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Precipitation Over Ireland—Observed Change Since 1940

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Abstract

Using a low pass-filter (10 year moving average), the non-parametric Pettitt-Mann-Whitney-Statistic and the Mann-Whiteny-Wilcoxon-Test, time series of hourly precipitation records for 8 meteorological stations in Ireland were investigated for the period since the 1940's to determine trends in the precipitation. Three of the stations are located on the West-cost, one on the North, one on the South coast, two on the East-coast and one inland.

We analysed the time series of the annual, half-yearly, quarterly and monthly precipitation for each site and applied the statistical tests to these time series. Change points in these time series were identified at all sites and most of the change points occur in the mid seventies. For the annual series two sites on the West-cost and the one site on the North-cost show an increase in precipitation after the change point year. For the monthly time series we found change points at six of the eight stations for the month of March. The change in the precipitation is concentrated in the months February to April and October. A decrease in the time series was determined for three of the time series of monthly precipitation in the summer-months and statistically not as significant as the increase between autumn and spring. The increased trend is clearly identified at the stations on the West-coast. The stations on the east coast show insignificant change. © 1998 Elsevier Science Ltd. All rights reserved.

1. Introduction

Climate Change is one of the most discussed topics in recent years. On a global and local scale several hydrologic parameters have been investigated for changes in the mean and variance. Apart from temperature, precipitation is one of the most important hydrological parameters. A change in precipitation will have an effect on runoff, agricultural conditions (erosion, soil moisture distribution, irrigation), design and planing (floods). Rowling (1989) and Smith (1994) showed that due to rainfall variability, the recent increased runoff has some implications for flooding and water management in Scotland. The investigation of the atmospheric circulation in Western Europe by Bardossy and Caspary (1990) shows that a change in the atmospheric circulation (in the winter months) since the 1970's has caused the more mild and frequent wet climate in Northern Europe. Kiely et al (1998) identified increased annual precipitation at Valentia on the west coast of Ireland since 1975.

In this investigation eight time series of hourly precipitation records from stations all over Ireland were used to determine a possible trend in the precipitation over Ireland since the 1940's. We computed the ten-year moving average and the non-parametric 'Pettitt-Mann-Whitney-Test' (Pettitt, 1979) to detect a change point in the annual, half-yearly, quarterly and monthly time series. To check the results we applied the 'cumultative sum technique' (Page, 1954) and the 'Mann-Whitney-Wilcoxon-Test' (Sachs, 1997).

2. Description of the sites and time series

The data used in this investigation was collected by the 'Irish Meteorological Service'. The following investigation includes the digitised time series for the meteorological stations Valentia, Shannon, Belmullet and Malin Head (West coast and North coast); Dublin and Rosslare (East coast); Cork (South coast) and Birr (inland). The stations are located between 51.8°N and 55.4°N and between 6.2° and 10.2°W. The exact position and altitude of each of the eight sites and the length of the corresponding time series is shown in Table 1. We used the available hourly precipitation records, between three to five decades in

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length (see Table 1) to compute the annual, half-yearly, quarterly and monthly series and applied the statistical tests to these time series to detect a change in the mean. The annual rain amount varies from about 750 mm in the Dublin area at the East coast to around 1250 mm at the West coast. The average monthly precipitation varies from about 50 mm in the drier months February to June at the locations on the East coast (Dublin, Rosslare) up to more than 150 mm each month for some Stations on the West coast (Valentia) in autumn and winter.

Table. 1 : Location of the meteorological stations and length of the time series

Name	Position / County	Altitude	Length of the Time series
Valentia Observatory	51.93° N / 10.19° W Kerry	9 m	01.01.1940 - 30.09.1994
Shannon Airport	52.70° N / 8.90° W Clare	14 m	01.01.1946 - 30.09.1994
Belmullet	54.23° N / 10.00° W Mayo	9 m	01.01.1957 - 31.12.1996
Malin Head	55.37° N / 7.30° W Donegal	20 m	01.01.1956 - 31.12.1996
Dublin Airport	53.43° N / 6.20° W Dublin	68 m	01.01.1942 - 31.12.1995
Birr	53.08° N / 7.80° W Offaly	70 m	01.01.1955 - 31.12.1994
Rosslare	52.25° N / 6.30° W Wexford	23 m	01.01.1957 - 31.12.1994
Cork Airport	51.85° N / 8.40° W Cork	153 m	01.04.1962 - 31.05.1996

3. Statistical Tests

Initial estimates of the trends in the mean annual precipitaion were determined using a low pass filter (moving average, MA).

$$MA_t = \frac{1}{2 \cdot L}\left(\frac{1}{2}\cdot x_{t-L} + \sum_{j=-(L-1)}^{L-1} x_{t+j} + \frac{1}{2}\cdot x_{t+L}\right) \qquad (1)$$

The figures for the annual precipitation data and the 10 year moving average (L=5) are shown in Figure 1.

