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Estimation of extreme wet and dry days through moving totals in precipitation time series and some possibilities for their consideration in agrometeorological studies

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Abstract. Moving totals of daily precipitation are a more exact tool for indicating the most extreme weather periods and their frequency than monthly or 10-day precipitation totals. Therefore the terms 'extreme wet' and 'extreme dry' are used for the last day of a period of calculating the moving total of precipitation if that is larger or smaller than the specified limits. These terms qualify a day with extra wet or dry meteorological and surrounding conditions. The number of extreme days and limits that lead to a large yield loss vary by crops and phenological phases. Calculation of moving totals in precipitation long time series in any number of successive days allows presenting the dependence of the observed maximal and minimal amount of precipitation on the number of successive days in a period. Such dependence seems to be useful in estimating the climate resources in an area. Examples are given for Jõgeva, Pärnu and Ristna precipitation time series of 1957–2008.

Estimation of extreme wet and dry weather conditions on the basis of moving totals of daily precipitation allowed distinguishing the most drastic periods and trends of the precipitation regime in Estonia in the last 50 years. A day is considered as extreme wet when the moving total of precipitation is at least 10 mm on 10 successive days leading up to this day. A day is considered as extreme dry when there was no precipitation during the successive 20 days till the observed day. By these criteria years with especially wet or dry periods are easily distinguished. Inter-annual variability of the average number of wet and dry days in Estonia increased notably in 1957–2006. The growing trend of annual total number of extreme (wet + dry) days is statistically significant.

Key words: climate extremes, daily precipitation, flooding, drought, moving total, Estonia.

INTRODUCTION

It has always been important to know the risk of extreme weather, such as heat- and coldwaves, drought and wet periods, heavy rainfall, high winds, etc. in an area. Numerical estimation of these risks is required in agricultural production as well as in hydrology, irrigation projects, disaster plans, etc.Estimation of the frequency and intensity of extreme weather events also helps to regard weather risks as indicators of climate changes that a farmer should consider when compiling a successful action plan. The prime aim of a flood or drought risk study in an area is to estimate the frequency and intensity of periods of heavy precipitation and zero precipitation through a long time series. The meteorological service can then inform people about the significant

risk factors, pimarily extremely large precipitation amounts or many days without rain lead to flooding or drought..

The lack of precipitation is mostly connected with anticyclonal weather, which occurs in Estonia often in spring or early summer, and, in the recent decade, also in late summer (Eesti keskkonnaseire 2004–2006, 2008). A drought can be divided into meteorological, agricultural, hydrological and socioeconomical drought (IFAS, 1988; Hales et al., 2003). Meteorological drought is a measure of departure of precipitation from normal. Agricultural drought refers to a situation when the amount of moisture in the soil no longer meets the needs of a particular crop. High values of precipitation in Estonia are mainly of two types: 1) heavy convective rainfall lasting for a few hours and extending typically over a few hundred square kilometres, which occurs predominantly in the warm season. If this rainfall is heavy enough, the 10-day or even monthly precipitation totals will be large in the sites of rainfall; 2) multi-day wet spells, which are connected with the cyclones, passing over Estonia in most cases from the south (from the Mediterranean and Black Seas) bringing heavy precipitation. The area of precipitation is then large and the monthly or 10-day precipitation amounts are often great in many areas of the country (Scientific ..., 1990). In recent years, extremely dry as well as extremely wet periods have occurred in Estonia: the rainfall during July 2006 made up only about 22% of the average precipitation, which caused large losses in agriculture; the events of heavy precipitation in summer 2008 resulted in flooding of fields in many districts (Eesti keskkonnaseire..., 2007; Keskkond 2008, 2009).

MATERIAL AND METHODS

Traditional analysis of precipitation conditions is usually carried out through precipitation totals in a day, 10-day periods, month and year or the number of dry and wet days in a month and in a year (Scientific..., 1990; ECA&D, 2004). There are many other indices to characterise the precipitation regime for a region (Klein Tank, et al., 2002), but these are not sufficient for describing a continuous long dry or wet spell lasting from one month or from one year to another.

