Cyclic Variation in the Precipitation Conditions of the Mátra-Bükkalja Region and the Development of a Prognosis Method

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ABSTRACT

The cycle properties of the annual average, absolute maximum and minimum precipitation values have been calculated from precipitation data for the Mátra and Bükk regions in publications [1] and [2]. The cycle parameters of annual average and annual absolute maximum precipitation values have been determined using the data of a shorter 34-year (1970-2006) and a longer 53-year (1960-2012) period (38 precipitation measurement stations) through the determination of the parameters of frequency, amplitude and phase with an analytic version of Discrete Fourier Transformation (DFT), and the values obtained on the basis of the two periods have been compared. Using prognosis parameters, a prognosis until 2025 has been made. Then, the regression function of the variation in time of average and absolute maximum precipitation values has been determined on the basis of actual and prognosticated data for the whole period (1960-2025).

Keywords: Mátra-Bükk region, precipitation, cyclic, prognosis method

1. INTRODUCTION

The analysis of precipitation data in the Mátra-Bükkalja region between the years 1960 and 2012 has given the result that that both the 53 years’ average values of specific precipitation and the annual absolute maximum values of the measured values for the 38 precipitation measurement stations (settlements) show cyclicity for both 3-5 year and longer periods. [1,2] Minimum and maximum 'local' values recur for both annual average and annual maximum values. With the cyclic variation of annual precipitation values, annual average precipitation displayed constancy around the 600 mm/year value in both the Mátra and Bükkalja regions even on the basis of the combined set of data. With respect to annual absolute maximum and minimum values, regarding these parameters as indicators of extreme weather, plenty of precipitation or years of drought, the data of 53 years showed a decreasing tendency.

In the present paper, the cycle parameters of the average and absolute maximum precipitation values are calculated using the data sets in reports and publications [1] and [2], analyzing the precipitation data of the region investigated (Mátra-Mátraalja, Bükk-Bükkalja) and developing a calculation method of cycle parameters as a research task in the Carpathian basin [3]. Based on this, a prognosis is made for the period until 2025.

2. THEORETICAL BASIS OF ANALYSIS AND CALCULATION, THE FOURIER TRANSFORMATION

In the interpretation of frequency, amplitude and phase, a $2\pi$ periodical $\cos(t)$ function has been taken as starting point, where $T = 2\pi$ is the period length of the function. Next, the argument of the cosine function has been transformed:

$$
\cos(t) = \cos\left(\frac{2\pi}{2\pi} t\right) = \cos\left(\frac{2\pi}{T} t\right) = \cos\left(2\pi \frac{1}{T} t\right) = \cos(2\pi ft)$$

$$
\cos(2\pi f [t+\Delta]),
$$

Factor A is called amplitude. In the case of a monofrequency periodical signal, the amplitude equals half of the difference between the maximum ($F_{\text{max}}$) and minimum ($F_{\text{min}}$) of signal value:

$$
A = \frac{F_{\text{max}} - F_{\text{min}}}{2}
$$

Following a further transformation of the argument of the cosine function:
The quantity \( \phi \), thus introduced, is called phase (phase angle). Absolute phase shows with what part of the phase length (phase time or wavelength) the maximum of the signal has shifted in relation to the origin \( (t = 0) \). As can be seen in Figure 1, in the case of \( \Delta t = 0 \), the maximum shifts to the left while in the case of \( \Delta t < 0 \) to the right of the origin. Absolute phase can be given in both radians and degrees:

\[
\phi = 2\pi \frac{\Delta t}{T} \quad \text{(rad)} \\
\phi = 360 \frac{\Delta t}{T} \quad \text{(deg rees)}
\]

Relative phase (\( \Delta \phi \)) is interpreted between two signals and shows that in relation to the maximum of one of two signals of identical frequency, with what part of the period length the other’s maximum has shifted. As can be seen in Figure 2, let the two signals be \( x(t) \) and \( y(t) \) while the difference of the maximums of the two signals \( \Delta_{xy} \). The relative phase between the two signals can also be calculated:

\[
\Delta \phi_{xy} = 2\pi \frac{\Delta_{xy}}{T} \quad \text{(rad)}
\]

\[
\Delta \phi_{xy} = 360 \frac{\Delta_{xy}}{T} \quad \text{(deg rees)}
\]

The relative phase can also be calculated as the difference of the absolute phases of the two signals:

\[
\Delta \phi_{xy} = \phi_y - \phi_x
\]

With the help of the Fourier transformation, signals can be transferred from the space-time domain into the frequency domain. During the process, the mappings of signals in the frequency domain are called Fourier spectra.