An approximation for continuous data of the non-parametric Pettitt-Mann-Whitney-Test (Pettitt,1979) was used to identify a change-point in the time series (annual, half-yearly, quarterly and monthly) and is briefly described in the following.

The time series (length T; $x_1, \ldots, x_T$) is considered as two samples represented by $x_1, \ldots, x_t$ and $x_{t+1}, \ldots, x_T$. The indices V(t) and U(t) are calculated from :

$$V_{t,T} = \sum_{j=1}^{T} \mathrm{sgn}(x_t - x_j) \qquad (2)$$

$$U_{t,T} = U_{t-1,T} + V_{t,T} \qquad for\ t = 2,T \qquad (3)$$

where $U_{1,T} = V_{1,T}$ and

sgn(x) = 1 for x>0

sgn(x) = 0 for x=0

sgn(x) = -1 for x<0

The most significant change-point is found where the value $|U_{t,T}|$ is maximum:

$$K_T = \max |U_{t,T}| \qquad (4)$$

The approximate significance probability *p(t)* for a change-point is :

$$p(t) = 1 - \exp\left(\frac{-6 \cdot U_{t,T}^2}{T^3 + T^2}\right) \qquad (5)$$

We computed the probability for a change-point for all time series of each site (altogether 152 time series) and determined the year with the most significant change-point. The results for Valentia are shown in Table 2. Time series including a change-point with a significance probability >0.90 are marked in bold table 2.

The results of the Mann-Whitney-Wilcoxon Test for Valentia are also included in Table 2. This statistic allows us to test the hypothesis that the means of two samples are equal. The hypothesis of equal means is rejected if :

$$|Z_c| > u_{1-\alpha/2} , \qquad (6)$$

where $u_{1-\alpha/2}$ is the '*1-α/2* quantile' of the standard normal distribution (we choose the significance level $\alpha = 0.05$).

