XIV. Summary

Analysis of the spatial and spatial-temporal structure of maximum daily precipitation in Poland in the years 1956-1980

Among forecasts made on the basis of global and regional climatic models is one of a high probability of an increase in the frequency and intensity of extreme precipitation events. This corresponds with many published analyses of archival measurement series indicating the appearance of such tendencies in the latter half of the 20th century. Learning the regularities underlying the recurrence and spatial extent of extreme precipitation is obviously of great importance, both economic and social. A full insight into those problems can only be gained by combining ground-based point measurements with areal remote-sensing data. Regrettably, it is still hard to formulate generalisations because of the relatively short period for which remote-sensing data are available and difficulties involved in making precise assessments of precipitation intensity on their basis. That is why, irrespective of the new measuring techniques being introduced, it is necessary to perform an analysis and reinterpretation of archival data, making use of the possibilities created by the development of GIS.

In the case of discontinuous meteorological elements - such as precipitation - there can be changes in both, their temporal and spatial characteristics because a change in the point-registered frequency of precipitation in the various intensity or duration classes can be due to a real change in its frequency of occurrence or a change in its spatial range. Hence, the observed increase in the extreme 'amounts' of rain can only be associated with its greater spatial extent, without any changes in its recurrence. Analyses of changes in climate characteristics, which have concentrated almost exclusively on their temporal aspect so far, should also consider a potential evolution of their spatial structure. It is therefore necessary to employ archival multi-year data to identify the basic properties of this structure that could provide a reference point against which possible trends of change might be tested.

The main goal of the dissertation was to analyse regularities underlying spatial and temporal variations in monthly and annual maximum daily precipitation totals (MDPTs) observed in Poland over the years 1956-1980. The basic source material employed was maximum daily precipitation

totals recorded at weather and rainfall stations in the particular months of the multi-year period 1956-1980 and published in the Atmospheric Precipitation yearbooks. They were augmented with the date of occurrence of a maximum annual daily precipitation total. Apart from the data from Poland, a similar pluviometric material was obtained for all the measuring sites existing in the years 1956-1980 in the former GDR in a belt of up to 30 km from the Polish border. In total, the database employed contained 747,486 maximum daily precipitation figures in the particular months (2,492 on average) and 61,940 dates / totals of maximum annual daily precipitation (2,478 on average).

These data are specific because apart from being spatially discontinuous, which is typical of precipitation, they are also non-synchronic. A given monthly MDPT figure could have been recorded at any locality on any day of the month. Still, the point-measured MDPTs are not results of independent, totally random phenomena. Each precipitation event takes some time and has a specified spatial range. Hence there is a non-zero probability that it will be recorded in a greater number of localities, and that in at least some of them it will be classed as a periodic MDPT. The present work rests on the hypothesis that the probability of MDPT occurrence displays spatial autocorrelation, and hence spatial continuity.

The main aim of the dissertation was accomplished via several detailed goals:

- determination of the chief statistical features of the analysed sets of monthly and annual MDPTs, including their seasonal and multi-year variability,
- identification and typology of the spatial structure of monthly and annual MDPTs,
- determination of the character and probable origin of events generating MDPTs,
- quantitative assessment of the contribution of the particular events to the overall MDPT figures,
- examination of potential seasonal variations in the spatial structure of MDPTs,
- verification of the hypothesis about differences in the spatial structure of MDPTs in different classes of rainfall amount,
- checking the spatial structure of MDPTs for significant tendencies in the entire period under analysis,
- determination of seasonal differences in the probability of occurrence and the level of annual MDPTs, and
- examination of regional variations in the date of occurrence of annual MDPTs.

The analysis of the spatial structure of MDPTs was carried out in two approaches. In one, use was made of 325 models of spatial structure, one for each of the analysed sets of monthly and annual

MDPTs. The models were built on the basis of empirical isotropic semivariograms of normalised data with a range of 212.5 km (85 lag intervals 2.5 km in width).

In the other approach, the analysis of variations in the structure of monthly and annual MDPTs depending on precipitation levels was performed using indicator semivariograms. For each data set, 13 threshold values were determined based on the empirical distribution function: the 1st, 5th, 10th, 20th, ..., 90th, 95th, and 99th percentile (4,225 models in total). Calculations were made for 15 intervals, 2.5 km each.

To assess the probability of the date and level of annual MDPTs, use was made of the method of kernel density estimation. The spatial variability of the dates of occurrence of annual MDPTs was also analysed with the help of the local statistics of their dates (the number of the day in the Julian year).

The MDPT field in Poland is usually the sum of the outcomes of three types of processes operating at various spatial scales: local (<10-20 km), regional (50-150 km), and supra-regional (>200 km). The spatial scales are probably connected with a convective/orographic, a frontal and a 'climatological' genesis of high precipitation (planetary waves?). Their contributions are highly variable. Generally predominant, however, are high daily precipitation totals with a spatial extent of 50 to 150 km connected with mesoscale phenomena and the migration of atmospheric fronts (35-38%). The spatial extent of areas of high local-scale precipitation usually varies at random, especially in the warm season. At supra-local scales, structures of repetitive size predominate.

