t) - m_1(t)$.

This $h_{11}(t)$ is an approximation of the first IMF. To determine it more accurately $h_{11}(t)$ is treated as a new signal or data set and the above steps from 1 to 4 are repeated leading to $h_{12}(t)$. This iteration, the so called sifting process, is repeated a number of times until the number of zero-crossings of h_{1k} equals the number of extrema (± one) and until the symmetry around local zero mean is obtained. Also, standard deviation,

$$SD = \sum_{t=0}^{T} \left[\frac{\left| h_{1(k-1)}(t) - h_{1k}(t) \right|^2}{h_{1(k-1)}^2(t)} \right] \tag{1}$$

is computed from the two consecutive sifting steps and is used as an additional stopping criterion: when *SD* value falls under 0.3 the sifting process is stopped (Huang, 1998). Satisfying all these conditions, h_{1k} is called the first intrinsic mode function, being designated as IMF_1. Except those conditions that control the sifting process, it is valuable to stress the importance of smoothing of the local mean, since during the process, mean of the envelopes should become smoother and approach zero. Subtracting IMF_1 from the original signal or data set $x(t)$, the first residue, $r_1(t) = x(t) - IMF_1$, is computed and subsequently analysed by the same procedure. Applying steps 1 to 4 to $r_1(t)$ and repeating the sifting process as many times as necessary according to the stopping criterion, the estimate of IMF_2 is obtained. The second residue, $r_2(t) = r_1(t) - IMF_2$, is formed and the process is continued until either IMF_n or r_n fall below some predetermined level of interest, or the residue r_n becomes a monotonic function from which no more IMFs can be extracted. Even for zero mean data, the final residue can still be different from zero; for data with a trend, the final residue should be that trend. At the end, for a given signal $x(t)$, EMD gives a representation of the form:

$$x(t) = \sum_{j=1}^{n} IMF_j + r_n . \tag{2}$$

For the interpolation between local minima (maxima), in the step 2, the Akima cubic spline is used (Akima, 1970). This interpolation avoids wiggling common to many interpolation methods, thus giving generally smoother results than those obtained by tensioned or by monotonic splines. Following the prescribed stopping criterion the sifting process applied to our data usually took between 10 and 20 iterations.

The EMD corresponds to an automatic and adaptive (signal-dependent) time-variant filtering: it picks out the highest frequency oscillation still remained in the signal so that each IMF contains lower frequencies than the one extracted previously. As EMD is build on the idea of identifying various scales in the data, IMFs in general, do carry the physical significance. However, individual component may not have a well-defined physical meaning, therefore discussion will be focused on the sums of IMFs, following Loh et al. (2001) and Zhang et al. (2003).

The data we are dealing with are annual and seasonal averages of temperature (T), cloudiness (C), air pressure (P) and annual and seasonal sums of global radiation (Q) and precipitation (R) for the period 1862–2002 thus giving a series of 141 values. Only the global radiation data comes from the period 1862–1990 giving a series of 129 values. The data for 1862–1990 are taken from Penzar et al. (1992), while the rest is provided by Andrija Mohorovičić Geophysical Institute database. Seasonal averages are calculated from three months of the year that represent a season, *i.e.* March, April and May for spring, June, July and August for summer etc.

3. Results and discussion

In this section every single climatic element (its annual and seasonal averages) is analysed by EMD and subsequently discussed. The influence of particular seasonal average on the annual average as well as correlations between the climatic elements are examined.

(a) Annual averages data

The aim of the first step of the analysis is to find low-frequency variations on decade-to-century scale. Decomposed data series of all five considered climatic elements are presented in Figures 1–5. Since our focus is on low-frequency variations the first two IMFs which contain the short periods of few years are excluded from further analysis. However, we must keep in mind that these short-periodic IMFs, treated here as 'climatic noise', have the highest amplitudes.

As mentioned before, the analysis is focused on the sums of IMFs because individual components may not carry well-defined physical meaning. Discarding 'climatic noise' and summing just the low-frequency IMFs component by component, starting from the residual and the last IMF, the reconstruction of present climatic fluctuations may be obtained. In the following text these sums of low-frequency IMFs will be called 'long-term variations'. For the more convenient representation of the sums, IMFs are renamed: the last

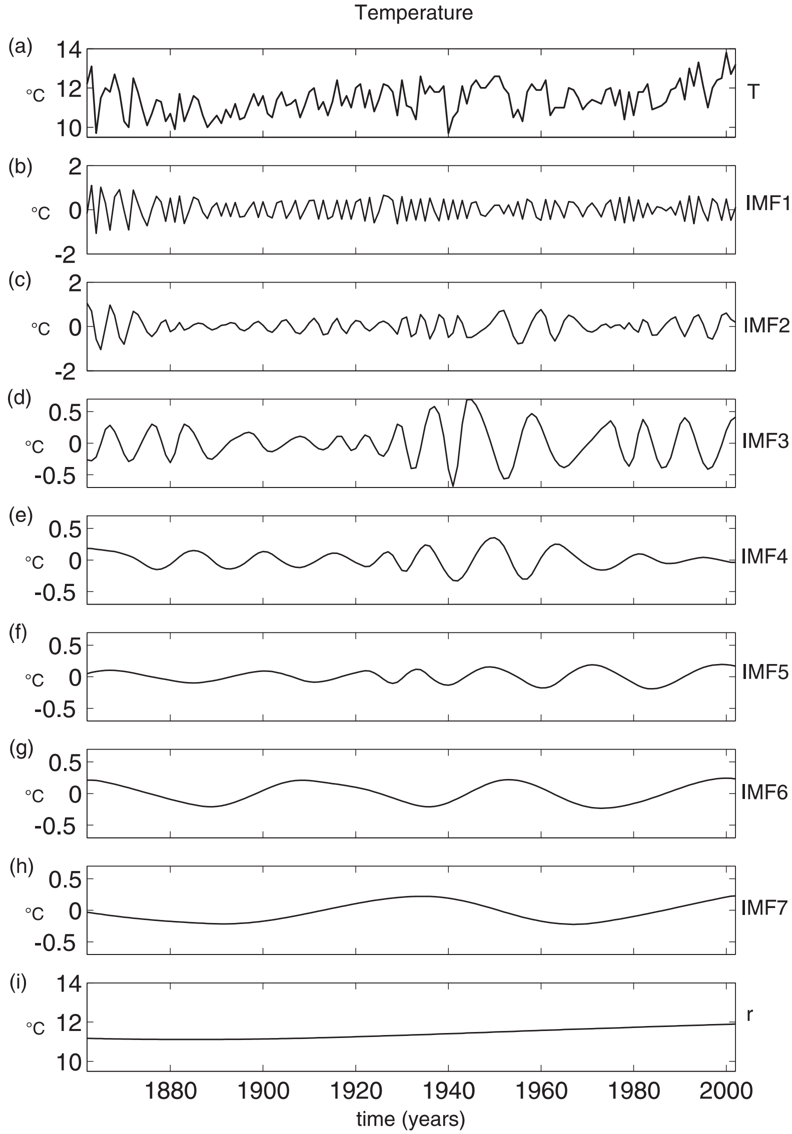

Figure 1. Data series of temperature (T) annual averages and its decomposition into IMFs.