Working with harmonic functions \([\cos(2\pi ft), \sin(2\pi ft)]\) in the analytic Fourier transformation, a complex Fourier spectrum is obtained, which can be divided into a real and an imaginary part. The \( \text{Re}[F(f)] \) real part of the spectrum can be written up with a real cosine transformation

\[
\text{Re}[F(f)] = \int_{-\infty}^{\infty} f(t) \cos(2\pi ft) dt \quad (1)
\]

while its imaginary part with a real sine transformation

\[
\text{Im}[F(f)] = \int_{-\infty}^{\infty} f(t) \sin(2\pi ft) dt \quad (2)
\]

The complex Fourier spectrum can be written up with two real spectra:

\[
F(f) = \text{Re}[F(f)] + j\text{Im}[F(f)].
\]

The real spectrum gives the weights of cosine components falling into a frequency band unit around any \( f \) frequency while the imaginary spectrum those of the sine components for the formation of the signal.

The \( F(f) \) complex spectrum can also be defined in an exponential form by the introduction of two other real spectra:

\[
F(f) = A(f) e^{j\phi(f)}
\]

The \( A(f) \) spectrum, thus introduced, is called amplitude spectrum while the \( \phi(f) \) spectrum is called phase spectrum. The amplitude spectrum gives the weight in the formation of the signal of the harmonic component falling into a frequency band unit around any \( f \) frequency while the phase spectrum shows with what part of the period length the maximum of this harmonic component shifts in relation to the maximum of base function \( \cos(2\pi ft) \), taken at point \( t = 0 \).

The amplitude and phase spectra are the following in the knowledge of real and imaginary spectra with the help of the correlations yielded by Figure 3:

\[
A(f) = \sqrt{(\text{Re})^2[F(f)] + (\text{Im})^2[F(f)]}
\]

\[
\phi(f) = \arctg \frac{\text{Im}[F(f)]}{\text{Re}[F(f)]}
\]

Real and imaginary spectrum values can also be calculated from amplitude and phase spectra:

\[
\text{Re}[F(f)] = A(f) \cos[\phi(f)]
\]

\[
\text{Im}[F(f)] = A(f) \sin[\phi(f)]
\]

### 3. SPECTRAL ANALYSIS

In the search for the deterministic periodic components, the spectrum of the \( Y(t) \) deviations from the \( \bar{Y} \) expected values has been investigated with the following correlations:

\[
\bar{Y} = Y(t) - \bar{Y}
\]

\[
Y(f) = \int_{-\infty}^{\infty} \Delta y(t) e^{-j2\pi ft} dt
\]
Fig 1: The interpretation of absolute phase.

Fig 2: The interpretation of relative phase.

Fig 3: Plotting of Fourier spectra in a complex plane.
The period lengths of the deterministic periodic components to be found in the stochastic signal are given by the reciprocal values of the \( (f_{1,\text{max}}, f_{2,\text{max}}, \ldots, f_{N,\text{max}}) \) frequencies belonging to the maximums of the \( A(f) \) amplitude density spectrum of the \( Y(f) \) spectrum:

\[
T_1 = \frac{1}{f_{1,\text{max}}}, \\
T_2 = \frac{1}{f_{2,\text{max}}}, \\
\ldots \\
T_N = \frac{1}{f_{N,\text{max}}},
\]

Where \( N \) is the number of deterministic periodic components (the number of the maximums of the \( A(f) \) spectrum.)

It can be calculated from the \( \Phi(T_i) \) values of the phase-density spectrum belonging to the given period time with what \( \Delta t(T_i) \) time the maximum of the given component of any \( T_i \) (\( i = 1, 2, \ldots, N \)) period time has shifted in relation to the starting year (1973) of data registration:

\[
\Delta t(T_i) = T_i \frac{\Phi(T_i)}{2\pi} \quad \text{radian}
\]

or

\[
\Delta t(T_i) = T_i \frac{\Phi(T_i)}{360} \quad \text{degree}
\]

The \( A_i \) amplitudes of a component of any \( T_i \) period time are given by the values of \( A(f) \) amplitude density:

\[
A_i = A(T_i).
\]

Figure \( A_i \) gives the amplitude of the deterministic component with \( T_i \) period time.