The preliminary task in discussing dry or wet spells is to define a dry and a wet day. The simplest definition of a dry day is zero precipitation while a wet day is a day with precipitation surpassing a certain threshold, which depends on the climate conditions of the observed area. It is also important to consider how much the data are rounded. The number of subsequent dry and wet days or mean dry and wet spell length then serve as indicators of the extreme precipitation regime (Schmidli, Frei, 2005). In studying environmental moisture conditions it is most significant to consider the precipitation amount not only in the observed day but also within some period till the observed day. Therefore we find extreme wet and extreme dry conditions for a day by counting the moving total (or average) of daily precipitation till this day using a period with the number of days depending on the object of the study (plant, field, phenophase etc.). So a wet or a dry day is a day with too much or too little precipitation for a specific object in a specified period till the observed day (Tammets, 2007). The moving total of precipitation is calculated through the daily precipitation time series without breaking that time into months or years.

Mathematically, based on a sequence $a_1, a_2, \ldots, a_i, \ldots, a_N$, the sequence of moving totals over subsequent n terms $s_i^{(n)}$ ($i= n, n+1,\ldots,N$) is expressed as:

$$s_i^{(n)} = \sum_{j=i-n+1}^{i} a_j \tag{1}$$

and similarly for moving averages $m_i^{(n)}$:

$$m_i^{(n)} = \frac{1}{n} \sum_{j=i-n+1}^{i} a_j, \tag{2}$$

where N, in our case, is the total number of days in the precipitation time series and n the number of days through which the moving average is calculated. We find drought and flooding days by calculating $s_i^{(n)}$ within time period n for each day i in the time series interval $n \le i \le N$ and choosing the days with values of $s_i^{(n)}$, that are smaller or larger than the given threshold t. In agrometeorological studies the given limits and time periods n depend on the plant species, state of vegetation, soil conditions, air temperature, humidity, etc.

To show the extreme precipitation totals in a precipitation time series for any number of successive days n we suggest composing a special curve characterising climate resources in an area. If we choose the maximal and minimal moving totals of precipitation in the time series for each time period with the step of one day, we get the dependence of the observed extreme values in each time period (y-axis) on the number of successive days in this time period n (x-axis). It is possible also to find the dependences of the percentiles, quartiles and other characteristics on n. As an example, the dependence of the observed maximal and minimal precipitation totals on the number of days in the time period in Jõgeva, Pärnu and Ristna in 1957–2008 is presented (Fig. 1).

In agrometeorological studies the limits for extreme wet conditions have been set as the mean daily precipitation amount 10 mm or more on successive 10 days (n=10) (Kivi, 1998): if the moving average for a 10-day period $m_i^{(10)} >= 10$ mm, the last day of the period is regarded as a wet day. Extremely dry conditions for field plants mean that there is no precipitation during 20 successive days (Kivi, 1998); then $s_i^{(20)} = 0$ and the last day of the period has been counted as a dry day. To analyse the number and distribution of wet and dry days in the last 50 years we counted the 10- and 20-day moving totals (averages) of precipitation for data of 1957–2006 of 56 meteorological and precipitation stations in Estonia (Tammets, 2007; Tammets, Jaagus, 2007).

RESULTS AND DISCUSSION

With the increase of the time period, the growth rates of precipitation maximums in Jõgeva (East Estonia), Pärnu (South-West Estonia) and Ristna (West-Estonia) differ. Overall, the maximum values of Jõgeva precipitation totals exceed the maximum values in Pärnu and Ristna in any time period (Fig. 1). Differences in precipitation totals in 50-day and shorter periods in Jõgeva and Pärnu are small and vary by the length of the period. In Ristna the maximum of precipitation totals in any number of successive days is generally lower than in Jõgeva and Pärnu, especially in longer time

periods. The minimums of precipitation totals grow almost equally with the number of days in the three stations.