IMF become k_1, the second to the last become k_2, etc. The sums are presented for all climatic elements in Figures 6–10.

In order to explain the physical causes of climatic fluctuations we turn to the internal variability of the atmospheric system. In the middle latitudes, general atmospheric circulation (GAC) is in unstable balance between

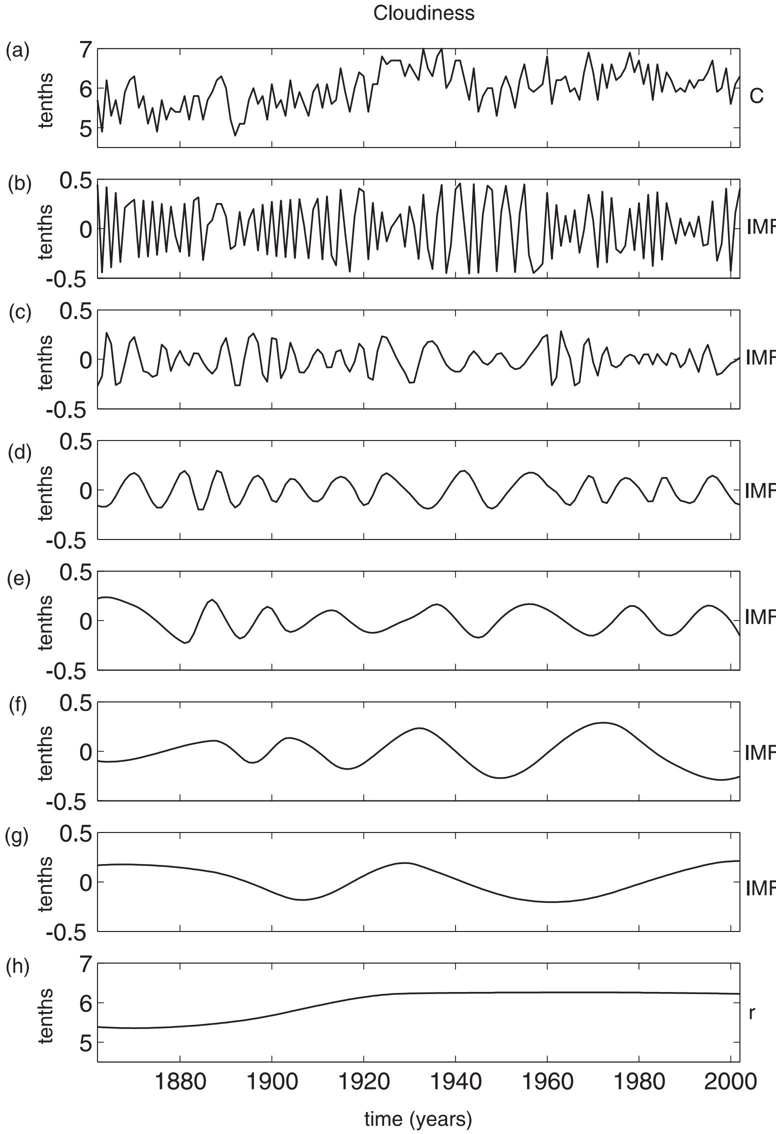

Figure 2. Data series of cloudiness (C) annual averages and its decomposition into IMFs.

Hadley's zonal symmetric regime and Rossby's wave regime which is characterized by changeable weather and more fluctuating climate (Lamb, 1975).

For the temperature data (Figure 1), the IMF_2, IMF_3 and IMF_4 reveal relatively low amplitudes of temperature variations during 1880–1930, as compared to the amplitudes in the period afterwards. These low amplitudes

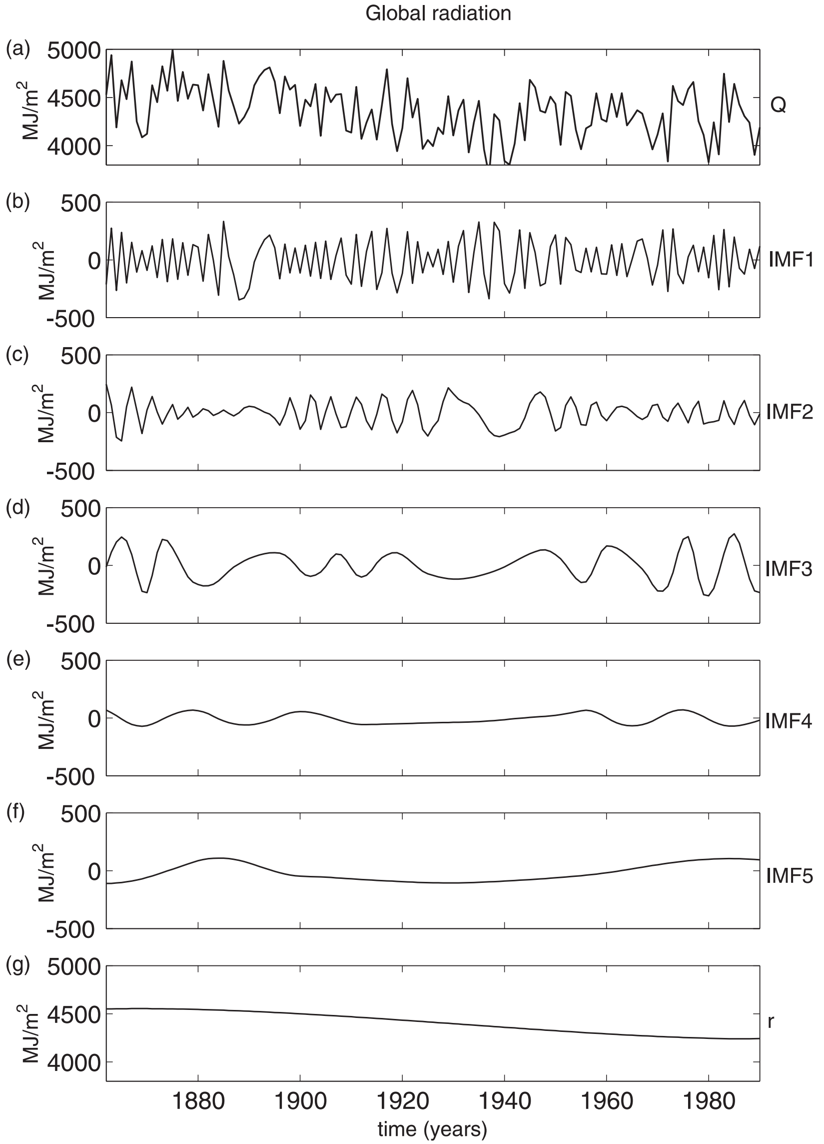

Figure 3. Data series of global radiation (Q) annual sums and its decomposition into IMFs.