Let \( A(f)_{\text{max}} \) denote the maximum of the \( A(f) \) amplitude density spectrum. The relative amplitude density spectrum normed to maximum value \( (A(f)_{\text{rel}}) \) as the percentage of maximum value can be calculated as follows:

\[
A(f)_{\text{rel}} = \frac{A(f)}{A(f)_{\text{max}}} \times 100\%.
\]

Relative amplitude density spectrum values show how many per cent of maximum amplitude density the amplitude density of any given component of \( T = 1/f \) period time is.

4. SPECTRAL ANALYSIS OF THE VARIATION OF ANNUAL PRECIPITATION AMOUNT ON THE BASIS OF MÁTRAALJA AND BÜKKALJA PRECIPITATION DATA

In research [6], the cycle properties of the variation in time of precipitation have been investigated on the basis of the territorial average values of precipitation data in the years 1960-2012 in 23 settlements/precipitation measurement stations in the Mátra-Mátraalja region and 15 settlements/precipitation measurement stations in the Bükk-Bükkalja region. Table 1 shows the average annual precipitation values and the annual absolute maximum precipitation values on the basis of the data of the two regions and combined data. In order to show/assess the effect of the registration period on results, cycle properties have been calculated for a shorter (1973-2006, 34 years), and a longer (1960-2012, 53 years) period.

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<td>724</td>
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<td><strong>Bükk</strong></td>
<td><strong>Average</strong></td>
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### Table 1: Precipitation Values for Years 1973-1986

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<td>659</td>
<td>504</td>
<td>444</td>
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<td>453</td>
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<td>781</td>
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<td>555</td>
<td>581</td>
<td>791</td>
<td>814</td>
<td>566</td>
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### Table 2: Precipitation Values for Years 1987-2006

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<td>486</td>
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<td>1,092</td>
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### Table 3: Precipitation Values for Years 2001-2012

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<th>2011</th>
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<td>657</td>
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<td>791</td>
<td>777</td>
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<td>1,195</td>
<td>462</td>
<td>486</td>
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<td>777</td>
<td>736</td>
<td>1,195</td>
<td>488</td>
<td>557</td>
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4.1 The results of spectral analysis on the basis of precipitation data for the years 1973-2006

Registration time (Treg): 33 years (period with end sampling, 34 years’ period with middle sampling). Sampling rate (t): 1 year, number of samples: 34. Analyses have been performed with an analytic version of Discrete Fourier Transformation (DFT) [5]. The complex amplitude density spectra of the function of annual precipitation values have been determined as the function of discrete period time values. Of the four real spectra describing the complex spectrum (real spectrum, imaginary spectrum, amplitude spectrum and phase spectrum), amplitude spectra are presented. In the plotting, logarithmic linear scale has been chosen to illustrate spectrum maximums more clearly.
In the calculation of spectra, the spectrum of deviations from expected values has been determined:

$$\Delta y(t) = y(t) - \bar{Y}$$

The minimum period time that can be theoretically found in the signal is defined by Nyquist frequency ($f_N$):

$$\Delta t = 1 \text{ year}$$

The (T_{min}) minimum period time that can be found in the signal is defined by Nyquist frequency ($f_N$):

$$f_N = 0.5 \frac{1}{\text{ year}}$$

As in the case of all the six time series, the analysis can only reveal cycles of longer period time than 2 years in the changes everywhere.

From the theory, maximum period time ($T_{max}$) is determined by 'registratum' time ($T_{reg}$):

$$T_{max} = T_{reg} - \text{ in case of end sampling}$$

and

$$T_{max} = T_{reg} + \Delta t - \text{ in case of middle sampling}$$

Therefore, the maximum period time that can be revealed by analysis is:

$$T_{max} = 33 \text{ years} - 34 \text{ years}$$

With the data in Table 1, both the amplitude spectra of amplitude density and relative spectra have been determined. In the latter case, spectra have been normed to maximum spectrum value. In all the six cases – Mátra, Bükk, Mátra+Bükk, annual average and annual absolute maximum precipitation – similar amplitude and relative amplitude spectrum functions have been obtained.