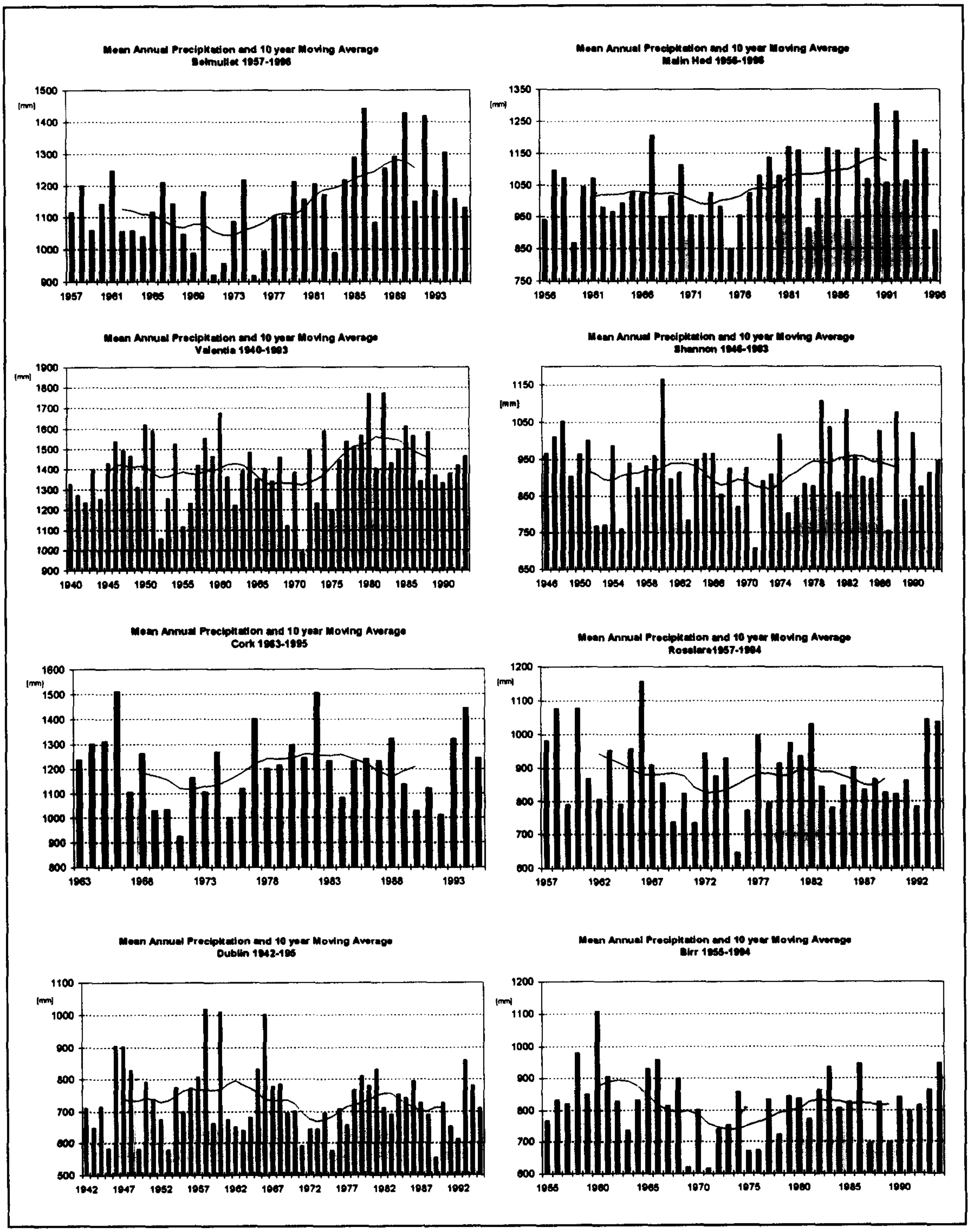

Fig.1 : Mean monthly precipitation and 10 year moving average

The index Z_c is calculated as follows :

$$Z_c = \frac{w - \frac{n \cdot (T+1)}{2}}{\sqrt{\frac{n \cdot (T-n) \cdot (T+1)}{12}}} \tag{7}$$

To compute the variable w the single time series (n elements) is divided into two new partial-series with the elements : $[x_1, \ldots, x_m]$ and $[y_1, \ldots, y_{n-m}]$. Each of these two time series should contain at least eight elements (Mann and Whitney, 1947). The variable w is the sum of the ranks $r(x_i)$ of the elements of first partial series $[x_1, \ldots, x_m]$ in a new series j which is defined by rearranging the elements of both partial series (x and y) in increasing order.

$$w = \sum_{i=1}^{m} r(x_i) \tag{8}$$

The 'cumulative sum technique' (Page, 1954,1955 and McGilchrist 1975) can also be used to detect changes in the mean value of a sequence of observations ordered in time, but has shortcomings if the time series contains obvious outliers.

$$S_i = \sum_{i=1}^{i} (X_i - k) \tag{9}$$

We computed the cumulative sum for the time series and the results confirm the change points which were detected with the Pettitt-Mann-Whitney and the Mann-Whitney-Wilcoxon Test. In these calculations k was chosen to be the average of the time-series. Using this technique the hypothesis of no change in the mean value is rejected if $\max_i |S_i|$ becomes too large.

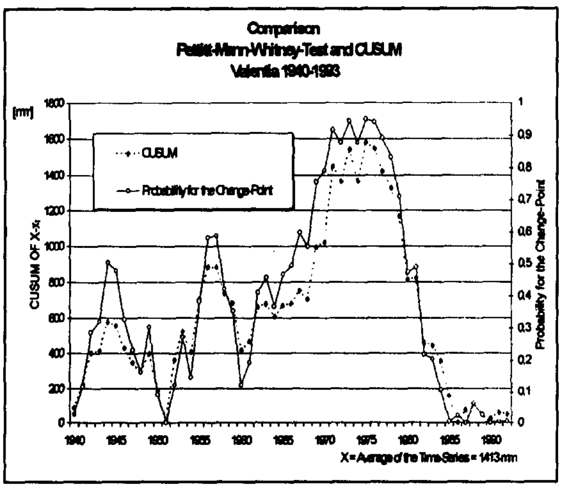

Fig. 2. Results of the Pettitt-Mann-Whitney-Test (probability for the change-point) and the Cusum for the annual precipitation at Valentia

An example of the cumulative sum and the approximate significance probability (equation (5)) for the change-point for Valentia is shown in Figure 2.

