Период активной вегетации в Украинских Карпатах
Скриник О. А.
Используя данные о среднесуточной температуре воздуха за период с 1961 по 2010 гг., полученные в рамках международного климатического проекта CARPATCLIM, проведено исследование особенностей периода активной вегетации в Украинских Карпатах. Выявлено изменение дат начала, окончания и продолжительности вегетационного периода в 1981-2010 гг. по сравнению с 1961-1990 гг. Установлена зависимость выявленных изменений от метода расчета дат устойчивых переходов температуры воздуха.
Ключевые слова: *вегетационный период, Украинские Карпаты, изменения климата*

The growing season of heat-loving plants in Ukrainian Carpathian region
Skrynyk O. A.
Using the daily air temperature data for the period 1961-2010 which were obtained in the frame of the CARPATCLIM project the features of growing season of heat-loving plants in Ukrainian Carpathian region were studied. A change of the beginning, the end and the length of the growing season in 1981-2010 comparing to 1961-1990 have been revealed. Depending of the changes revealed on calculating method for the beginning and the end of the growing season has been shown.
Keywords: *growing season of heat-loving plants, Ukrainian Carpathians, climate change*
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THE USE OF SPLINE FUNCTION IN THE DETERMINATION OF GENETIC TYPES OF RAINFALL IN POLAND

Keywords: *extreme rainfall events, types of rainfall, spline function*

Numerous studies concerning precipitation differ significantly depending on the purpose of the study. Meteorological and climatological studies are usually focused on the processes acting in the atmosphere. Hydrologists are mostly interested in the effects of these processes, in other words, in the rainfall reaching the surface of the earth. The combination of these two research fields is required for hydrological prognoses. Developing methods of quantitative rainfall forecasting has been an important but still unsolved problem.

The primary idea of this study was to analyse the time structure of precipitation at the selected rain-gauge stations within the territory of Poland. However, the results of first attempts of statistical rainfall analyses have proven that rainfall events of various duration cannot be regarded as a homogeneous process.

Definition of genetic types is not an easy task due to the significant diversity of rainfall inducing processes. The more recent classifications (Herzegh and Hobbs 1980, Hobbs et al. 1980, Atkinson 1981, Sumner 1988) combine the genesis of rainfall with its general characteristics: duration, intensity, and areal extent. According to different precipitation producing mechanisms Sumner (1988) identified three genetic types of rainfall, i.e. convection, cyclonic and orographic.

Convection type rainfall arises as the result of rapid uplift of masses of air. Intense rainfall cells produced by such processes are not large in size. They are most often limited to tens or hundreds of square kilometres. Convection cells in the form of vertically developed clouds, cause a very intense rainfall and are limited to a relatively small area about 100 km^2. Multi-cell convection configurations consist of two or more convection cells functioning within the same system. Large scale convection complexes are organized into groups or squall line systems with axes perpendicular to the direction of configuration shift. In the moderate climate linear configuration of convection cells occurs quite often in the zone preceding the cold front. Each of the cells may produce very intensive rainfall. In the case of such configuration the convective processes have a mezoscale extent and the area of precipitation reaching hundreds of km^2.

Cyclonic type of rainfall is associsted with circulation systems of the atmosphere at mezo- or macroscale. In temperate climates, atmospheric depressions have low-pressure centres and a well-formed systems of fronts. The main precipitation producing process in horizontal convergence of air masses at considerable areal scale. A typical range usually includes hundreds to tens of thousends square kilometres. Intensity of this type of rainfall is rarely high.

Typical frontal depressions reaching Europe are formed over the Atlantic, as the eastern coast of the United States of America and Canada. It takes 2-3 days to pass over Atlantic, theh they move for the next 2-3 days over the sea at the coastal part of western Europe. They decay over the continental distance from the Atlantic, which is the source of humidity, becomes longer, precipitation intensity and total depth decrease. Precipitation induced by Atlantic depression nay relocate by as many as 1000 to 10 000 kilometers. In the summer in southern and eastern Poland high depth rainfall may also be induced by depressions genetically associated with the Mediterranean sea and coming to Poland from the Hungarian lowland and southern Ukraine (Michalczewski and Mycielska 1972, Kupczyk and Suligowski 2011, Suligowski 2013).