The cycle properties of annual average precipitation in the Mátra region are the following on the basis of amplitude peaks, cycle time and amplitude density:

- Major cycles: 1. $T_1 = 4.9$ years, $A_1 = 1,243$ mm; 2. $T_2 = 3.5$ years, $A_2 = 1,195$ mm; 3. $T_3 = 29.8$ years, $A_3 = 946$ mm; 4. $T_4 = 9.9$ years, $A_4 = 806$ mm; minor cycles: 1. $T_1 = 7.3$ years, $A_1 = 476$ mm; 2. $T_2 = 6.3$ years, $A_2 = 440$ mm.

Cycle properties revealed on the basis of Bükk data are, cycle time and amplitude density: major cycles:

- $T_1 = 28.7$ years, $A_1 = 1,216$ mm; 2. $T_2 = 3.5$ years, $A_2 = 1,064$ mm; 3. $T_3 = 4.9$ years, $A_3 = 1,035$ mm; 4. $T_4 = 9.5$ years, $A_4 = 929$ mm; minor cycles: 1. $T_1 = 7.3$ years, $A_1 = 541$ mm; 2. $T_2 = 6.1$ years, $A_2 = 308$ mm.

The combined treatment of Mátra+Bükk data has also revealed 4 major and 2 minor cycles in the variation of annual precipitation values (Figures 4 and 5), cycle time and amplitude density: major cycles 1. $T_1 = 5.0$ years, $A_1 = 1,139$ mm; 2. $T_2 = 3.5$ years, $A_2 = 1,119$ mm; 3. $T_3 = 29.2$ years, $A_3 = 1,080$ mm; 4. $T_4 = 9.7$ years, $A_4 = 860$ mm; minor cycles 1. $T_1 = 7.4$ years, $A_1 = 508$ mm; 2. $T_2 = 6.2$ years, $A_2 = 310$ mm.

Cycle properties that can be revealed on the basis of the amplitude spectrum and relative amplitude spectrum detected in the variation of annual absolute maximum precipitation values for the Mátra region are, cycle time and amplitude density: major cycles 1. $T_1 = 3.5$ years, $A_1 = 1,561$ mm; 2. $T_2 = 5.0$ years, $A_2 = 1,434$ mm; 3. $T_3 = 10.9$ years, $A_3 = 1,352$ mm; 4. $T_4 = 31.4$ years, $A_4 = 1,262$ mm; minor cycles 1. $T_1 = 7.5$ years, $A_1 = 741$ mm; 2. $T_2 = 6.2$ years, $A_2 = 474$ mm.

Cycle properties of Bükk absolute maximum precipitation data are, cycle time and amplitude density: major cycles 1. $T_1 = 27.0$ years, $A_1 = 1,408$ mm; 2. $T_2 = 3.4$ years, $A_2 = 1,297$ mm; 3. $T_3 = 5.0$ years, $A_3 = 1,168$ mm; 4. $T_4 = 9.7$ years, $A_4 = 973$ mm; minor cycles 1. $T_1 = 7.4$ years, $A_1 = 796$ mm; 2. $T_2 = 6.2$ years, $A_2 = 362$ mm.

Cycle properties of Mátra and Bükk combined data on the basis of amplitude spectra (Figures 6 and 7) are, cycle time and amplitude density: major cycles 1. $T_1 = 3.5$ years, $A_1 = 1,482$ mm; 2. $T_2 = 5.0$ years, $A_2 = 1,413$ mm; 3. $T_3 = 10.9$ years, $A_3 = 1,256$ mm; 4. $T_4 = 11.1$ years, $A_4 = 1,225$ mm; minor cycles 1. $T_1 = 7.5$ years, $A_1 = 734$ mm; 2. $T_2 = 6.2$ years, $A_2 = 298$ mm.

On the basis of the above results, the following generalizations can be made:

- In the case of all the six time series examined with respect to annual precipitation variation, cycles of approximately identical period times can be revealed.
- In the case of all the six time series, there have been found periods of 3.5 years, 5 years, 10-11 years and 27-31 years as major cycles. (To prove the existence of 27-31 year cycles in a more reliable way, longer data series would be needed.)