Table 2.1. Results of the Pettitt-Mann-Whitney Test (year, shift up (u) / shift-down (d), probability of the change-point) and the Mann-Whitney-Wilcoxon Test (year including a change-point)

Site / Time-Series	Valentia	
	Pettitt	Wilcoxon
Annual	**75 - u - .949**	**1971-1978**
JAN - JUN	**71 - u - .900**	--
JUL - DEC	75 - u - .776	--
JAN - MAR	**71 - u - .971**	--
APR - JUN	57 - u - .520	--
JUL - SEP	79 - u - .333	--
OCT - DEC	**75 - u - .907**	--
January	68 - u - .440	no
February	65 - u - .710	no
March	**75 - u - .990**	**73,75,76**
April	70 - d - .641	no
May	86 - d - .461	no
June	75 - u - .520	no
July	64 - d - .695	no
August	77 - u - .614	no
September	83 - d - .400	no
October	**74 - u - .869**	**74**
November	58 - u - .369	no
December	75 - u - .669	no

4. Results and discussion

The figures of the moving average (see Figure 2) show an increase of the annual precipitation for the three meteorological stations – Valentia, Malin Head and Belmullet - situated at the West and North coast of Ireland since the mid 1970's. For the stations Valentia, Belmullet and Malin Head this increase is highly significant. For the stations Shannon, Dublin and Cork the moving average is nearly constant in the observed periods. The annual precipitation at the meteorological stations Birr and Rosslare seems to decrease, but this change is not as clear as the increase observed on the West coast sites.

Yearly Time Series

The results of the Pettitt-Mann-Whitney Test and the Mann-Whitney-Wilcoxon Test confirm these changes in the annual series. We determined change points at the stations Valentia, Malin Head and Belmullet. The approximate significance probability for a change-point varies from 0.949 at Valentia up to 0.989 at Belmullet. The change points are found in the second half of the seventies (Valentia 1975, Malin Head 1977, Belmullet 1978).The increase in mean annual precipitation for the post change point years is: 9.65% for Valentia, 9.95% for Malin Head and 12.97% for Belmullet Applying the Mann-Whitney-Wilcoxon Test change points are found for the same stations in the same period.

For all the other stations (Dublin, Rosslare, Cork, Shannon and Birr) the computed significance probability is less than 0.90 for the annual values. The high number of possible change points determined with the Mann-Whitney-Wilcoxon Test (e.g. 13 for Belmullet, 1976-1988) and the graph of the significance probability computed with Pettitt-Mann-Whitney-Tests (Figure 3) show that with these tests a period of several years is determined as the 'change period in precipitation' and not a single year.

Half-yearly Time Series

Considering the half-yearly values (January-June, July-December) we obtain change points for the same three west coast stations – Valentia, Malin Head and Belmullet - which show a change in the mean annual precipitation. All these stations show a change (an increase) for the time-series 'January-June' and at the station Belmullet both half-yearly time series show a change-point (increase). A decrease is determined in the time series (July-December) at the meteorological Station Birr. The change point is in 1968 and the corresponding significance probability is 0.941.

Quarterly Time Series

Applying the statistical tests to the quarterly time series we identified a change-point (increase) for four stations (Valentia 1971, Malin Head 1976, Belmullet 1987 and Shannon 1973) in the first quarter of the year. No time-series for the second and third quarter (April-June, July-September) shows a change-point. Considering the last quarter of the year again three stations show a change-point (increase): Cork 1975, Belmullet 1976 and Valentia 1975. A decrease was not found in any of the quarterly time series.

Monthly Time Series

As we found out so far, the change in the precipitation is not distributed uniformly over the year and not uniformly over Ireland. An increase was only found in the first and last quarter of the year. By analysing the monthly time series we can determine if the change is not only concentrated in particular seasons (autumn and winter) but also in particular months.

In March six of the eight stations, namely: Valentia (1975); Shannon (1977); Belmullet (1975); Malin Head (1977); Dublin (1975) and Birr (1976), show a change-point in the monthly series. For all these meteorological stations the approximate significance probability for a change-point in March is greater than 0.93. The monthly increases for march are: Valentia (up by 52.6%), Shannon (up by 48.3%), Belmullet (up by 49.3%), Malin Head (up by 50,7%), Dublin (up by 28.3%) and Birr (up by 43.1%).