are likely to be a result of Hadley's regime of the GAC that prevailed over middle Europe during that period. Obviously, the situation changed after 1930 when enhancement of Rossby's wave regime, which carries more irregularities and frequent changes of weather, is seen in almost all IMFs as increased amplitudes of variations. The temperature fluctuation, contained al-

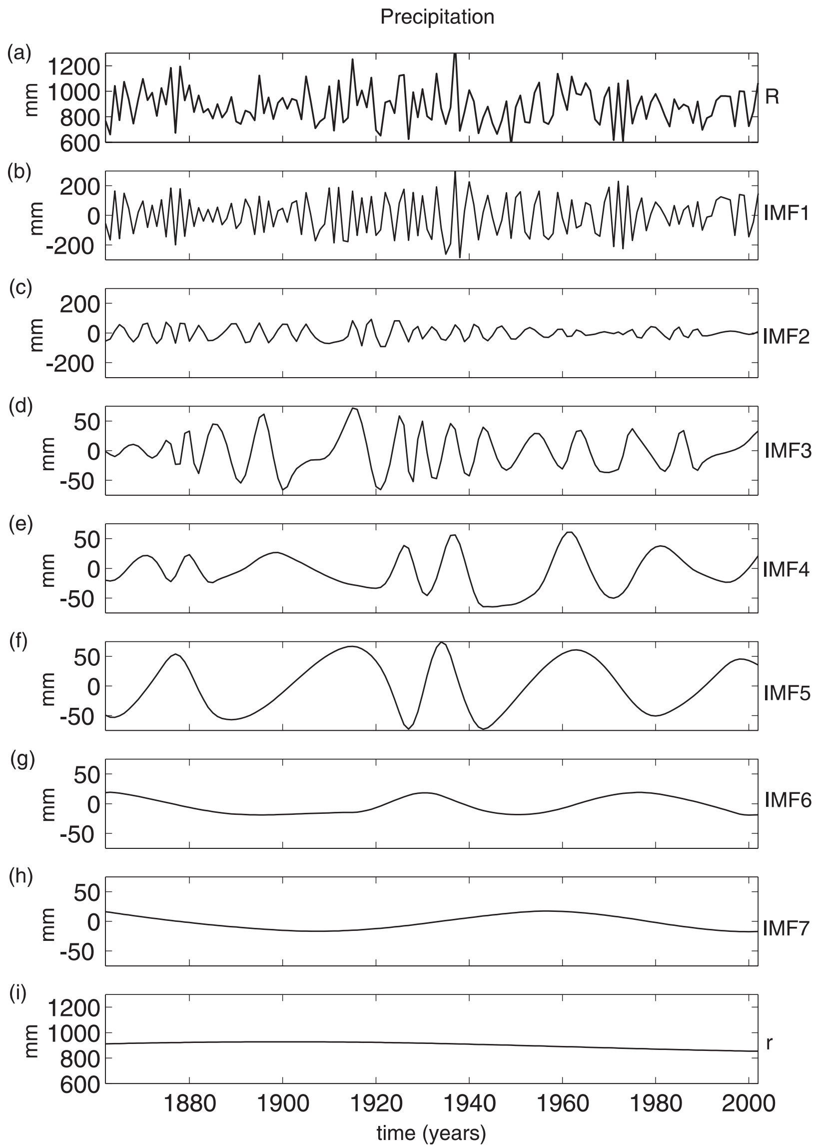

Figure 4. Data series of precipitation (R) annual sums and its decomposition into IMFs.

ready in the sum of trend and the last two IMFs (Figure 6c), reveals the two main characteristics: fast increase of temperature in the first half of the 20th century, also known as Arctic warming (Makjanić, 1977), and temperature increase during the last two decades. If we consider these periods of warming as response to the internal variability in global circulation, a coarse statisti-

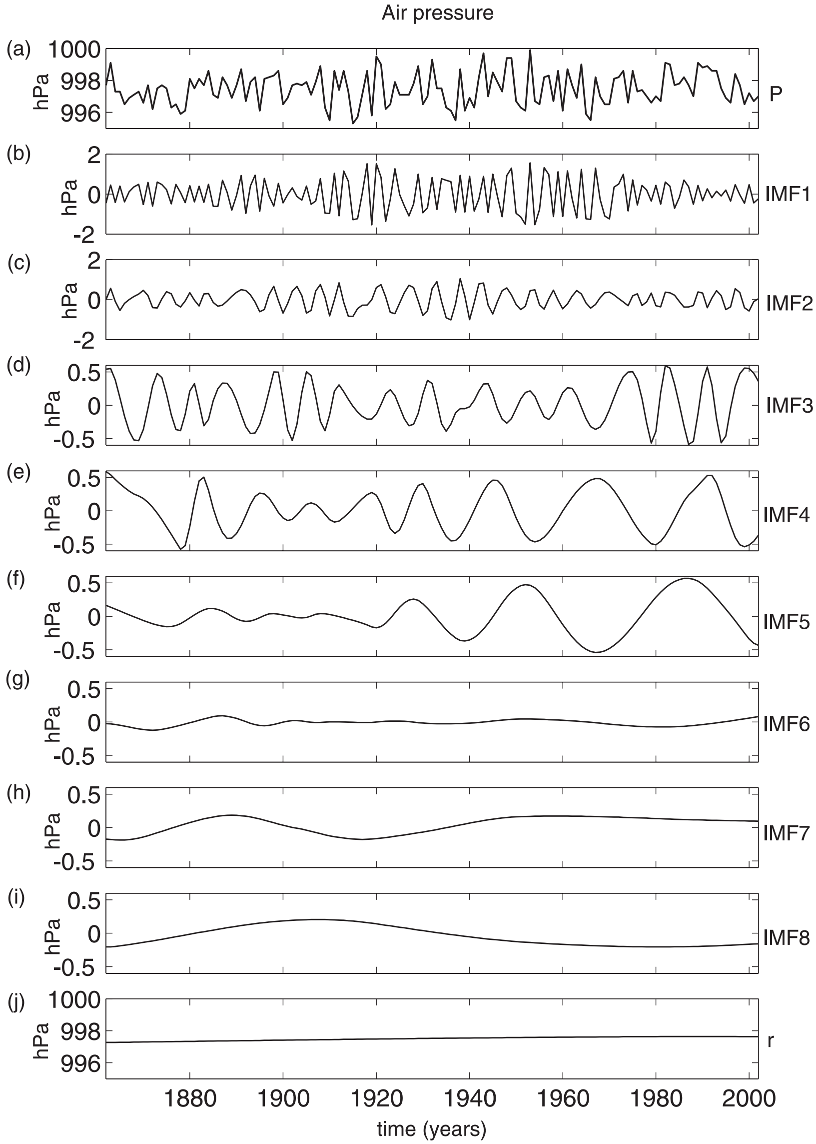

Figure 5. Data series of air pressure (P) annual averages and its decomposition into IMFs

cal prediction for Zagreb temperatures can be stated: Due to IMF_7 and IMF_6, which contain quasi-periods of 70 and 40 years, and their sum, a recent warming will reach the maximum around 2020. Afterwards the decrease of temperature will follow with minimum reached around 2050. Nevertheless, if the observed linear trend (Figure 6a) of warming continues, predicted period

