06 - PRODUCTION OF OPERATIONAL CLIMATE EXTREME INDICES PRODUCTS AT MET ÉIREANN

Seánie Griffin[1] and Keith Lambkin[1]
[1] *Climate Services Division, Met Éireann, Dublin, Ireland*

Abstract
The newly established Climate Services Division at Met Éireann aims to provide relevant and up-to-date climate products to stakeholders and policymakers to aid in their decision making. One such area is the production of operational climate monitoring indices based on long term records in Met Éireann's national climate archive.

The United Nations backed global international Expert Team (ET) on Climate Change Detection and Indices (ETCCDI) formulated a list of 27 core climate indices. These are based on daily values of max/min temperature and precipitation. These indices are used to highlight and identify the occurrence of climate extremes, which can then be used to assess for any potential trends in these events. Many of the precipitation indices are relevant to hydrology, such as total annual precipitation (PRCPTOT), maximum number of consecutive wet days (CWD) and dry days (CDD). An analysis of recent trends in these indices, based on Met Éireann's digital records, will be presented. These results will be compared to recent publications in this area, including analyses of global trends in these indices and also in the area of data rescue and homogenisation in Ireland, where time series have been extended back to the start of the previous century.

Another climate index with direct applications to hydrology is the Standardized Precipitation Index (SPI) which presents month and multi-month rainfall anomalies in a standardized format. The production of monthly SPI maps has been developed, based on gridded observations of monthly aggregated rainfall, and are being produced operationally in Met Éireann. These offer the ability to spatially assess up-to-date information about current conditions, as well as past periods of both drought and excess rainfall.

With the ongoing modernisation and automation of Met Éireann's observing network, an outline will be given on future plans to also operationally produce maps of the Standardized Precipitation-Evapotranspiration Index (SPEI). As a greater number of automated temperature measurements are expected to become available, the production of such maps in near real-time will become possible. The temperature component of the SPEI enables the end user to capture the potential impact of additional evapotranspiration due to warming temperatures.

1. INTRODUCTION

Climate indices offer a concise method for summarising climate variability and climate change. Two such sets of these indices which have potential hydrological applications are the ETCCDI indices and a drought-monitoring index called SPI. The ETCCDI indices are a collection of temperature and precipitation indices, which summarise the occurrence of climate extremes. The rainfall indices monitor values of total precipitation, the occurrence of extreme rainfall events and prolonged wet/dry spells, which would be relevant for hydrology. Meanwhile the SPI statistically relates a given observed rainfall accumulation to the historical distribution of values for that time of year. Both ETCCDI indices and SPI are currently being operationally produced and updated at Met Éireann.

The ETCCDI (Expert Team on Climate Change Detection and Indices) was a UN-backed working group which formulated a list of 27 core indicators for monitoring climate extremes and their associated trends. Global analyses of gridded versions of these indices have highlighted the widespread warming trends found across most of the global landmass (Dunn et al., 2020). This is seen for a large variety of temperature indices, from decreases in the number of frost days to an increasing frequency of warm events. Trends in rainfall indices are less spatially uniform but some areas of the globe are indicating trends for greater frequency of heavy rainfall events and total precipitation. The Climate Status Report of Ireland 2020, which was recently published by Met Éireann, Marine Institute and EPA, highlighted trends being observed in Ireland, (Cámaro García and Dwyer, 2021), including a 6% increase in annual precipitation, when comparing the 30-year period of 1989–2018 to 1961-1990. Some results from the calculation of the 27 core indices are Met Éireann's synoptic weather stations are presented here, with a particular focus on rainfall.

The primary drought monitoring index calculated currently at Met Éireann is the Standardized Precipitation Index (SPI). This is a simple index which considers rainfall anomalies on different timescales and contextualises the current conditions based on the distribution of past values. It is a widely used methodology for monitoring current drought events and studying past droughts (Noone et al., 2017, Falzoi et al., 2019). These indices are being calculated and updated on a monthly basis at Met Éireann using gridded values of monthly precipitation.

The following sections provide an overview of the data and methods used to calculate these indices, along with an outline of some results from the production of these indicators.

2. DATA & METHODS

2.1 Data

The data used to calculate the indices outlined here come from different aspects of Met Éireann's observing network and climate database. This includes the 25 synoptic weather stations, shown in Figure 1 (left). These stations are automated and operated by Met Éireann. Data from these stations are stored in Met Éireann's national climate archive and can go back as far as 1941. Values of daily maximum and minimum temperature and daily total precipitation are available in near real-time and are used for calculating and updating the ETCCDI core climate indices.