By analysing the results for the other months, it becomes obvious that the increase in the annual precipitation since

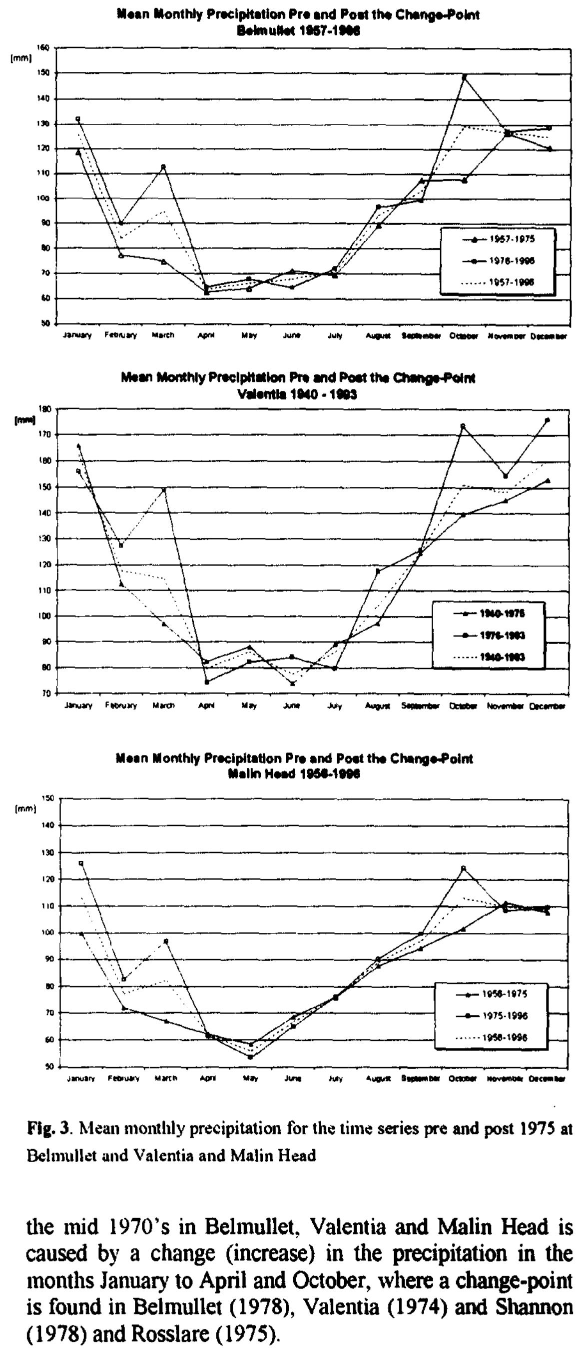

Fig. 3. Mean monthly precipitation for the time series pre and post 1975 at Belmullet and Valentia and Malin Head

the mid 1970's in Belmullet, Valentia and Malin Head is caused by a change (increase) in the precipitation in the months January to April and October, where a change-point is found in Belmullet (1978), Valentia (1974) and Shannon (1978) and Rosslare (1975).

A decrease in monthly time-series is only determined for Rosslare in July (1973), Dublin in September (1976) and Malin Head in May (1986). The change in the spring and winter is more distinct for the stations on the West-coast and North-coast than for those on the East-coast. Figure 3 presents the mean monthly precipitation for three stations situated at the West-coast (Belmullet, Malin Head and Valentia). In this figure the different changes during the year become clearly visible. These stations show significant increases in the spring (February and March) and in October.

5. Conclusions

In this work we found change points in the precipitation for all sites. The change points are concentrated in the mid seventies. Analysing the monthly time series we found the highest change in the months March and October. The change is more significant for the sites on the west cost (Valentia, Belmullet, Malin Head) than for those in the east coast. Analyses from Cork and Rosslare do not show the same trends as the Western sites. This may be due to the short time series (1962-1996). This work confirms findings by others (Smith, 1995; Bardossy and Caspary 1990, Schoenwiese 1990,1993) that the precipitation increases in Northern Europe since the mid 1970's. Bardossy and Caspary (1990) found that changes in the European atmospheric circulation patterns since the 1970's are leading to a more frequent mild and humid climate in Northern Europe. Investigations of the Scottish precipitation characteristics by Smith (1995) show that thelargest sustained anomaly in the records since 1757 is the 1980's and 1990's.The analyse of the Schoenwiese (1993) and Smith (1995) show that these trends can not only be observed in a short run (the last four or five decades) but also that the increase can be regarded as unusual even in the context of long-runs (100 to 250 years).

As a next step changes in the variability of the precipitation (changes in the occurrence and intensity) and the extreme-events should be analysed (Katz and Brown 1992) to give a complete description of the change in the precipitation during the last decades.

Future work will consider the relevance of atmospheric circulation patterns to the changes identified in this paper. In addition, the most significant changes have occurred in the months of March and October, we will investigate the relevance of Spring and Autumn solstice to the changes identified.

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