Generation of orographic precipitation defined by Sumner (1988) and other authors depends on a specific relief configuration. The area affected by the rainfall is connected with the orographic barrier and the formation of clouds and rain mainly happens on the windward side. As the rainfall area does not relocate, a significant rainfall totals may reach a very limited area.

Rainfall intensity differs depending on the nature of the local circulation near the orographic barrier, atmosphere stratification, and air humidity. These processes are clearly visible in the areas where topographic barriers occur relatively near to the sea-shore, for example in western and north-western Europe. In Poland orographic type of rainfalls have been observed in the Podkarpacie region even though their occurrence are not clearly defined due the transformation of air masses and low intensity of humidity inflow.

Thus the nature of precipitation producing mechanisms forms the temporal structure of rainfall, amount and territorial extention.

The problem of classification of rainfall data according to the type of rainfall is important for this study. Rainfall could be subdivided on the basis of synoptic analysis and local meteorological conditions of each storm event, or by the statistical analysis of rainfall characteristics depicting the genetic type feature. The first method required additional information and is very time-consuming, so it was found not useful in practice. The most important task in the statistical approach was to identify the fundamental rainfall characteristics reflecting the main feature of distinguished type of rainfall. After several attempts it was found that the key characteristic is the functional relation of total depth of rainfall events to its time of duration.

Basic precipitation data derived from selected 40 polish meteorological stations (fig. 1) in the years 1961-90 and concerning only summer season (V-X) rainfalls, were subdivided into 13 classes of duration (tab. 1).

Figure 1. **Location of rain gauges stations used in the study**

Table 1. **Rainfall classes, selected with respect to time of its duration**

Class number	Rainfall duration (t_r) in hours
0	$t_r \leq 0.5$
1	$0.5 < t_r \leq 1.5$
2	$1.5 < t_r \leq 2.5$
3	$2.5 < t_r \leq 3.5$
4	$3.5 < t_r \leq 4.5$
5	$4.5 < t_r \leq 5.5$
6	$5.5 < t_r \leq 6.5$
7	$6.5 < t_r \leq 7.5$
8	$7.5 < t_r \leq 8.5$
10	$8.5 < t_r \leq 11.5$
12	$11.5 < t_r \leq 13.5$
18	$13.5 < t_r \leq 24.0$

Changes in the depth – duration relationship were tested with the spline function method (Suits et al. 1978, Smith 1979) with the use of the computer programme. The programme makes it possible of subdividing the whole range of function variability into sectors with different courses of functional dependence, to perform the zoning in the optimum way and to determine parameters of regression equations in the selected sectors. The division of the whole range of the observed characteristics into sectors was optimalized using minimum mean deviation criterion:

$$\sum_{i=1}^{n}[f(x_i)-y_i)]^2 = \min$$

where: n – number of all measurements, y_i – measurement of the characteristics, x_i – time of measurement, $f(x_i)$ – spline function value.

The search of optimum division into sectors is carried out by determination of standard value for all possible cases subsets, and the selection of the one with the smallest value. In the result of analysis of the $h = f(t_r)$ function the whole range of rainfall duration has been divided into three sectors: 90 minutes (or less – depending on stations) (tab. 2), from 91 minutes to 4.5 hours or up to 13.5 hours, and longer rainfall.

