Rialtas na hÉireann
Government of Ireland

Met Éireann

Summer 2018

An Analysis of the heatwaves and droughts that affected Ireland and Europe in the summer of 2018

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1. Introduction

In Ireland, the current definition of a heatwave is classified as five consecutive days with a maximum temperature in excess of 25°C. Heatwaves occur in summer when high pressure develops over the country. High pressure systems, also known as anticyclones, can be slow-moving and persist for a prolonged period of time, resulting in dry and settled weather. In anticyclones, strong subsidence, where cool air descends from aloft and diverges outwards at lower levels, leads to strong warming of the mid and lower levels of the atmosphere. The subsidence also supresses the formation of clouds and rain. When an anticyclone materialises over Ireland, the jet stream is usually located to the north of Ireland, keeping low pressure systems away.

Different air masses affect Ireland at different times of the year and this has a major impact upon the weather we experience in this country. The Tropical Continental air mass, which can originate over North Africa, is the least frequent air mass affecting Ireland and is most common in summer. Although the lower layers of this air mass are usually quite stable, unstable upper layers may give rise to severe thunderstorms. Its low humidity tends to bring us clear skies and long periods of sunshine. The highest temperatures experienced in Ireland usually occur under the influence of this air mass giving maximum temperatures in excess of 30°C.

Ireland only experiences occasional heat waves compared to other European countries. In August 1976, Birr, Co Offaly recorded heat wave conditions lasting 14 days (the maximum temperature recorded at that station during this event was 28.2°C (8.9°C above its Long Term Average (LTA))). More recently, heat wave conditions occurred in the summers of 2018, 2017, 2013, 2006, 2003, 1995, 1989 and 1983.

Droughts can be classified into four types, "meteorological (1–3 months), defined on the basis of rainfall deficiency; agricultural (1–6 months), when soil moisture is insufficient and results in a lack of crop growth and production; hydrological (6–24 months), when there is a lack of water in the hydrological system; and socio-economic, when the demand for water exceeds the supply" *(Falzoi et al., 2019).* In Ireland there are three different meteorological drought classifications; A dry spell is a period of 15 or more consecutive days with daily precipitation of less than 1 mm. An absolute drought is a period of 15 or more consecutive days with daily precipitation less than 0.2 mm. A partial drought is a period of at least 29 consecutive days with a rainfall total averaging less than 0.2 mm of rain per day *(Murphy, 2020).*

During June and July 2018, Ireland experienced a prolonged spell of hot, sunny weather, associated with blocking high pressure conditions, which steered a weakened jet stream and Atlantic low pressure systems away to the North. The abnormally high temperatures and low rainfall amounts led to drought conditions. These conditions were also experienced in much of Northern and Western Europe.

This report describes and analyses the meteorological drought conditions and the warm weather spell of Summer 2018, which affected Ireland and Northwestern Europe. It also examines the widespread impacts on agriculture, ecosystems and infrastructure and outlines the attribution of this particular extreme weather event to climate change.

2. Event Evolution

This section of the report will describe the synoptic situation for each of the summer months and the summer as a whole. It gives an overview of the meteorological conditions that led to the dry and fine weather in Ireland during much of the summer.

2.1 Summer Synoptic Setup and summary

The summer of 2018 will be remembered in Ireland for the heatwaves and droughts that affected the country during June and July especially. The fine weather persisted for much of august in the South and East, whereas the North and West had a more average month. Intense thunderstorms were also a feature at the start of the meteorological season. Temperatures were above normal and rainfall amounts were below normal at most stations. Large blocking high pressure systems were the dominant feature of the summer. This kept the north Atlantic jet stream to the north of Ireland. In between the dry settled spells and especially during August a weak jet stream moved south over Ireland, with frontal troughs and showers crossing the country from time to time. However most of the rain fell in the north and west of the country.