4.2 The result of spectral analysis on the basis of precipitation data in the years 1960-2012

The registration period is 1960-2012, the length of the registration period ($T_{reg}$) is 52 years with end sampling and 53 years with middle sampling, sampling rate ($\Delta t$) is 1 year, the number of samples is 53. The calculation process has been according to section 4.1, the maximum period time that the analysis can reveal is $T_{max} = 52$ years – 53 years.
On the basis of amplitude peaks, the following precipitation cycles can be revealed for the Mátra annual precipitation values, cycle time and amplitude density:

- **Major cycles**
  1. $T_1 = 5.0$ years, $A_1 = 2,765$ mm;  
  2. $T_2 = 3.6$ years, $A_2 = 2,074$ mm; 
  3. $T_3 = 41.1$ years, $A_3 = 1,555$ mm; 
  4. $T_4 = 10.7$ years, $A_4 = 1,494$ mm;

- **Minor cycles**
  1. $T_5 = 6.4$ years, $A_5 = 1,101$ mm;  
  2. $T_6 = 5.7$ years, $A_6 = 1,027$ mm;  
  3. $T_7 = 8.6$ years, $A_7 = 675$ mm; 
  4. $T_8 = 14.3$ years, $A_8 = 642$ mm; 
  5. $T_9 = 7.4$ years, $A_9 = 577$ mm; 
  6. $T_{10} = 19.8$ years, $A_{10} = 456$ mm.

In the Bükkalja region, the following cycles can be revealed in the variation of annual precipitation values on the basis of amplitude spectrum and relative amplitude spectrum, cycle time and amplitude density:

- **Major cycles**
  1. $T_1 = 5.0$ years, $A_1 = 2,567$ mm;  
  2. $T_2 = 38.6$ years, $A_2 = 1,759$ mm; 
  3. $T_3 = 10.5$ years, $A_3 = 1,747$ mm; 
  4. $T_4 = 3.6$ years, $A_4 = 1,719$ mm;

- **Minor cycles**
  1. $T_5 = 5.7$ years, $A_5 = 1,413$ mm;  
  2. $T_6 = 6.5$ years, $A_6 = 1,220$ mm;  
  3. $T_7 = 14.2$ years, $A_7 = 753$ mm; 
  4. $T_8 = 7.5$ years, $A_8 = 552$ mm; 
  5. $T_9 = 8.4$ years, $A_9 = 504$ mm; 
  6. $T_{10} = 19.8$ years, $A_{10} = 323$ mm.
The combined treatment of Mátra and Bükk data also reveals 4 major and 6 minor cycles on the basis of annual precipitation values (Figures 8 and 9), cycle time and amplitude density: major cycles: 1. $T_1 = 5.0$ years, $A_1 = 2,685$ mm; 2. $T_2 = 3.6$ years, $A_2 = 1,928$ mm; 3. $T_3 = 40.4$ years, $A_3 = 1,635$ mm; 4. $T_4 = 10.6$ years, $A_4 = 1,587$ mm; minor cycles: 1. $T_1 = 5.7$ years, $A_1 = 1,188$ mm; 2. $T_2 = 6.4$ years, $A_2 = 1,151$ mm; 3. $T_3 = 14.2$ years, $A_3 = 669$ mm; 4. $T_4 = 8.5$ years, $A_4 = 592$ mm; 5. $T_5 = 7.4$ years, $A_5 = 577$ mm; 6. $T_6 = 20.0$ years, $A_6 = 383$ mm.

The analysis of the absolute maximum values of annual precipitation reveals the following cycle properties on the basis of Mátra data, cycle time and amplitude density: major cycles: 1. $T_1 = 5.0$ years, $A_1 = 3,306$ mm; 2. $T_2 = 3.6$ years, $A_2 = 2,656$ mm; 3. $T_3 = 45.6$ years, $A_3 = 2,119$ mm; 4. $T_4 = 10.8$ years, $A_4 = 1,806$ mm; minor cycles: 1. $T_1 = 5.6$ years, $A_1 = 1,319$ mm; 2. $T_2 = 6.4$ years, $A_2 = 1,191$ mm; 3. $T_3 = 13.9$ years, $A_3 = 1,044$ mm; 4. $T_4 = 7.3$ years, $A_4 = 1,046$ mm; 5. $T_5 = 8.4$ years, $A_5 = 814$ mm; 6. $T_6 = 19.8$ years, $A_6 = 722$ mm.