Table 2. **Time range occurence of genetic types of rainfall at meteorological stations in Poland**

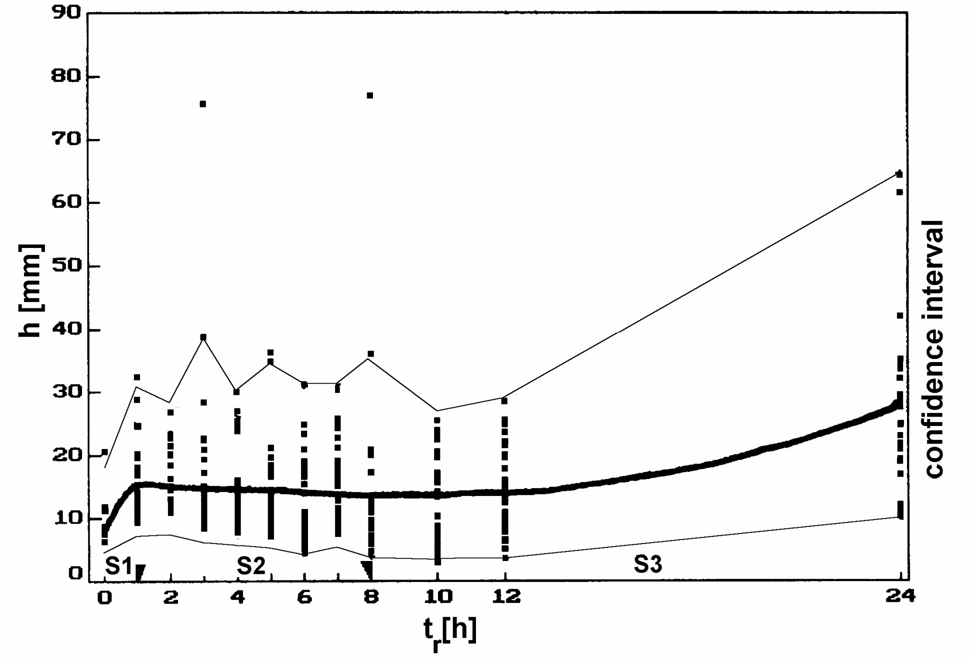
Station name	Rainfall duration (t_r)		
	Convection (sector S1) [min]	Frontal (sector S2) [h]	Atmosph. depression (sector S3) [h]
Białystok	1 – 90	1,5 – 5,5	> 5,5
Chełm Lubelski	1 – 90	1,5 – 4,5	> 4,5
Częstochowa	1 – 210	3,5 – 10,5	> 10,5
Elbląg	1 – 150	2,5 – 13,5	> 13,5
Gdańsk	1 – 90	1,5 – 13,5	> 13,5
Gniezno	1 – 90	1,5 – 8,5	> 8,5
Gorzów Wlkp.	1 – 150	2,5 – 7,5	> 7,5
Hala Gąsienicowa	1 – 150	2,5 – 13,5	> 13,5
Jarczew	1 – 90	1,5 – 5,5	> 5,5
Jelenia Góra	1 – 150	2,5 – 5,5	> 5,5
Kielce	1 – 150	2,5 – 13,5	> 13,5
Kołobrzeg	1 – 150	2,5 – 13,5	> 13,5
Legnica	1 – 90	1,5 – 7,5	> 7,5
Lębork	1 – 150	2,5 – 6,5	> 6,5
Lublin	1 – 150	2,5 – 5,5	> 5,5
Łódź	1 – 90	1,5 – 7,5	> 7,5
Mieroszów	1 – 150	2,5 – 6,5	> 6,5
Międzylesie	1 – 90	1,5 – 4,5	> 4,5
Nowy Sącz	1 – 90	1,5 – 4,5	> 4,5
Opole	1 – 90	1,5 – 6,5	> 6,5
Ostrołęka	1 – 90	1,5 – 5,5	> 5,5
Płock	1 – 150	2,5 – 10,5	> 10,5
Poznań	1 – 90	1,5 – 3,5	> 3,5
Rabka	1 – 150	2,5 – 13,5	> 13,5
Rzeszów	1 – 90	1,5 – 3,5	> 3,5
Suwałki	1 – 90	1,5 – 6,5	> 6,5
Szczecin	1 – 90	1,5 – 13,5	> 13,5
Szczecinek	1 – 210	3,5 – 7,5	> 7,5
Terespol	1 – 90	1,5 – 3,5	> 3,5
Toruń	1 – 90	1,5 – 6,5	> 6,5
Warszawa	1 – 90	1,5 – 6,5	> 6,5
Wieluń	1 – 90	1,5 – 3,5	> 3,5
Wisła	1 – 150	2,5 – 13,5	> 13,5
Wrocław	1 – 90	1,5 – 8,5	> 8,5
Zakopane	1 – 150	2,5 – 13,5	> 13,5
Zielona Góra	1 – 90	1,5 – 6,5	> 6,5