Beyond these stations, Met Éireann also has a network of rainfall stations. This is a dense network of over 450+ stations and are mostly operated by voluntary observers. While this a fantastic resource, it comes with significant delays. Observations for a given month are often filled in by hand and physically posted to Met Éireann, where they need to be manually quality controlled before being added to the climate database.

Gridded datasets are an additional resource for climate analysis and are produced operationally at Met Éireann once a year at monthly resolution and are published on the Met Éireann website (Met Éireann, 2022a). To bridge the gap to produce near real-time products, contingency measures have been put in place whereby a small subset of climate observers send in their observations electronically. This provides enough data for members of the Climate Services team to produce "provisional rainfall grids" for the most recent months. These data are used as input to calculate the values of the Standardized Precipitation Index (SPI) at Met Éireann.

An ongoing piece of work at Met Éireann is the Climate Automation and Modernisation Project (CAMP), which has installed automated temperature and rainfall sensors at 78 locations around Ireland, Figure 1 (right). These data are expected to become operationally available to the Climate Services team in Met Éireann in the near future. Combining these with the 25 synoptic stations, will improve the capacity to produce near real-time climate products, such as provisional rainfall and temperature grids.

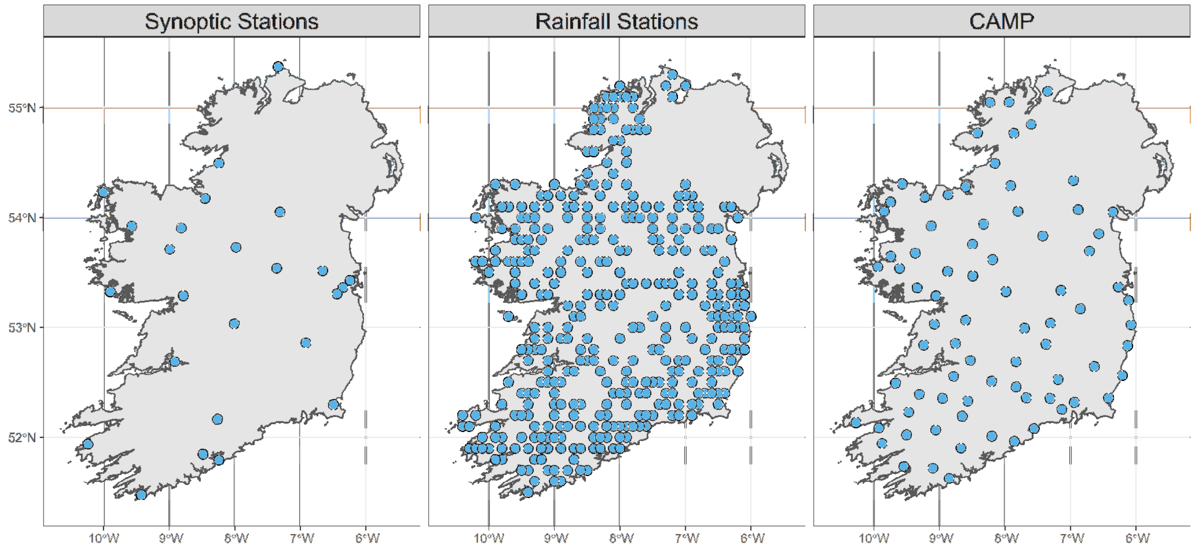

Figure 1: *Locations of (left) synoptic, (centre) manual rainfall and (right) CAMP stations in the Met Éireann surface observing network.*

2.1 ETCCDI Indices

The 27 core ETCCDI indices are being operationally calculated at the 25 synoptic stations in Ireland and are available for download through the Met Éireann website. They are based on daily observations of temperature and rainfall (taken from 09-09UTC), with 16 temperature-based indices and 11 precipitation indices. The full set of 27 indices are calculated on an annual basis and a subset of 20 indices are also calculated for monthly and seasonal values.

Temperature indices use daily minimum temperature (TN) and/or maximum temperature (TX). They are made up of annual max/min values, fixed and percentile-based threshold exceedances, prolonged warm/cold spells and the length of the growing season. Precipitation indices focus on annual total precipitation, fixed and percentile-based threshold exceedances, annual maximum 1-day and 5-day rainfall events and prolonged spells of wet/dry weather.