The parameters characterising the spatial structure of MDPTs display a marked seasonal cyclicity and variability depending on the precipitation level. The seasonal variability of the proportion of the random component (nugget variance), for instance, is very close to the average multi-year pattern of factors correcting the errors of standard precipitation measurements. Their primary sources are wind-generated turbulence, solid-state precipitation, as well as evaporation- and wetting-related losses. The absolute C_0 value was also found to depend on variations, both global and local, of the MDPT field. Also the relative share of the variance of the first component displayed a highly significant seasonal variability with a maximum in June and May and a minimum in October. Such a yearly cycle probably reflects the changeable proportion of convective precipitation, which attains a maximum in months with the greatest thermal contrasts. The characteristics of the spatial structure of MDPTs depend on a relative rainfall amount connected with its location along the empirical distribution function to a greater extent than on the absolute total.

The multi-year period under analysis was too short to make a reliable assessment of long-term tendencies in the evolution of the climate. Still, the changes found to occur in the elements of the spatial structure, largely connected with local-scale events, show that the hypothesis advanced at the beginning - as to a potential effect of changes in the spatial structure of extreme precipitation events on their point-registered frequency - is a promising research perspective and should continue to be tested.

On the basis of a kernel density estimation, 14 periods were distinguished that varied in the level and gradient of the probability of occurrence of annual MDPTs in various rainfall-amount classes. They last from 12 to 58 days. While an annual MDPT can potentially occur every day on the territory of Poland, the probability of its occurrence between 16 December and 19 March is extremely low. On the other hand, the probability that it will appear between 21 April and 5 November is as high as 95.6%. The period with the greatest chance of occurrence of an annual MDPT lasts from 28 June to 22 August. The probability curve reaches its annual maximum, 1.03%, on 23 July. Its lowest daily values occur at the turn of the year and range from 0.005 to 0.008%. Thus, the difference spans three orders of magnitude. From mid-December to the end of March the predominant annual MDPTs are lower than 20 mm. From mid-June to the last decade of August the most frequent are annual MDPTs of about 40 mm and more. In the remaining part of the year the predominant class of precipitation is that in the interval from 20 to 40 mm. The maximum probability of occurrence of annual MDPTs from the individual rainfall-amount classes falls on the short period between 20 and 26 July. The mean dates of MDPT occurrence in Poland range from 27 June (the 178th day of the year) to 11 August (the 223rd day), with the average date for the entire country being 22 July (the 203rd day). This result differs by a mere day from that read from the probability curve. Variations in the dates of occurrence of annual MDPTs, despite the random character of the highest rainfall, turned out to differ markedly regionally. They seem to be a resultant of factors acting at a variety of scales, one of the major ones being the general oceanic-continental gradient between Western and Eastern Europe. It is modified directly by the Baltic and terrain topography. It was also found that the dates of occurrence of annual MDPTs displayed marked spatial autocorrelation which can be modelled in a standard way. The average ranges of the components of models of the spatial structure of the MDPT dates are similar to those found for the MDPT figures (15.8, 102.8 and 180 km). However, in the case of individual data sets, there are no apparent relations between them. This also holds for the number and type of components making up a model. Probably those differences are an effect of a greatly reduced role of the long-term component. The total spatial variability of the date of occurrence of annual MDPTs is largely (in about 69%) shaped by short-range precipitation (from single convective cells) and random factors affecting their internal structure and movement.

While the conducted analyses have thrown much light on the issue of the spatial variability of the highest daily precipitation totals, there is still much to be done. Many of the newly found regularities need a deeper genetic interpretation, which is hard, if not impossible, to conduct without additional data and a wider context of their analysis.

Special studies should be conducted of individual cases typical of the spatial structure classes distinguished. To perform them, it is necessary to have a complete set of daily precipitation totals from the whole of Poland embracing a period of several days before, during, and after the episode analysed, and most importantly, synoptic charts showing the precipitation-generating conditions.

Another potentially fruitful direction, and one not involving a labour-consuming compilation of new databases, is the study of relations between the occurrence of the distinguished spatial structure types of monthly and annual MDPTs and the frequency of various air masses appearing over Poland defined on the basis of calendars of circulation types.

Attention should also be paid to potential regional differences in the spatial structure of maximum daily precipitation. The regularities established in the present work are likely to obtain over a much more extensive area than our country, perhaps even over the entire humid temperate zone. Regional dissimilarities, therefore, may involve not qualitative characteristics, but primarily more or less distinct statistical differences in the frequency of appearance and relative significance of individual components. A study of such differences is currently perfectly possible and scheduled for the next stage of the research.

A promising line of inquiry is also using annual MDPTs to perform co-simulations of both, their level and time of occurrence. This is a logical consequence of the spatial autocorrelation present in both, the set of precipitation totals and the dates of their appearance. As a result, it will be possible to make reliable, fully probabilistic, spatial-temporal assessments of the risk of heavy precipitation at the scale of regions, or even medium-sized river catchments. So far such assessments have been made exclusively on the basis of point data whose spatial representativeness was hard to test. Scale relations allowing a 'conversion' of point probabilities into areal ones have been unknown.

Empirical semivariograms of MDPT data are complex in nature - they consist of two to five elementary models. This is usually interpreted, as has been mentioned in the text, as a result of the operation and summing up of the effects of events occurring at various spatial scales. The method of factorial kriging offers a promising way of differentiation among, and quantitative assessment of, the chief components forming the MDPT field.