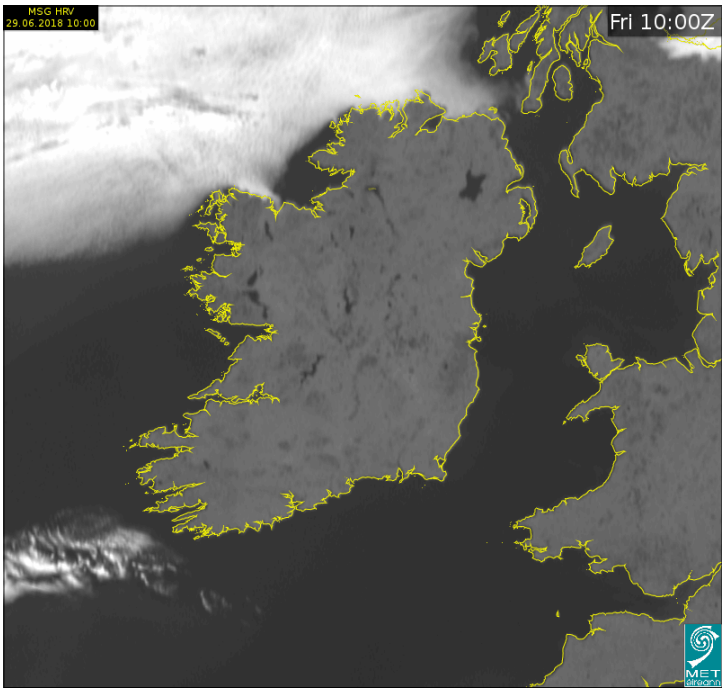

Figure 1 Meteosat Visible Satellite 29th June *(Meteosat Visible Satellite, 2018)*

2.2 June Synoptic Setup and summary

There were intense thunderstorms especially on the 1st and 8th June, but in general the dry, settled weather from the end of May continued for the first two weeks of June with high pressure in charge in a slack easterly flow. The north Atlantic jet stream stayed well to the north. There was a break in the fine weather for the third week of the month. Storm Hector passed close to the Northwest, giving two days of rain and gales on the 13th and 14th followed by frontal systems crossing the country from the west up to the 20th. Even during this unsettled spell, rainfall totals were very low especially in the

Figure 2 Dog's Bay, Galway, summer 2018 *(Moore, 2018)*.

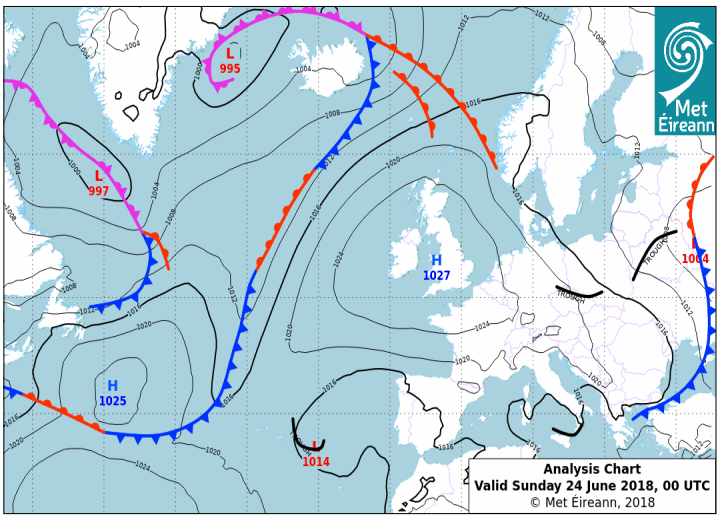

Figure 3 Surface analysis 00UTC 24th June 2018 *Met Éireann*

South and East. From the 21st, the remainder of the month was settled and exceptionally dry due to an area of high pressure building over Ireland. Heat wave and partial drought conditions were reported in several locations.