2.1 Standardized Precipitation Index

The primary drought monitoring index calculated currently at Met Éireann is SPI. It considers rainfall anomalies on different timescales and contextualises the current conditions based on the distribution of past values. The method involves fitting a gamma distribution to the historical data; then transforming the distribution and the observation of interest to a unit-normal distribution (mean of zero, variance of one). This results in a unitless index centred on zero, which captures the magnitude of the anomalies at a given location. The accumulation period considered typically varies from 1-24 months, with different potential applications for each index, from surface water runoff to groundwater recharge for shorter and longer accumulations respectively. These indices are calculated using gridded monthly rainfall data, as described earlier, which has been aggregated to catchment averages for each river catchment in the country.

3. RESULTS

3.1 ETCCDI Indices

For temperature-based indices in the ETCCDI suite, the signal is consistent across most indices and locations. This is shown for the four percentile-based temperature indices at Valentia Observatory, Figure 2. The rate of exceeding the climatological 90th percentile ("warm nights/days") is increasing for both TN and TX. Conversely the rate of falling below the climatological 10th percentile ("cold nights/days") is decreasing in both cases. Warming trends are also seen for the other temperature indices, with reductions in the number of frost days, longer growing seasons and increases in annual maximum and minimum values of both TN and TX (not shown).

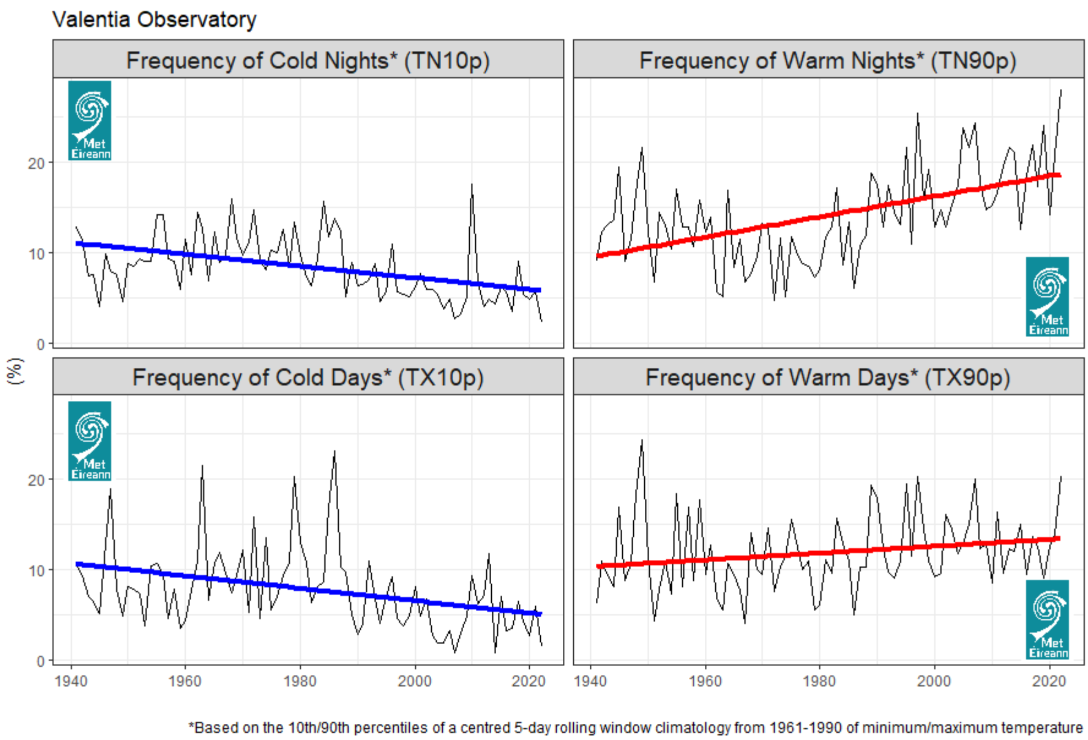

Figure 2: *Annual time series of TN10p, TN90, TX10p and TX90p indices at Valentia Observatory with linear trendlines overlaid.*

While the results for temperature are broadly uniform and consistent in space, the same cannot be said for precipitation indices. Time series of rainfall indices are dominated by large amounts of year-to-year variability, making assessments of trends more uncertain.

The PRCPTOT index (annual total precipitation on "wet days") is one of the indices which has some regional variations to its trends, Figure 3(a), with increasing rainfall at western coastal locations and more uncertainty for inland and eastern stations. The recently published Climate Status Report of Ireland 2020 found a 6% increase in overall total precipitation in recent years compared a past climatological period, (Cámaro García and Dwyer, 2021), and these increases are mostly concentrated at these western coastal stations and are more prominent in winter (not shown here).