In the case of rainfall classified to the first sector their depth increases rapidly with the duration increase. This is because of a high average intensity of all rainfall events in this sector, regardless of whether their duration is 10 or 60 minutes.

The second sector with a very diversified rainfall duration shows lack of dependence between rainfall depth and its duration in the initial section (duration 1,5-8.5 hours), and at many stations reveals a negative dependence – the depth of rainfall decreases in the 9.5-13.5 hours duration class. This means that the mean intensity of rainfall with the duration longer than 8,5 hours is significantly smaller than those of shorter duration (for example 6 hours; fig. 2). These results, however suprising, have been confirmed in the works of others authors, outside Poland. It was expressed in the $h = f(t_r)$ function analysis and resulted in negative correlation coefficient of two characteristics: depth and duration of rainfall in this class.

The third group – long duration rainfalls with the time exceeding 13.5 and 24 hours reveal a distinct depth increase accompanying the increase of duration.

The examples of formulae describing rainfall depth – duration relationship and division in the sectors (S1, S2, S3) according to the spline function method have been presented in Figures 2.



S1	S2	S3
$h= -10.53t_r^2 + 20.75t_r +6.72$	$h= -0.31t_r +17.25$	$h= 0.044t_r^2 -0.83t_r +18.81$

Figure 2. **Maximum depth of rainfall events against time of its duration at Toruń**

In the first and third sector (S1 and S3 in figure 2) a parabolic form of the relationship between rainfall duration and its depth was obtained. Thus the spline function in these sectors has been described by the following second degree polynomial:

$$y = cx^2 + dx + e$$

In the second sector (S2 in figure 2) the following linear approximation turned out to be sufficient:

$$y = ax + b$$

Function parameters of the second section were calculated using least square method, by minimization the following function:

$$\sum_{i=1}^{k}[y_i - (ax_i + b)]^2 = \min$$

Values of parameters in the first and third sector were obtained by the introduction of continuity at the borders of sectors, which resulted in the condition of equality of the first derivatives at the borders of these sectors:

$$\sum_{i=p}^{q}[y_i - (cx_i^2 + dx_i + e)]^2 = \min$$

where: p = 1, q = 1 (sector 1); $p = k$, $q = n$ (sector 3).

Parameters values of the $h = f(t_r)$ function were determined assuming the 0.95 confidence level. The actual bias error which we made while preserving continuity of function at the sector border only at some stations was slightly higher than the optimum bias error.

In the result of the described statistical analysis we obtained a division of the whole set of rainfall events at each station into three subsets with different relationships of two basic rainfall characteristics: depth and duration. A rapid change of this dependence occurring in particular at transition from the first to the second sector is a proof that the processes which form rainfall events are not homogeneous. Thus it can be believed that rainfall in the defined duration sectors are induced by different mechanisms. Inflection points for the $h = f(t_r)$ function (in an averaging picture) determine domains, where the precipitation process can be regarded as homogenous. This argumentation in connection with the established rainfall classifications (after Sumner 1988) made it possible to identify three types of rainfall in Poland where the objective criterion of the identification is the duration of rainfall.

Convective rainfalls. They are induced by singular convection cells or sets of cells with intense ascending and descending currents which rarely form squall line configurations under our climatic conditions, The most frequent and most intense convection rainfalls have been observed in the central part of Poland, forced by considerable diversification of thermal features of the substratum, for example the area near Gniezno, Plock, Toruń. High frequency of convection rainfalls is also observed in eastern Poland (Terespol, Białystok, Chełm Lubelski) which is connected with continental climate characteristics of these area.