Similarly, 4 major and 6 minor cycles can be revealed on the basis of the Bükk-Bükkalja absolute maximum precipitation data, cycle time and amplitude density: major cycles: 1. $T_1 = 5.0$ years, $A_1 = 2,646$ mm; 2. $T_2 = 38.6$ years, $A_2 = 2,138$ mm; 3. $T_3 = 45.6$ years, $A_3 = 2,024$ mm; 4. $T_4 = 10.8$ years, $A_4 = 1,758$ mm; minor cycles: 1. $T_1 = 5.6$ years, $A_1 = 1,434$ mm; 2. $T_2 = 6.4$ years, $A_2 = 1,351$ mm; 3. $T_3 = 14.0$ years, $A_3 = 885$ mm; 4. $T_4 = 8.4$ years, $A_4 = 883$ mm; 5. $T_5 = 7.3$ years, $A_5 = 445$ mm; 6. $T_6 = 19.4$ years, $A_6 = 454$ mm.

Cycle properties of absolute maximum precipitation values in the combined assessment of the Mátra+Bükk region (Figures 10 and 11), cycle time and amplitude density: major cycles: 1. $T_1 = 5.0$ years, $A_1 = 3,168$ mm; 2. $T_2 = 3.6$ years, $A_2 = 2,468$ mm; 3. $T_3 = 46$ years, $A_3 = 2,271$ mm; 4. $T_4 = 10.7$ years, $A_4 = 1,842$ mm; minor cycles: 1. $T_1 = 5.7$ years, $A_1 = 1,273$ mm; 2. $T_2 = 6.4$ years, $A_2 = 1,127$ mm; 3. $T_3 = 13.7$ years, $A_3 = 982$ mm; 4. $T_4 = 8.5$ years, $A_4 = 721$ mm; 5. $T_5 = 7.3$ years, $A_5 = 726$ mm; 6. $T_6 = 19.6$ years, $A_6 = 714$ mm.

From the cycle properties determined on the basis of the data of 53 years’ precipitation time series, the following generalizations can be made:

- Cycles of nearly identical period time can be revealed on the basis of the six time series investigated with respect to annual precipitation variation.
- In the case of all the six time series, the 3.6 year, the 5 year, the 10.5-10.8 year and the 38.6-46 year periods appear as major cycles.
- In all the cases, the 5.6-6.7 year, 6.4 year, 7.3-7.5 year, 8.4-8.6 year, 13.7-14.3 year and 19.4-20 year periods appear as minor cycles.

The comparison of the cycle time data of the major and minor cycles revealed on the basis of the two time series of different lengths (34 years and 53 years) has yielded the following results:

- With all the three data groups, the number of major cycles that can be revealed on the basis of both time series is the same: four,
- In the case of the shorter time series, 2 minor cycles have been found for all the three data groups while for the longer time series (53 years), 6 minor cycles have been revealed.
- With the shorter, generally maximum 10 year cycle times, practically identical/equivalent cycle time has been revealed for both the major and minor cycles, namely, Mátra: 3.5-3.6 years, 4.9-5.0 years, 9.9-10.7 years, 6.3-6.4 years, 7.3-7.4 years, Bükk: 3.5-3.6 years, 4.9-5.0 years, 9.5-10.5 years, Mátra+Bükk: 3.5-3.6 years, 5.0-5.0 years, 9.7-10.6 years, 6.2-6.4 years, 7.4-7.4 years.
Fig 8: Amplitude spectrum of annual precipitation in the Mátraalja and Bükkalja regions (sampling rate = 1 year)

Fig 9: Relative amplitude spectrum of annual precipitation in the Mátraalja and Bükkalja regions (sampling rate = 1 year)

Fig 10: Amplitude spectrum of annual precipitation in the Mátraalja and Bükkalja regions (sampling rate = 1 year)

Fig 11: Relative amplitude spectrum of the absolute maximum of annual precipitation in the Mátraalja and Bükkalja regions (sampling rate = 1 year)
- In all the three areas, it has been identically found for longer cycle times (above 30 years) that on the basis of the 34 year time series a shorter major cycle time while on the basis of the longer time series, a longer major cycle time has been revealed, namely, Mátra: 29.8 years, 41.1 years, Bükк: 28.7 years, 38.6 years, Mátra+Bükк: 29.2 years, 40.4 years.