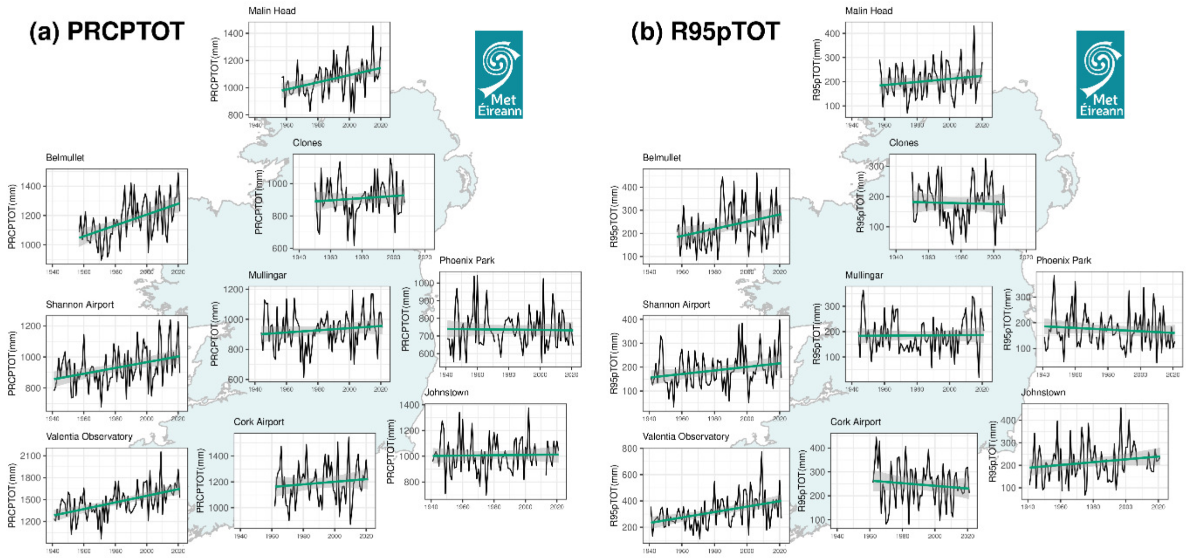

Figure 3: *Annual time series of (a) PRCPTOT and (b) R95pTOT indices at 9 stations overlaid on a map of Ireland.*

Studies in the area of data rescue and homogenisation also highlight the challenges of assessing trends in Irish rainfall. The rescue and homogenisation of monthly rainfall totals back to 1850 and early 1700s both highlighted a predominant increasing trend in winter precipitation and decreases in summer rainfall, (Noone et al., 2016, Murphy et al., 2018). The statistical significance of these trends were found to be dependent on the choice of start and end points of the time series. The reductions in summer rainfall that were observed for these longer series are not seen in the shorter digitized records presented here.

Similarly, a recent study on data rescue of daily observations dating back to the start of the 20th century found that while an increasing trend in PRCPTOT was apparent at the majority of stations analysed, the statistical significance of these trends reduced when the time series was extended to the start of the century, compared to the current digitized record, (Ryan et al., 2021).

Even more variability is found for threshold-based rainfall indices. Similar trends are seen for events of moderate-heavy intensity, shown in Figure 3(b) for R95pTOT (accumulated rainfall on days that exceed the 95th percentile of daily rainfall) as well as R5mm and R10mm, with increases observed for western coastal locations. However the most extreme single day rainfall events, R20mm (days with

>20mm rain), Rx1day (annual maximum 1-day rainfall) and R99pTOT (accumulated rainfall on days that exceed the 99th percentile of daily rainfall) are much more uncertain, with a lack of statistically significant trends for these indices at almost all stations considered in the digitized records.

The aforementioned study on data rescue of daily observations also found an increasing trend for heavy rainfall events in the midlands and southeast of the country, (Ryan et al., 2021). These particular stations are not part of the digitized record of synoptic stations and further research will be needed to investigate this area further.