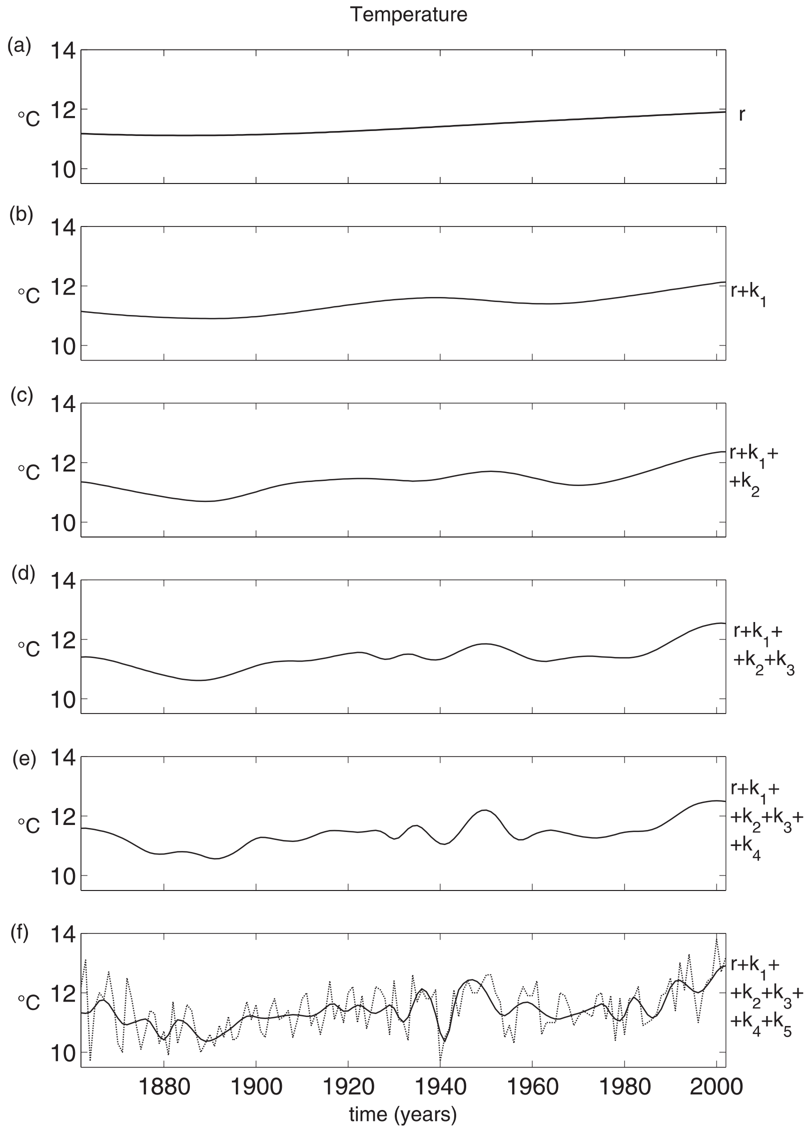

Figure 6. Cumulative sums of IMFs for temperature (T) annual data, starting from the residue (r) backward (k_1 is the last *i.e.* the lowest frequency IMF, k_2 is the second to the last IMF and so on). The first two (*i.e.* highest frequency) IMFs are excluded from the sums. The original data is shown at the bottom plot using the dashed curve.

of lower temperatures around 2050 will show the temperatures that are 1 °C higher than the temperatures from the recent period of long-term-variation minimum (around 1970, Figure 6c). The increasing anthropogenic impact to

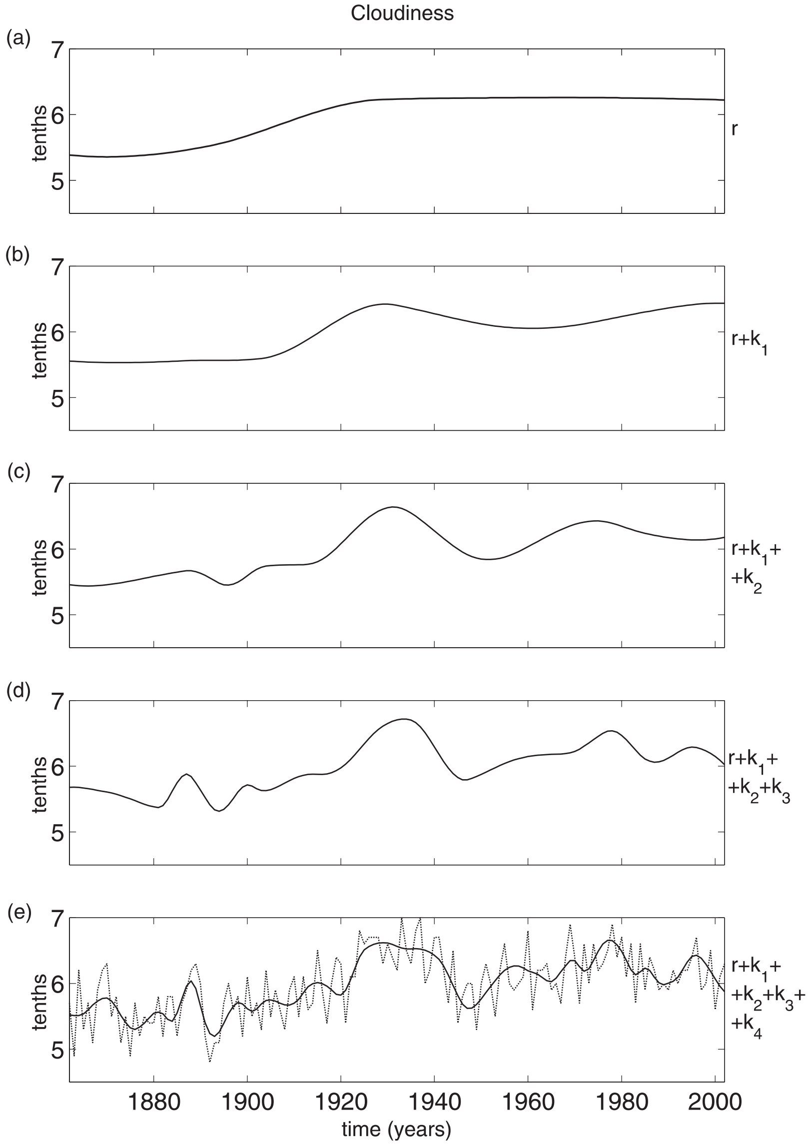

Figure 7. Same as in Figure 6, but for cloudiness (C).

recent warming due to enhancement of greenhouse gasses (IPCC, 2001) can broaden the range of uncertainties in our prediction.