In Jõgeva, the maximum 10-day precipitation total is 148.1 mm, observed on 24.07.1990; of Pärnu 129.1 mm on 03.09.1978 and of Ristna 140.1 mm on 15.09.1997. The wet days with average 10-day precipitation of 10 mm and more occur in Estonia only from June to November, most frequently in July and August (Fig. 2).

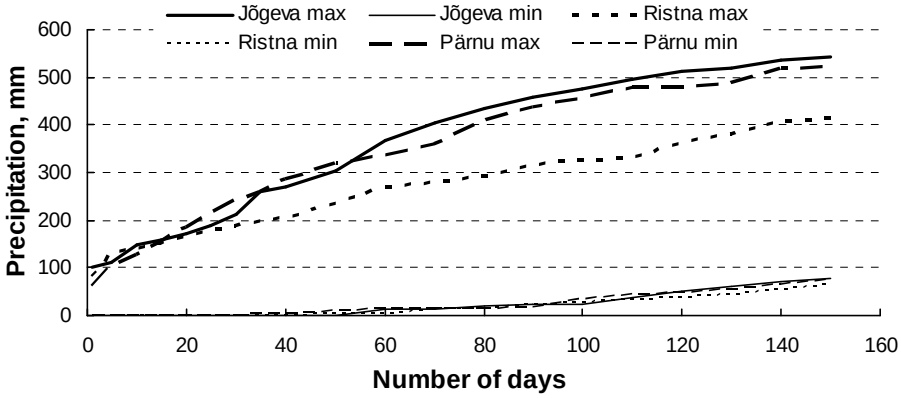

Figure 1. Dependence of the maximal and minimal precipitation totals in Jõgeva, Pärnu and Ristna in 1957–2008 on the number of the successive days in the period.

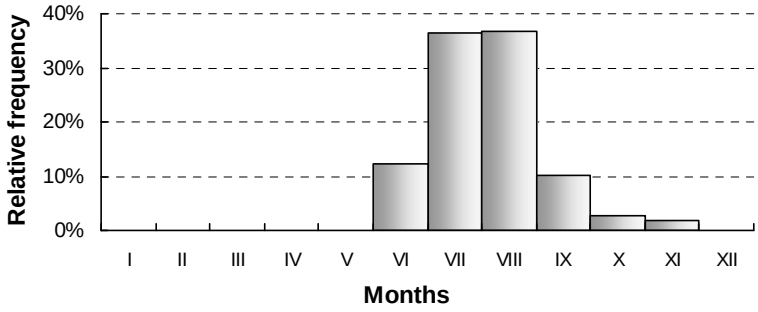

Figure 2. Monthly distribution of wet days, mean of 56 meteorological stations.

A 20-day period without precipitation may occur in any month (Fig.3). The largest number of dry days (20th day without precipitation) may occur in August, in May-June and in the late summer-autumn period.

Frequently extreme wet days as well as extreme dry days follow each other and the number of extreme days shows the intensity of a wet or a dry spell. In some years the number of wet or dry spells is two or more, but in the majority of cases the number of wet or dry days in a year has been counted within one wet or drought spell. In May-September the probability of wet days is 0.48% in Jõgeva; 0.50% in Pärnu and 0.23% in Ristna. In Jõgeva the probability of dry days in May-September is 0.39%, in Pärnu 0.59% and in Ristna 0.83%.

Inter-annual variability of the average number of wet and dry days in Estonia has notably grown in the last 50 years (Fig. 4). The wet and dry years contrast quite clearly. In 1957–1977 the dry days, and in 1978–1989, the wet days predominated. As

an average of 56 stations there was no more than one wet day a year in 1951–1977. Since 1978 the mean number of wet days per year has essentially risen – the mean number of wet days was near zero only in four years after 1978. The wettest years were 1978 and 1987 with four wet days (average of 56 stations). The number of dry days has essentially risen