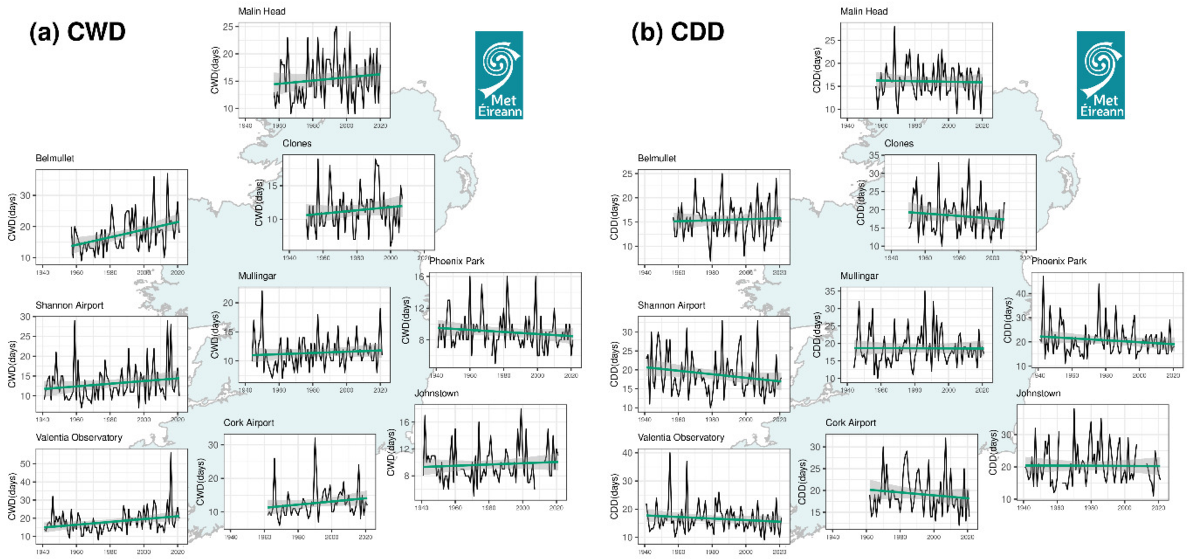

Figure 4: *Annual time series of (a) CWD and (b) CDD indices at 9 stations overlaid on a map of Ireland.*

Extreme prolonged rainfall events are also very relevant for the hydrology sector and can be considered using the annual maximum number of consecutive wet days (CWD) and consecutive dry days (CDD) indices. The CWD has increased at some western stations, Figure 4(a), though the statistical significance of these trends are generally low. The largest value of CWD occurred at Valentia Observatory between the 23rd of November 2015 and 17th of January 2016, a period of 56 consecutive days with at least 1mm of rain. Prolonged dry spells generally lack any clearly defined trends, Figure 4(b). The largest value for CDD occurred at Oak Park (Carlow) between the 12th of August 1972 and 29th of September in 1972, a period of 49 consecutive days with less than 1mm of rainfall recorded.

Due to the large degree of spatial variability in precipitation indices, planned future work in this area will include the calculation of these indices using gridded daily rainfall data (in development).

3.2 Standardized Precipitation Index (SPI)

The Standardized Precipitation Index is being operationally calculated for 37 river catchments (5 of which are border catchments, where the area north of the border has been excluded from the analysis). Gridded monthly rainfall data (a combination of published and "provisional") on a 1km x

1km grid over the country is used to calculate catchment average rainfall for 1941-present. This is then used to calculate the 6 SPI values, which can be displayed as a map plot for a snapshot in time, as in Figure 5, or as a time series for a given catchment, as in Figure 6.