Variations of GAC can be indicated by North Atlantic Oscillation (NAO) winter indices. NAO had prevailing influence on the long-term variations over the whole Northern hemisphere (Hurrell et al., 2003) and in particular

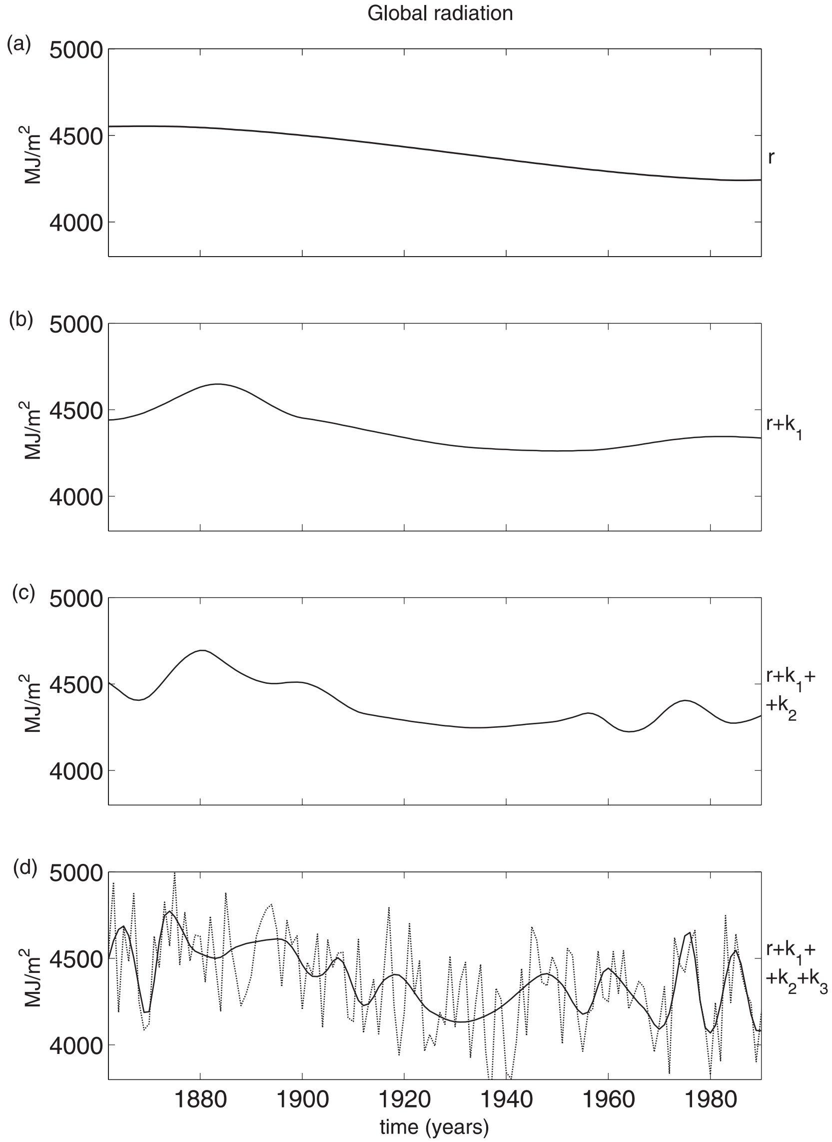

Figure 8. Same as in Figure 6, but for global radiation (Q).

over the Zagreb area. Therefore, indices of the mean winter NAO are taken from Hurrell et al. (2003), (Figure 11) and compared with the long-term variations of Zagreb regime as determined by the EMD. When the NAO index is positive, enhanced westerly flow that occurs across the North Atlantic during winter, carries relatively warm (and moist) maritime air over much

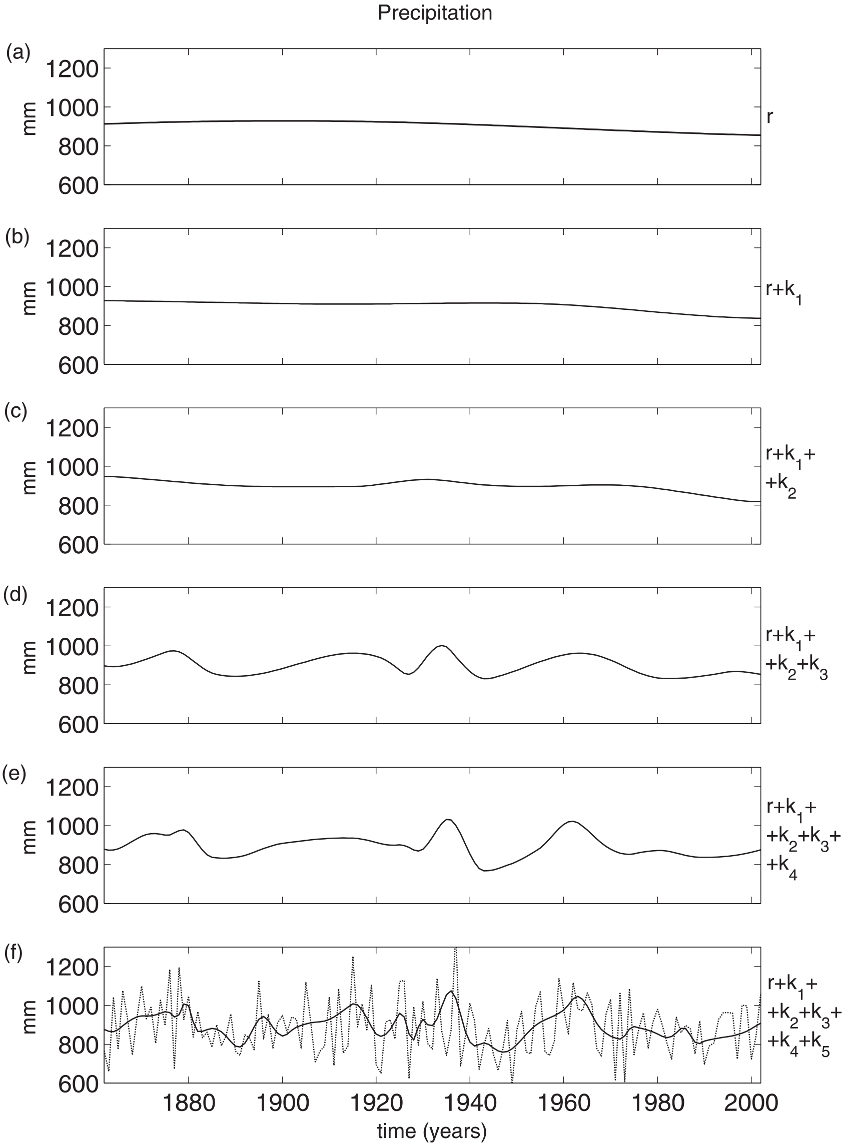

Figure 9. Same as in Figure 6, but for global precipitation (R).