Sunshine

The highest daily sunshine for June 2018 was 16.5 hours at Malin Head, Co Donegal on the 28th. A value of 16.0 hours was recorded at Knock Airport on the 24th June, its highest daily value since the station opened in 1997. All stations had above average sunshine for June. Percentage of monthly sunshine values ranged from 139% (monthly sunshine total of 200.6 hours) at Knock Airport, Co Mayo to 160% (monthly sunshine total of 256.6 hours) at Casement Aerodrome, Co Dublin. Monthly sunshine totals for June were highest at Johnstown Castle, Co Wexford with 279.9 hours. *(Past Weather Statements - Met Éireann - The Irish Meteorological Service, 2020)*

The warmest period of the summer

On June 21st, an area of high pressure was centred to the west of Ireland, bringing a northwesterly air flow across the country. In the days that followed, the high pressure system intensified and drifted over, and then just to the east of Ireland drawing up a very warm tropical continental air mass from the southeast. This setup brought the warmest weather of the season, with the highest maximum temperature of 32.0°C recorded at Shannon Airport, Co Clare (13.7°C above its LTA) on the 28th. Over three days, 27th, 28th and 29th, five stations in counties Clare, Tipperary, Roscommon, Galway and Mayo recorded maximum screen air temperatures over 30°C. On the 27th, Shannon Airport recorded 30.8°C (12.5°C above its LTA) and Mount Dillon, Co Roscommon recorded 30.5°C (12.4°C above its LTA). On the 28th, Shannon Airport (mentioned above), 30.3°C was recorded at Mount Dillon, Co Roscommon (12.2°C above its LTA), 30.2°C was recorded at both Claremorris, Co Mayo (12.7°C above its LTA) and at Athenry, Co Galway (12.2°C above its LTA) and 30.1°C recorded at Moore Park, Co Cork (11.8°C above its LTA). On 29th June, Shannon Airport, Co Clare and Gurteen, Co Tipperary recorded temperatures above 30°C with a temperatures of 31.1°C (12.8°C above its LTA) and 30.1°C (11.8°C above its LTA) respectively. The highest (minimum) night-time temperature was 18.8°C recorded on the 29th at Mace Head, Co Galway (8.1°C above its LTA). *LTA : Long-Term-Average period 1981-2010 (30 Year Averages - Met Éireann - The Irish Meteorological Service, 2020).*

DECADE	TEMPERATURE	STATION	DATE
1940's	30.3°C	Shannon Airport, Co Clare	29th July 1948
1950's	29.8°C	Valentia Observatory, Co Kerry	24th August 1955
1960's	29.6°C	Moore Park, Co Cork	15th July 1969
1970's	32.5°C	Boora, Co. Offaly	29th June 1976
1980's	32.2°C	Oak Park, Co Carlow	14th July 1983
1990's	31.5°C	Oak Park, Co Carlow	2nd August 1995
2000's	32.3°C	Elphin, Co Roscommon	19th July 2006
2010's	32.0°C	Shannon Airport, Co Clare	28th June 2018

Table 1 Highest maximum temperatures per decade since the 1940's (Values prior to 1961 are limited to Synoptic stations, after 1961 the network increased to include climate stations)

2.3 July Synoptic Setup and summary

High temperatures and drought conditions, most prolonged in the East and South, were also experienced during July. The first half of the month was characterised by a large area of blocking high pressure stretching from the Azores to Scandinavia pushing the north Atlantic Jet Stream well to the north away from Ireland. This gave dry and very warm conditions with a lot of sunshine and light variable winds, with heat wave conditions continuing for a few days at the beginning of the month. For the second half of the month, up to the 26th, pressure stayed relatively high, but Atlantic weather fronts broke through on some occasions, giving somewhat cooler conditions with some rain at times to Western and Northern areas and more generally on the 15th, 20th and 23rd. An area of low pressure to the northwest became dominant from the 26th to the end of the month, with associated frontal troughs bringing wind, rain or heavy thundery showers. The latter part of July saw temperatures drop back to near normal levels for the time of year and the rainfall ended the Absolute drought status and Partial drought status in all areas.