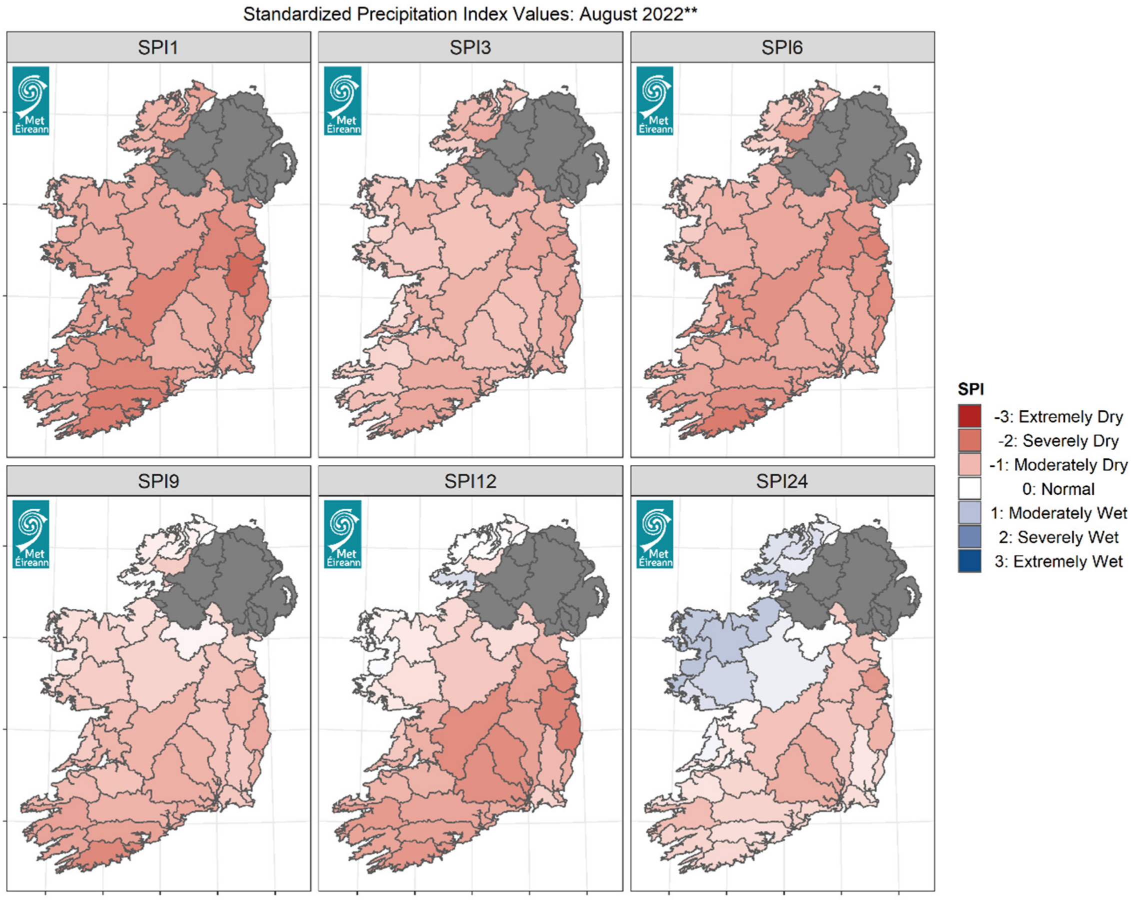

Figure 5: Maps of catchment-averaged SPIs (SPI1-SPI24) for August 2022.

The summer of 2022, and more broadly the year of 2022 as whole, was associated with below average rainfall. All SPI indices out to SPI12 had negative values at the end of August 2022 indicating shortfalls in precipitation across many timescales. Ultimately the magnitude of these negative anomalies was kept within a manageable range during the summer by timely rainfall events near the end of each month. This is shown in Figure 7 at Phoenix Park in Dublin and Sherkin Island in Cork. All three months of the summer (June-August) contained prolonged spells of low rainfall. The months of June and July were punctuated by spells of rain at the end of both months. Meanwhile the moderate deficits observed at the end of August, shown in Figure 5, were then reduced by rain at the start of September at both locations and across the country, Figure 7.

This past summer did not exceed the rainfall deficits that had been previously observed during the heatwave of June/July 2018 or the dry period during spring 2020, Figure 8 and 6, where values for SPI3 exceeded -2 and almost reached -3. The July 2018 values were also accompanied by heatwave conditions, which likely exacerbated the drought conditions and caused a great deal of impacts to society (Falzoi et al., 2019).