of the Europe and far downstream. At the beginning of the 20th century variations of NAO index reached maximum positive values while annual averages of Zagreb temperature have increased (Figures 6b, c). After 1930 the NAO indices oscillated around negative values, in accordance with enhancement of wave regime, while during the last two decades indices again

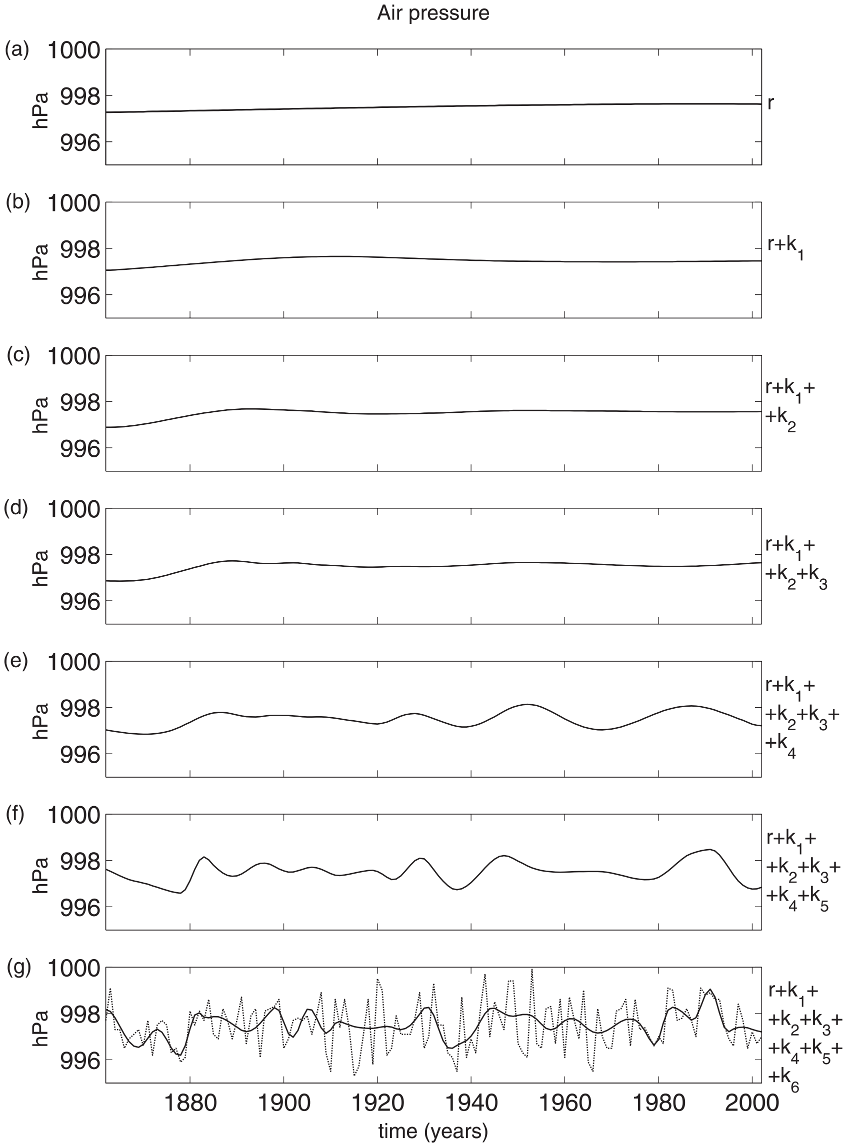

Figure 10. Same as in Figure 6, but for air pressure (P).

reached more positive values and the increase of temperature was observed (Figures 6b–e).

In cloudiness data, the sum of the residual (trend) and the last IMF emphasizes fast increase of cloudiness at the beginning of 20th century (Figure 7b). This is a result of increased advection of water vapour from the west due

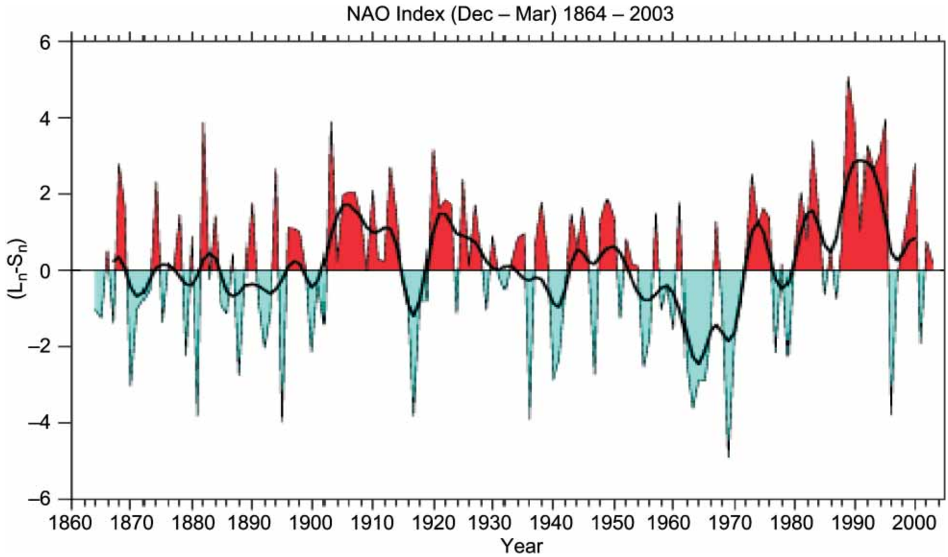

Figure 11. Normalized indices of mean winter (December–March) NAO constructed from sea-level pressure, after Hurrell et al. (2003). See http://www.cgd.ucar.edu/~jhurrell/nao.html for updated time series.

to zonal circulation. Also, in the same period frequent occurrence of positive NAO winter indices was observed, as mentioned earlier. The difference between average annual cloudiness in the periods before and after 1920 is obvious: average cloudiness in the second period is raised for almost 1 tenth, as compared to cloudiness from the period before. Again, this can be a result of enhanced wave regime of GAC causing the inflow of moister air to become more frequent. Adding IMF_5 to the sum of IMFs (Figure 7c) a slight decrease of cloudiness for the last two decades is revealed.