The differences found in the latter case confirm the former observation that for a long-time prognosis, a time (data) series longer than 50 years is required.

5. DETERMINATION OF PROGNOSIS VALUES

On the basis of sections 2 and 3, including the summary of the basics of spectral data processing, the \( y(t) \) time series of precipitation values can be restored through the 'use' of the \( A(f) \) amplitude density and \( \varphi(f) \) phase density spectra, defined in the previous analyses:

\[
y(t) = \bar{y} + \int_{-f_N}^{f_N} A(f) e^{i[2\pi f t + \varphi(f)]} df
\]

where \( f_N \) - Nyquist frequency is \( (0.5 \frac{1}{\text{year}}) \)

As the Fourier spectrum is even, the former equation can also be written up in the following form:

\[
y(t) = \bar{y} + \int_{0}^{f_N} A(f) e^{i[2\pi f t + \varphi(f)]} df
\]

With the use of the \( T_i \) (i = 1,2,…, N=10) period times of major and minor cycles and the \( A_i \) (i = 1,2,…, N = 10) amplitude and \( \varphi(T_i) \) (i = 1,2,…, N = 10) phase values, it is possible to define the \([y(t)_{\text{det}}]\) time series of the amount of precipitation attributable to deterministic causes:

\[
y(t)_{\text{det}} = \bar{y} + \frac{2}{T_{\text{reg}}} \sum_{i=1}^{10} A_i \cos \left[ \frac{2\pi}{T_i} (t - 1960) + \varphi(T_i) \right]
\]

Using the \( \{R_i[F(T_i)]\} \) and \( \{I_{\text{det}}[F(T_i)]\} \) values calculated for given \( T_i \) period times of real and imaginary spectra, the \( \varphi(T_i) \) phases of the specific components can be defined with the following correlation:

\[
\varphi(T_i) = \arctan \frac{I_{\text{det}}[F(T_i)]}{R_i[F(T_i)]}
\]

The difference between the \( y(t) \) actual time series and \( y(t)_{\text{det}} \) represents the accidental (stochastic) impact.

If \( t > 2012 \) values are put in the former equation, the amount of precipitation that can be expected in the given years can be estimated (forecast) with extrapolation. It must be added, however, that this estimation would only yield a prognosis of 100% reliability by using spectra calculated from an infinitely large \( y(t) \) registratum (annual data), which, of course, cannot be expected in the case of the 53 years’ long time series investigated.

Furthermore, there is a possibility of estimating periodicity with modern statistical methods (analysis with autocorrelation functions, factor and cluster analysis) although these tools would only give similarly precise results as the spectral analysis applied on the basis of data series of several hundred years.

Using the spectrum data in Figure 8, taking into account the impact of the four deterministic major cycles (5; 3.6; 40.4 and 10.6 years) and taking into consideration the impact of the further 6 minor cycles in Figure 12 as well as that of the two cycles (2.1 years and 2.8 years), earlier omitted due to aliasing distortion, the prognosis values in Figure 14 are obtained. As according to Figure 4, the two short cycles are present in the prognosis of annual precipitation values with a relatively high amplitude, above 55%, there has been a spectacular improvement in classic statistical indicators. Deviation (RMS) has decreased from 16.1 % and 15.7% to 12.6% while the correlation coefficient \( (r) \) has increased from 0.78 and 0.79 to 0.89.

The amplitude data in Figure 10 and relative amplitude data in Figure 11 have been used in the calculation of annual absolute maximum precipitation prognosis. Taking the four deterministic and the further 6+2 cycle properties into account, the absolute maximum precipitation prognosis in Figures 15, 16 and 17 has been obtained.