Frontal rainfalls. They make quite a distinct group of rainfalls in Poland with a very diversified duration, ranging from 1.5 to 13.5 hours (Table 2). They differ in intensity and duration in comparison to rainfalls identified as cyclonic for the territory of western Europe. The differences are related to transformation of air masses over the western part of the continent, lower speeds of frontal zones relocation as well as a weakening of the dynamics of processes in the zone of fronts. Rainfalls preceding a warm front, in particular in the summer , do not give large precipitation depth. Rainfall area connected with warm front is very large and relocates slowly thus, long duration rainfalls (7.5 – 13.5 hours) are of low intensity. The stable thermal stratification behind a front does not offer good conditions for clouds and rainfall development. For this reason the next rainfall zone connected with a cold front is recorded as a separate event. Generally a cold front usually relocates faster, processes in front zone occur more dynamic, which leads to a higher intensity of rainfall of the 1.5 – 5.5 hours duration.

After a passage of a cold front, due to a high air transparency and good conditions for air masses heating from the ground, a very unstable air stratification is produced, in particular in the spring and early summer. As the polar and sea air masses a cold front are unstable and local heating processes occur, cloud forming processes become very active. Rainfalls of relatively high intensity connected with those processes are often occure as the extension of cold front rainfall (with the duration of 1.5 to 7.5 hours) shows a higher depth than that of long duration rainfalls (9.5-13.5 hours) connected with the passage of a warm front.

Atmospheric depression rainfall. They are connected with the passage of a deep atmospheric depression centres or series of depression with two active frontal surfaces or with large convergence zone in synoptic scale. These types of process produce of long duration rainfall with altered intensity. In continuous rainfall records observed at sites, a weakened intensity of rain or some breaks occur after passage of warm front. The hyetograph of rainfall connected with passing of whole depression configuration with active fronts system over Poland shows a definite intensity increase in the duration sector 10.5 - 24 hours, caused by intensive rain-inducing mechanisms of the cold front.

Conclusions. Three genetic types of rainfall were separated from whole series of rainfall events: convection, frontal and atmospheric depression rainfall .The best statistical criterion which, made it possible to divide rainfall events into genetic groups, turned out to be inflection points at the curve, reflecting functional relation of rainfall depth and its time of duration. The each group of events is connected with different precipitation producing mechanisms, thus rainfall characteristics differ considerably, which can be seen at. maximum rainfall intensity quantiles values. The temporal patterns of rainfall intensity along time of its duration are also differentiated.

References

1. *Atkinson B. W.* Mesoscale atmosphere circulations. – London : Academic Press, 1981. **2.** *Herzegh P. H.* The mesoscale and microscale structure and organization of clouds and precipitation in midlatitude cyclones. II: warm-frontal clouds / Herzegh P. H, Hobbs P. V. //. J. of the Atmospheric Sciences. – 1980. – *3*7(3). – P. 597–611. **3.**, The mesoscale and microscale structure and organization of clouds and precipitation in midlatitude cyclones. I: A case study of a cold front / Hobbs P. V., Matejka T. J., Herzegh P. H. etc // J. of the Atmospheric Sciences. – 1980. – 37(3). – P. 568–596. **4.** *Johnson A. R.* Applied multivariate statistical analysis / A. R. Johnson, D. W. Wichern. – Prentice Hall, New Jersey, 1982. **5.** *Kupczyk E.* Statistical description of the rainfall structure as the input to hydrological models / Kupczyk E., Suligowski R. // Prediction of the design storms and floods ; U. Soczyńska (ed.). – University of Warsaw, 1997. – P. 191–212. **6.** *Kupczyk E.* Temporal and spatial patterns of high intensity rainfalls in Poland / Kupczyk E., Suligowski R. // Miscellanea Geographica. – 2000. – 9. – P. 77–84. **7.** *Kupczyk E.* Rainfall types for hydrological purposes / Kupczyk E., Suligowski R. // Przegląd Geofizyczny. – 2011. – 3–4. – P. 235–246. **8.** *Michalczewski J.* Meteorological causes of floods in July 1970 / Michalczewski J., Mycielska H. ; Instytut Gospodarki Wodnej. – Warszawa : Wyd. Komunikacji i Łączności, 1972. **9.** *Smith P. L.* Splines as a useful and convenient statistical tool / P. L.Smith // The American Statistician, 1979. – 33(2). – P.57–62. **10.** *Suits D. B.* Spline functions fitted by standard regression methods / Suits D. B., Mason A., Chan L. // The Review of Economics and Statistics. – 1978. – 60(1). – P. 132–139. **11.** *Suligowski R.* Temporal and spatial structure of the rainfall in Poland. Attempt at the regionalization / R. Suligowski // Prace Instytutu Geografii Akademii Świętokrzyskiej. – 2004. – 12. – P. 3–110. **12.** *Suligowski R.* Maximum credible precipitation at the Kielce Upland (Poland) / R. Suligowski. – Kielce : Jan Kochanowski University, 2013. **13.** *Sumner G.* Precipitation. Process and analysis / G. Sumner. – London : John Wiley and Sons Ltd., 1988.