In global radiation data, the decreasing trend (Figures 8a, b), especially prominent at the beginning of 20th century, is a direct result of increase of cloudiness. This should be expected since the global radiation data were estimated directly from insolation and cloudiness.

The residual and sums of low-frequency IMFs for precipitation (Figures 9a, b) do not show any significant trend. Sum of residual and the last two IMFs (Figure 9c) reveal slight decrease of annual precipitation in the last two decades. By adding the other low-frequency IMFs variability at the time scales of around 20 years with minimum value reached between 1940–1950 (Figures 9d, e, f) is stressed.

Similarly to cloudiness, decomposition of air pressure annual averages does not indicate any significant trend (Figure 10a, b). In addition, no significant fluctuations and no signs of converting regimes of GAC are observed in long-term variations of pressure. It should be stressed that the pressure value itself does not provide any information about circulation pattern over some particular area. In a case of analysing pressure data it should be more useful to calculate pressure gradients or indices as in NAO, which can provide more information about temporal variations of GAC.

(b) Correlations between annual and seasonal data

The main goal of this part is to answer the following question: what is the season that contributes the most energy to the long-term variations of annual averages? Therefore, EMD method is applied to the annual series of seasonal averages for each season separately, and for every climatic element, but the IMFs themselves and their sums are not presented. Instead, correlation coefficients between seasonal and annual long-term components are calculated (Table 1).

For temperature series, the highest values of correlation coefficients (ρ) between long-term modes of variability are found in spring ($\rho > 0.79$) and in winter ($\rho > 0.54$) in accordance with some general characteristics of these two seasons. Namely, the most frequent cyclone passages appear in April and May and after that in November, December and February (Lončar and Šinik, 1993) so the change of the regime in GAC at the beginning of 20th century is mostly 'felt' in spring and winter seasons. Further support for seasonal 'forcing' come from Slonosky et al (2001) who calculated correlations between European temperatures and winter zonal circulation indices. It was shown that almost 70% of the variability in the temperature records is explained by variations in the winter zonal index. In the long-term variations of cloudiness, spring ($\rho > 0.84$) and autumn ($\rho > 0.76$) series explained most of the variance of annual series. Lower values of coefficients for precipitation confirm the well known fact that precipitation is highly variable climatic element so the regularity in seasonal 'forcing' is hardly expected.

Correlation coefficients for the air pressure between the original series indicate that winter contributed more energy to annual averages ($\rho = 0.727$) than other seasons did. It was mentioned in earlier studies (Juras, 1985) that changes in pressure annual cycle are mostly caused by pressure changes during winter when the most of pressure extrema occur. Regarding the correlations between sums of IMFs only autumn maintained somewhat higher coefficients ($\rho > 0.36$).

As a final remark, let us note that correlations coefficients between residuals (trends) are expected to be high, as is already seen in Table 1. Of course, this is caused by the fact that trends correspond to the longest time-scales, thus changing very slowly. However, adding the low-frequency IMFs in sequence might decrease this correlation rapidly or even change its sign. The example of this behaviour is best seen in Table 1 (precipitation and air pressure).

Table 1. Correlation coefficients between annual and seasonal series for every climatic element, calculated between the original data as well as between corresponding sums of IMFs. (wi–winter, sp–spring, su–summer, au–autumn, T–temperature, C–cloudiness, Q–global radiation, R–precipitation, P–air pressure; meaning of r, k_1, k_2, etc. is given in Figure 6.)

data series	T / Twi	T / Tsp	T / Tsu	T/ Tau
original	0.750	0.744	0.483	0.459
r	0.969	0.847	0.978	0.848
$r+k_1$	0.829	0.803	0.572	0.672
$r+k_1+k_2$	0.823	0.793	0.700	0.556
$r+k_1+k_2+k_3$	0.673	0.899	0.713	0.448
$r+k_1+k_2+k_3+k_4$	0.549	0.814	0.634	0.462
	C / Cwi	C / Csp	C / Csu	C / Cau
original	0.708	0.736	0.633	0.652
r	0.879	0.993	0.878	0.784
$r+k_1$	0.805	0.916	0.781	0.937
$r+k_1+k_2$	0.826	0.957	0.728	0.918
$r+k_1+k_2+k_3$	0.672	0.888	0.773	0.837
$r+k_1+k_2+k_3+k_4$	0.666	0.849	0.741	0.761
	Q / Qwi	Q / Qsp	Q / Qsu	Q / Qau
original	0.594	0.713	0.678	0.600
r	0.978	0.283	0.994	0.998
$r+k_1$	0.806	0.639	0.856	0.921
$r+k_1+k_2$	0.649	0.702	0.790	0.725
$r+k_1+k_2+k_3$	0.507	0.683	0.474	0.552
	R / Rwi	R / Rsp	R / Rsu	R / Rau
original	0.385	0.437	0.604	0.577
r	–0.951	0.009	–0.941	0.641
$r+k_1$	0.236	–0.393	–0.446	–0.233
$r+k_1+k_2$	0.192	0.458	–0.334	–0.110
$r+k_1+k_2+k_3$	0.157	0.535	0.137	0.203
$r+k_1+k_2+k_3+k_4$	0.313	0.569	0.337	0.263
	P / Pwi	P / Psp	P / Psu	P / Pau
original	0.727	0.464	0.275	0.432
r	–0.910	0.921	0.949	0.575
$r+k_1$	–0.125	–0.234	0.213	0.402
$r+k_1+k_2$	–0.002	0.393	0.740	0.915
$r+k_1+k_2+k_3$	0.005	0.335	0.213	0.570
$r+k_1+k_2+k_3+k_4$	0.150	0.418	0.122	0.467
$r+k_1+k_2+k_3+k_4+k_5$	0.254	0.348	0.213	0.363

(c) Correlations between climatic elements

The last goal of the paper is to discuss the interactions between the climatic elements. To that end correlation coefficients are calculated for every pair of considered elements (Table 2). The first row corresponds to the original series (of annual means) and subsequent rows to the long-term modes of variability as obtained by EMD. Our attention is directed toward higher correlation coefficients, having in mind the final remark from the previous section.

Table 2. Linear correlation coefficients between every pair of climatic elements. Symbols are the same as in Table 1.

data series	T/C	T/Q	T/R	T/P	C/Q	C/R	C/P	Q/R	Q/P	P/R
original	0.01	0.06	–0.19	0.04	–0.81	0.34	–0.29	–0.32	0.23	–0.51
r	0.77	–0.96	–0.98	0.91	–0.90	–0.62	0.94	0.87	–0.97	–0.80
$r+k_1$	0.93	–0.84	–0.79	0.13	–0.85	–0.61	0.33	0.33	–0.32	–0.10
$r+k_1+k_2$	0.51	–0.80	–0.66	0.13	–0.73	–0.21	0.39	0.17	–0.25	–0.52
$r+k_1+k_2+k_3$	0.48	–0.54	–0.17	0.10	–0.70	–0.01	0.24	–0.10	–0.23	–0.25
$r+k_1+k_2+k_3+k_4$	0.38	–0.38	–0.21	0.16	–0.64	0.01	0.14	–0.05	–0.10	–0.47

As expected, there is no high correlation in original data between the elements, except for global radiation and cloudiness (ρ = –0.81). This is explained by the fact that global radiation data were partly estimated from cloudiness.