On the basis of the classical statistical parameters (RMS = 16.2 %, \( r = 0.77 \)), it can be concluded here, too, that between 1960 and 2012, the four deterministic major cycles decisively determined absolute maximums (Figure 15). Taking the six minor cycles into account hardly improves classical statistical parameters (RMS = 15.6 %, \( r = 0.79 \)) in this case, either, but the prognosticated sections in Figures 15 and 16 are significantly different here, too. Taking into account the two short cycles (2.1 years and 2.8 years), also appearing here with a high amplitude, has considerably improved classical statistical indicators (RMS = 12.5 %, \( r = 0.87 \)). (Figure 17)

On the basis of the data in Figure 14, for the purpose of 'practical utilization,' it can be underlined in the prognosis that the exceedingly high, 1,079 mm/year amount of precipitation of 2010 – a uniquely high value in the last 53 years – will not recur in the next 12-15 years. The 850-900 mm/year annual precipitation, having occurred several times in previous years (1965, 1970,
1999) may ‘probably be expected’ in 2016. On the other hand, it is ‘good news’ that in the coming 12-15 years, no annual precipitation below 500 mm/year, causing/involving severe drought, may be expected.

The 1,100 mm/year maximum precipitation, shown in Figure 17, displaying absolute maximum values, which is prognosticated for 2016, remains 100 mm/year below the round 1,200(1,195) mm/year value of 2010 but may ‘reach’ the 1,100 mm ‘peak data’ of the years 1965, 1970, 1974 and 1999.

6. VARIATION IN TIME OF PRECIPITATION PROPERTIES BETWEEN THE YEARS 1960 AND 2025

With the combined ‘handling’ of the actual data for the years 1960-2012, presented in Table 1 but, of course, also included in Figures 14 and 17, and the prognosis data in Figures 14 and 17, related to the Mátra+Bükk region, the ‘time function’ of the variation of annual precipitation and absolute maximum precipitation values for the years 1960-2025 has been determined with the conventional statistical method.

The function in Figure 18 shows a ‘constancy’ of 620-605 mm/year of annual (average) precipitation with 0.23 = 23 % empirical deviation (D_{avg}/Y_{avg}). The correlation coefficient characterizing the closeness of the ‘function’ determined from the data of the 65-year time series is $r^2 = 0.00048$, which indicates the independence of the two variables of annual precipitation (average) and time (years) according to conventional statistical interpretation.

Figure 19 shows the regression function determined on the basis of actual and prognosis annual absolute maximum precipitation data between the years 1960 and 2025. With an acceptable (reliable) 19% corrected empirical deviation and a $r^2 = 0.00027$ regression coefficient, the function predicts the ‘constancy’ of the annual absolute maximum in the statistical sense while, for example, it predicts a 1,100 mm precipitation maximum for 2016.

Fig 12: Annual precipitation value in the Mátraalja and Bükkalja regions (Prognosticated on the basis of four cyclic components)
Fig 13: Annual precipitation value in the Mátraalja and Bükkalja regions (Prognosticated on the basis of ten cyclic components)

Fig 14: Annual precipitation value in the Mátraalja and Bükkalja regions (Prognosticated on the basis of twelve cyclic components)
Fig 15: Variation in the annual maximum of annual precipitation value in the Mátraalja and Bükkalja regions
(Prognosticated on the basis of four cyclic components)

Fig 16: Variation in the annual maximum of annual precipitation value in the Mátraalja and Bükkalja regions
(Prognosticated on the basis of ten cyclic components)
Fig 17: Variation in the annual maximum of annual precipitation value in the Mátraalja and Bükkalja regions (Prognosticated on the basis of twelve cyclic components)

Fig 18: Regression function of the variation in time of the annual precipitation conditions (1960-2012) and prognosis data (2013-2025) of the Mátra-Bükkalja region
Fig 19: Regression function of the variation in time of the annual absolute maximum precipitation properties (1960-2012) and prognosis data (2013-2025) of the Mátra-Bükkalja region

\[
Y = 0.1487 \times X + 488.9 \text{[mm/year]}
\]

\[
N = 66
\]

\[
X_{\text{average}} = 1992.5 \text{[year]}
\]

\[
Y_{\text{average}} = 785.288 \text{[mm/year]}
\]

\[
D_{dy} = 175 \text{[mm/year]}
\]

\[
r^2 = 0.00027
\]

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