Suligowski Roman

The use of spline function in the determination of genetic types of rainfall in Poland

A large number of studies has been undertaken by meteorologists and climatologists on precipitation phenomenon in many aspects, depending on the goal of investigation. Some of them classified precipitation events with respect to the different scale of atmospheric processes which cause the formation of clouds and precipitation. On the basis of 40-year (1961–2000) rainfall series analysis in Poland it has been stated that the whole range of rainfall duration cannot be regarded as genetic homogenous sample. Three genetic types of rainfalls were separated within the territory of Poland: convection, frontal and atmospheric depression rainfalls. Rainfall characteristics differ according to separated genetic groups. The best statistical criterion which made it possible to divide rainfalls into genetic classes turned out to be the inflection points at the curve reflecting functional relation of rainfall depth, and its duration. Changes in this relationship were tested with the spline function method.

Keywords: *extreme rainfall events, types of rainfall, spline function.*

Суліґовскі Роман

Використання сплайн-функції у визначенні генетичних типів дощових опадів у Польщі

Проведено велику кількість досліджень дощових опадів у різних аспектах. У деяких з них запропоновані класифікації опади відповідно до масштабу атмосферних процесів, що спричиняють формування хмар та опадів. На основі аналізу 40-річних спостережень у Польщі (1961-2000 рр.) стверджується, що тривалість опадів не може розглядатися як генетично гомогенна вибірка. На території Польщі виділяється три генетичні типи опадів: конвективні, фронтальні та пов'язані з атмосферними депресіями. Характеристики опадів розрізняються залежно від генетичних груп. Найточнішим статистичним критерієм, що дозволив виділити генетичні класи опадів, виявилися точки вигину на кривій, що відображає функціональне співвідношення інтенсивності опадів та їх тривалості. Зміни в цих співвідношеннях були перевірені за допомогою методу сплайн-функції.

Ключові слова: *дощові опади, типи опадів, сплайн-функція.*

Сулиґовски Роман

Использование сплайн-функции в определении генетических типов осадков в Польше

Проведено большое количество дождевых осадков в разных аспектах. В некоторые из них предложены классификации осадков в зависимости от масштабов атмосферных процессов, которые вызывают образование облаков и осадков. На основании анализа 40-летних наблюдений в Польше (1961-2000 рр.) утверждается, что продолжительность осадков не может рассматриваться как генетически гомогенная выборка. На территории Польши выделяются три генетические типы осадков: конвективные, фронтальные и связанные с атмосферными депрессиями. Характеристики дождей различаются в зависимости от генетических групп. Самым точным статистический критерием, который позволил выделить генетические классы дождей, является точка изгиба на кривой, отражающей функциональное соотношение интенсивности осадков и их продолжительность. Изменения в этих отношениях проверены с помощью метода сплайн-функции.

Ключевые слова: *дождевые осадки, типы осадков, сплайн-функция.*

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