Temperature and cloudiness trends show high positive correlations in the long-term variations (r, $r+k_1$), that are due to the greenhouse effect caused by clouds. This is in accordance with the results of Šinik (1992) who, by using the local climatic model of the temperature-cloudiness relationship, showed that positive radiative forcing occurs when cloudiness is between 4 and 6 tenths. According to the same model (Šinik, 1992), if the long term average of cloudiness is above 6 tenths the correlation between temperature and cloudiness may become negative. From Figure 7 it can be seen that after 1920, with enhancement of wave regime, cloudiness mainly oscillated above 6 tenths. We calculated correlation coefficients for the period 1920–2002 and obtained negative values (not shown).

High negative coefficients between long-term variations of temperature and global radiation confirm the significance of cloudiness forcing: increase of cloudiness corresponds to decrease of global radiation and warming of the earth through the longwave radiation processes.

High negative correlation between cloudiness and precipitation series obtained by summing the residue and the last IMF ($r+k_1$), indicates a domination of high clouds, not bringing precipitation. By adding other IMFs, correlation coefficients decrease towards zero. However, it should not be forgotten that these estimations of linear correlation coefficients are applied to the non-linear data. Thereby, comparing these series just by eye (Figures 7 and 9) their relation can be observed especially in the periods where secondary maxima and minima occurred (increase at the beginning of 20th century, minimum around 1940's, increase in 1950's). This means that periods in which cloudiness increased in the long-term variations, coincided with increase of precipitation sums.

Although, air pressure and precipitation did not show strong correlation between the original data series, the correlation coefficients between corresponding long-term variations have consistently negative values. Long-term variations ($r+k_1+k_2+k_3$) of these two elements (Figures 9d and 10d) indicate that in the period where one element reached its secondary maxima, the other element reached minima and vice versa. The negative correlation obtained could be explained by the typical weather characteristics due to low or high air pressure. Minimum values of pressure in long-term variations may indicate more frequent occurrence of cyclones and thereby more precipitation.

The analogous correlation analysis between climatic elements is applied to the series of seasonal values and it agrees mostly with the results for annual series. The negative correlations already obtained between the air-pressure and precipitation, are obtained for the long-term variations of winter and spring data, too (not shown). This agrees well with the general type of weather for these two seasons characterized by frequent passages of cyclones. On contrary, summer season shows low correlations ($\rho < 0.3$) between the two elements what can be explained by the following: precipitation during the summer is generally caused by local daily-developed clouds, resulting in short-period, daily air pressure oscillations as the main cause for rain occurrence (Lončar and Šinik, 1993). These short-periodic oscillations are lost in the averaging of air-pressure data over the month so correlation coefficients show the low values.

In general, the analysis of correlations has confirmed that the forcing of the climatic elements has been physically caused by GAC, including here all the interactions among elements. Intensified advection of moist air, driven by cyclones, resulted in increase of cloudiness. Intensified variation of warm and cold air advection directly influenced precipitation which has been a result of activities at the air fronts. Several secondary maxima and minima in long-term variations of cloudiness, especially those during the 20th century, coincided with precipitation extrema. Furthermore, these secondary precipitation extrema have been in opposite phase with secondary extrema of long-term air pressure variations.

4. Conclusion

The EMD is successfully applied to Zagreb climatological data. Analysis of low-frequency IMFs and their sums revealed the climatic fluctuations over north-west part of Croatia.

It has been confirmed that the main role in recent climatic fluctuations is played by general atmospheric circulation (GAC) over the middle latitude, where the enhancement of Rossby wave regime over the Hadley zonal regime is clearly visible in the period after 1930. This specially refers to the long-term variations of temperature that are found to be related to the corresponding changes in cloudiness. However, trying to explain the recent warming period it is not easy to distinguish between changes in GAC vs. the anthropogenic impact due to greenhouse gasses.

In analysis of seasonal variations and correlations it was showed that spring and winter long-term variations influenced most significantly the annual variations. This confirms a dominance of internal feed-back processes (Lorenz, 1990) which are biased to the colder part of the year.

The decomposition in the IMFs, each carrying its own time scales, could be used in statistical prediction of future climatic scenarios. However, these climate statistical predictions still remain as a challenge for future research.

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SAŽETAK

Analiza zagrebačkih klimatoloških nizova pomoću empirijski određenih prirodnih sastavnih funkcija

Valentina Radić, Zoran Pasarić i Nadežda Šinik

Metoda empirijskog rastavljanja (engl. *empirical mode decomposition*) EMD, (Huang, 1998) primjenjena je na godišnje i sezonske nizove srednjaka temperature, tlaka, naoblake te godišnje i sezonske sume globalnog zračenja i količine oborine mjerene u Zagrebu-Grič, za razdoblje 1862–2002. Metoda rastavlja originalne nizove na tzv. prirodne sastavne funkcije, intrinsic mode functions (IMFs), od kojih je svaka karakterizirana svojstvenom vremenskom skalom.

Međusobnom superpozicijom dugoperiodičnih prirodnih sastavnih funkcija pojedinog elementa uočena je prisutnost klimatskih fluktuacija. Potvrđeno je kako su klimatske fluktuacije svakog pojedinog elementa, posebno temperature i naoblake, rezultat varijacija opće cirkulacije atmosfere nad cijelom Europom. Trend i dugoperiodičke varijacije zagrebačke temperature dobro odgovaraju globalnom trendu općeg porasta temperature, ali i varijacijama zonalnog cirkulacionog indeksa. Pretpostavljena izmjena Hadleyevog zonalnog i Rossbyevog valnog režima opće cirkulacije atmosfere početkom 20. stoljeća očituje se u dugoperiodičkim varijacijama gotovo svih elemenata. Izračunati su koeficijenti linearne korelacije između godišnjih i sezonskih dugoperiodičnih varijacija te je pokazano kako se proljetne i zimske varijacije većine elemenata osjetno odražavaju na fluktuacije godišnjih srednjaka, što je u skladu s dominacijom internih procesa povratne sprege (engl. *feed back*). Također su izračunati koeficijenti korelacija između svaka dva klimatska elementa što je omogućilo zaključke o interakcijama među elementima na dugoročnoj skali.

Ključne riječi: metoda empirijskog rastavljanja (EMD), prirodne sastavne funkcije, klimatološki nizovi, klimatske fluktuacije, Zagreb

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