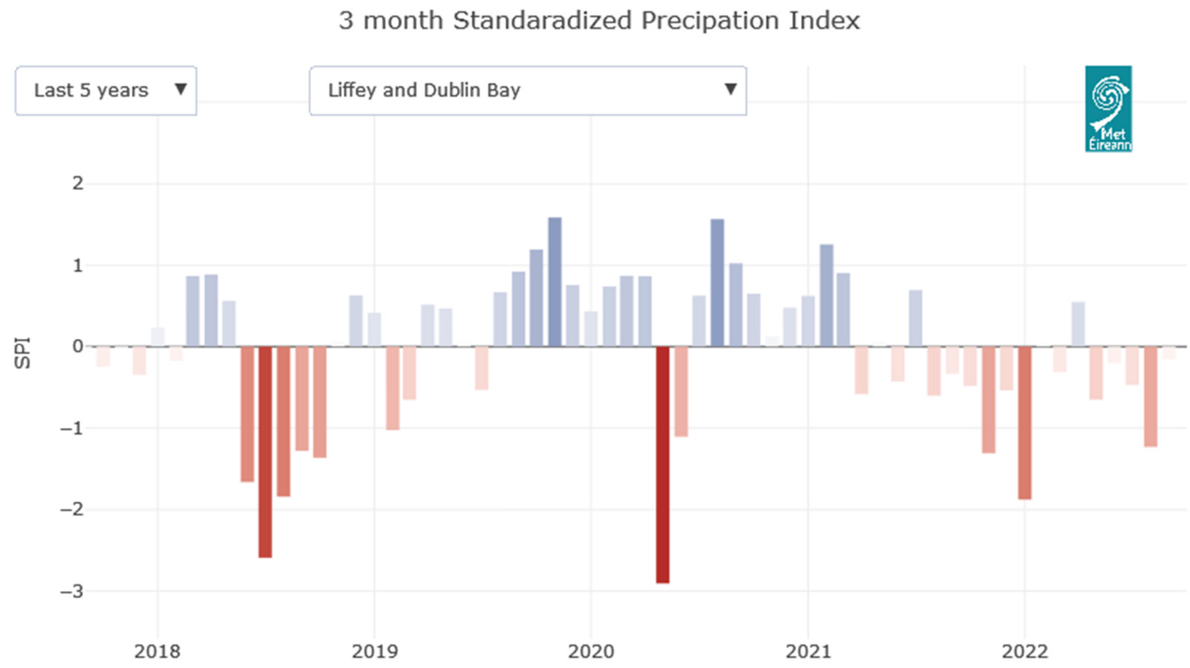

Figure 6: *Time series of SPI3 values for the Liffey-Dublin Bay catchment for 2018-2022.*

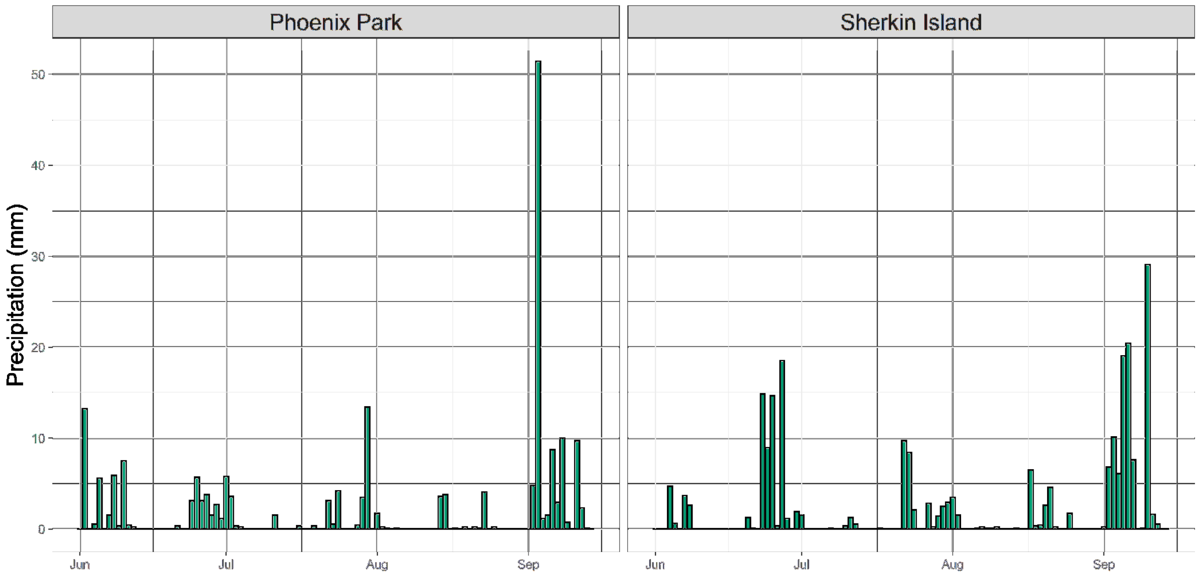

Figure 7: *Daily rainfall totals at (left) Phoenix Park and (right) Sherkin Island for June-September 2022.*