Figure 4 Skerries Beach, Dublin *(Moore, 2018)*

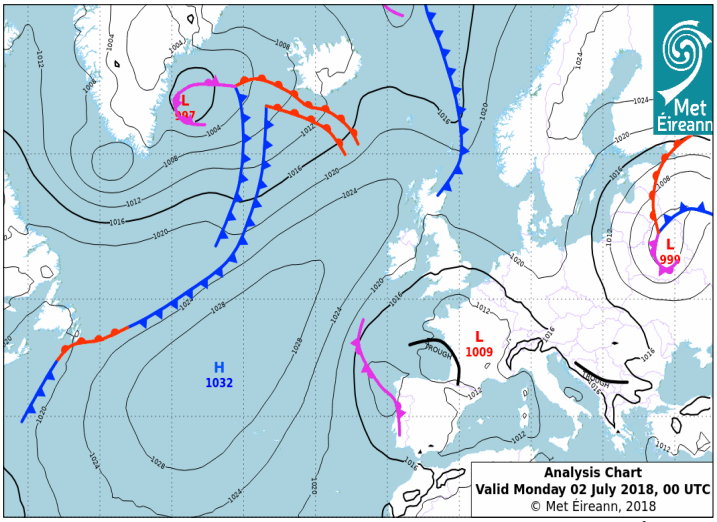

Figure 5 Surface analysis 00UTC 2nd July 2018 *Met Éireann*

For July, rainfall was about 80% of normal in the west and about 47% of normal in the east. Gurteen, Co Tipperary had only 36% of normal rainfall in July. This follows on from a dry and warm May and June. Phoenix Park recorded its lowest combined two-monthly rainfall total of 34.5 mm for June and July since records began in 1850.

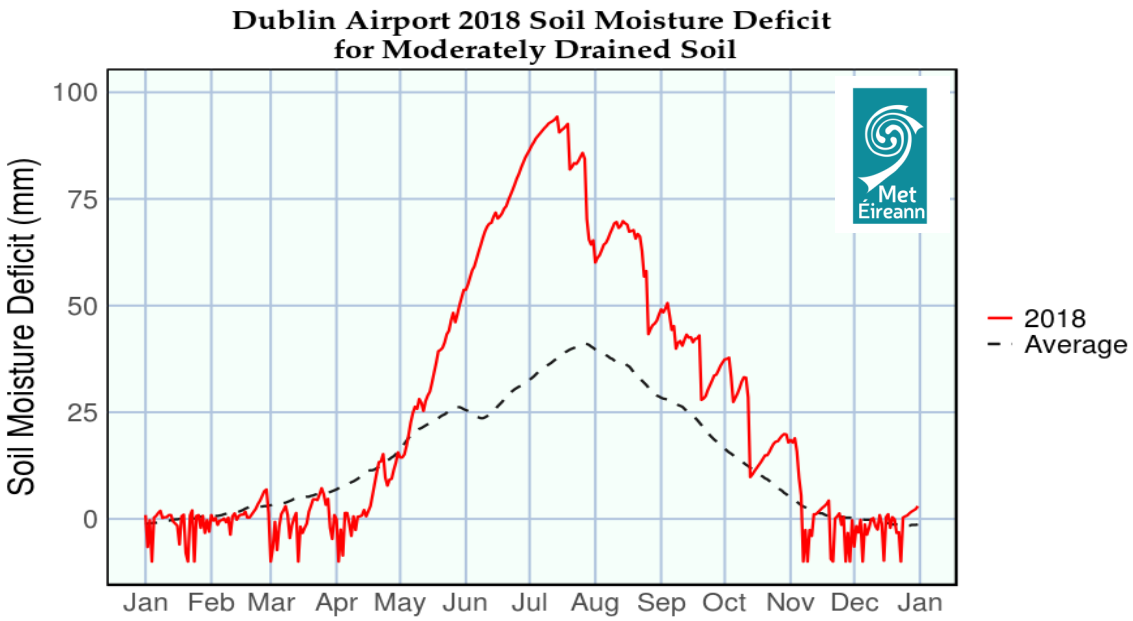

Figure 6 Dublin Airport soil moisture deficit for 2018. *(Agri-Meteorological Data - Met Éireann, 2020)*