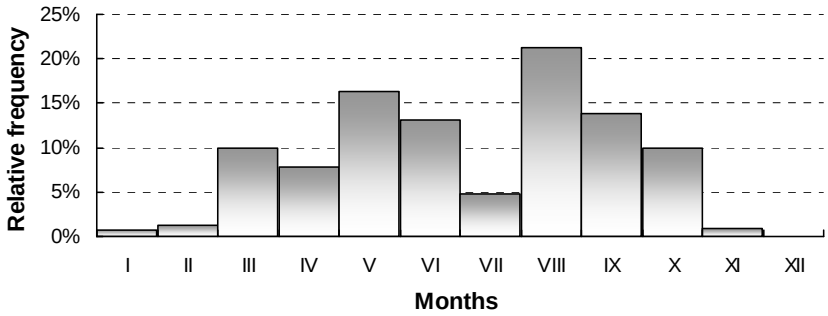

Figure 3. Monthly distribution of dry days, mean of 56 meteorological stations.

since the end of the 20th century. The severest drought occurred in 2002, when the mean number of 13 dry days was observed in August – September. The mean number of dry days in that year was more than twice greater than in 2006, which was the second driest year of 1957–2006. The period without precipitation lasted for 49 days in August-September in Valga and in Mauri. Two dry spells were observed that year in many districts – the first one in May and the second in July. It has been pointed out that the warming trend will lead to increased frequency and severity of extreme weather events (IPCC..., 2001). This confirms the statistically significant growing trend of the annual number of extreme wet and extreme dry days together (average of 56 Estonian stations) (Fig. 4) (Tammets, 2007).

CONCLUSIONS

Estimation of extremely wet and dry weather conditions on the basis of moving totals or averages of daily precipitation allows distinguishing the most extreme periods and trends of precipitation distribution. Very wet and very dry conditions for a day are easy to find through the moving total of daily precipitation data till this day. For every object we need to specify the limits of precipitation and the number of days within the time period that might cause damages. Maximal and minimal totals of precipitation in any number of successive days *n* can be represented through composing special curves for each long time series of daily data. For Pärnu, Jõgeva and Ristna stations these curves were calculated using the daily precipitation series of 1957–2008.

In Estonia, the average amount of precipitation, at least 10 mm on 10 consecutive days, causes extra wet conditions for the 10th day; 20 days without precipitation cause extra dry conditions for the 20th day. The mean number of these days at 56 Estonian meteorological stations in 1957–2006 allowed us to find severe wet and dry spells and to study the annual distribution of extreme days. The interannual variability of the total extreme (wet + dry) days shows an increasing trend.

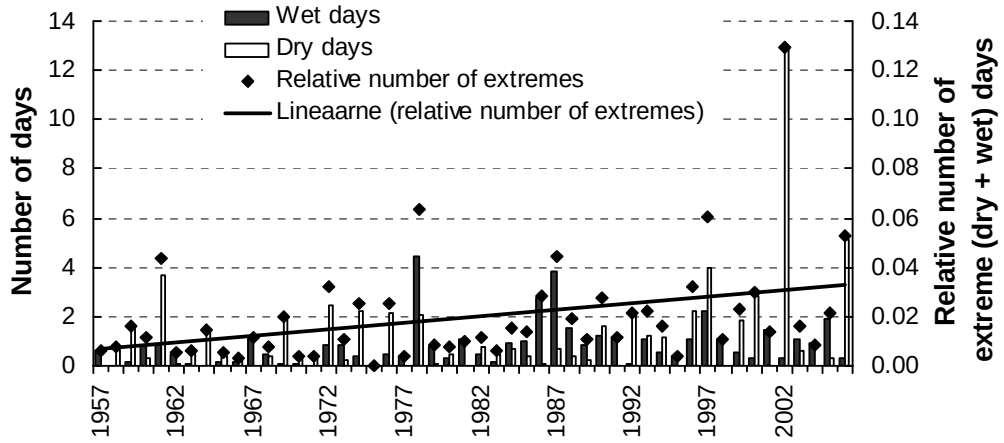

Figure 4. Number of wet and dry days (average of 56 stations) and relative number of extreme (dry + wet) days in 1957–2006.

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