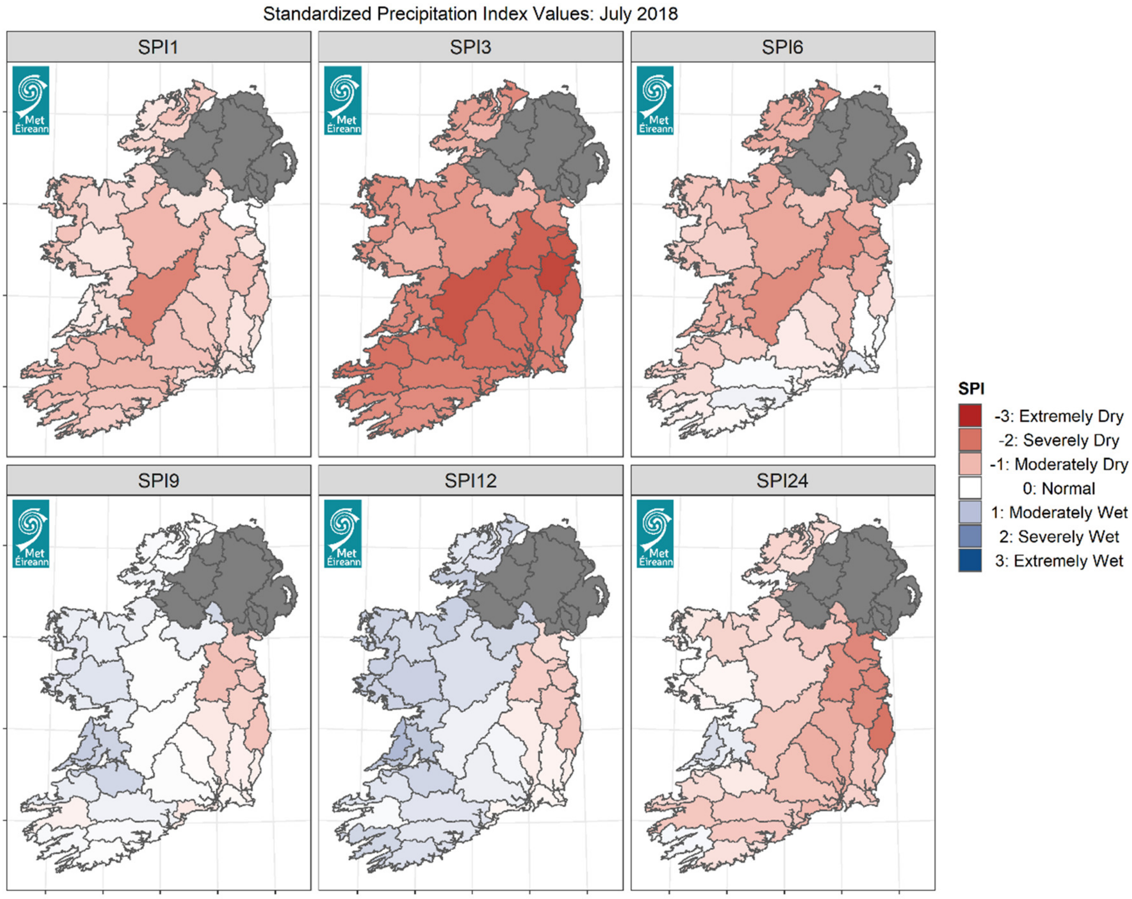

Figure 8: *Maps of catchment-averaged SPIs for July 2018 drought event.*

4. CONCLUSIONS

An overview was given of two operational products that have been recently developed at Met Éireann in the area of climate indices. The ETCCDI indices are a suite of climate indicators, quantifying the occurrence of climate extremes in Met Éireann's digitized national climate archive. This is being operationally produced, updated once a month and is freely accessible by the public, (Met Éireann, 2022b). Analysis of trends has found that temperature-based indices exhibit a consistent warming trend throughout, with a decrease in the severity and frequency of cold extremes and, conversely, an increase in the frequency of warm extremes. For precipitation indices, recent increases have been observed in total precipitation and some threshold-based indices at locations along the west coast. There is more uncertainty associated with trends in precipitation indices compared to temperature, and recent studies in the area of data-rescue highlight the importance of extending the time series beyond the current period of Met Éireann digitized archive to gain greater insight in this area, (Noone et al., 2016, Ryan et al., 2021).

In terms of drought monitoring, a spatial SPI product has been developed using gridded rainfall observations from 1941-present. Catchment-averaged rainfall from these gridded datasets are used to calculate SPIs. These data are updated on a monthly basis and can be made available to interested users. In the summer of 2022, timely spells of rain helped to avoid any major drought events, in comparison to more severe events such as July 2018 and May 2020.

4.1 Future Work

The use of high-resolution gridded daily rainfall datasets will be useful for assessing the spatial variability seen in the ETCCDI indices. These datasets are under development at Met Éireann currently and the aim is to produce gridded indices in the near future. This will highlight where the statistically significant trends in annual totals occur, see Figure 3(a), and also to investigate the increasing trends in heavy rainfall events in the southeast, which has been found in other studies (Ryan et al., 2021).

The data that will be made available through CAMP, highlighted earlier Figure 1 (right), will provide a better workflow to produce provisional rainfall grids for the production of current SPI values. Additionally, the temperature data from CAMP could also be used to generate provisional temperature grids which would enable the production of near real-time maps of the Standardized Precipitation-Evapotranspiration Index (SPEI), an additional drought index which incorporates the impact of temperature on the severity of drought events. This index would particularly be useful for droughts which occur in combination with heatwaves, such as July 2018 shown in Figure 8.

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