2.4 August Synoptic Setup and summary

For the majority of August there was low pressure to the northwest and high pressure to the south-east with Ireland caught in a westerly flow. A meandering north Atlantic jet stream moved over Ireland at times bringing frontal rain and showers, interspersed with high pressure ridges building from the south and pushing the jet stream further north giving many fine and dry days. This led to a split in the weather with the north and west having a cooler and wetter than average month, and the south and east having a warmer and drier than average month. The start of the month was typical of this pattern with rain affecting mainly the north and the west, followed by a transient ridge of high pressure building from the South. The remnants of post-tropical cyclone Ernesto affected the west and north again on the 18th. Only the 26th gave widespread heavy rain across the whole country.

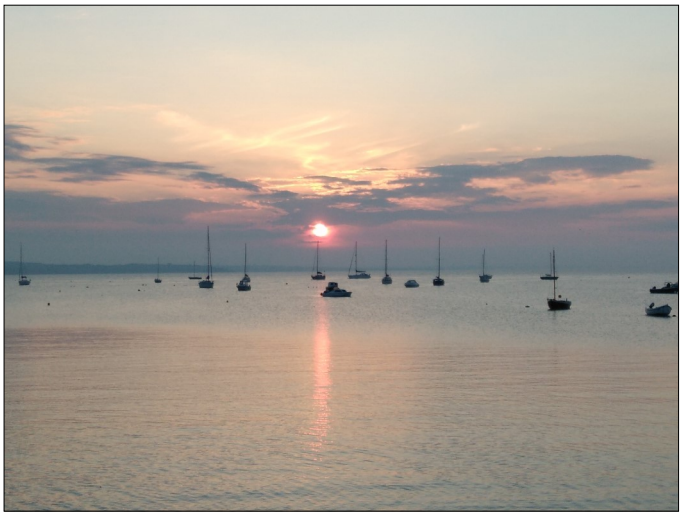

Figure 7 Skerries harbour, Dublin *(Moore, 2018)*

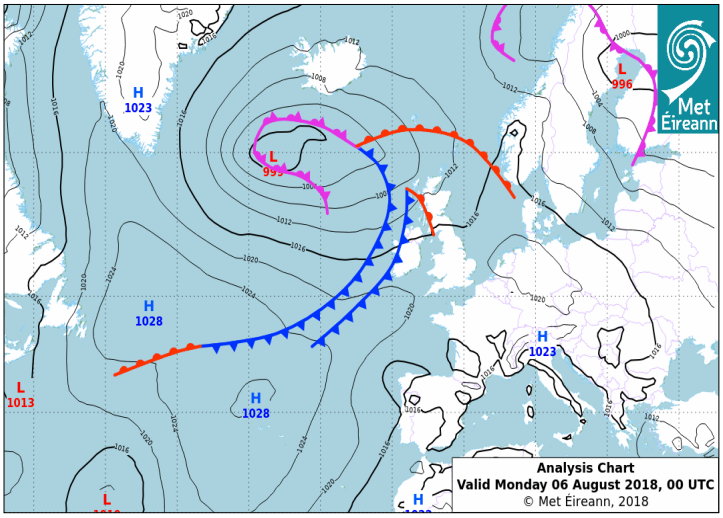

Figure 8 Surface analysis 00UTC 6th Aug 2018 *Met Éireann*

Summer Records

32.0°C recorded at Shannon Airport, Co Clare on the 28th, the highest temperature ever recorded at a synoptic station in Ireland.

109.5mm, total summer rainfall for Cork Airport, driest summer on record (record length 56 years).

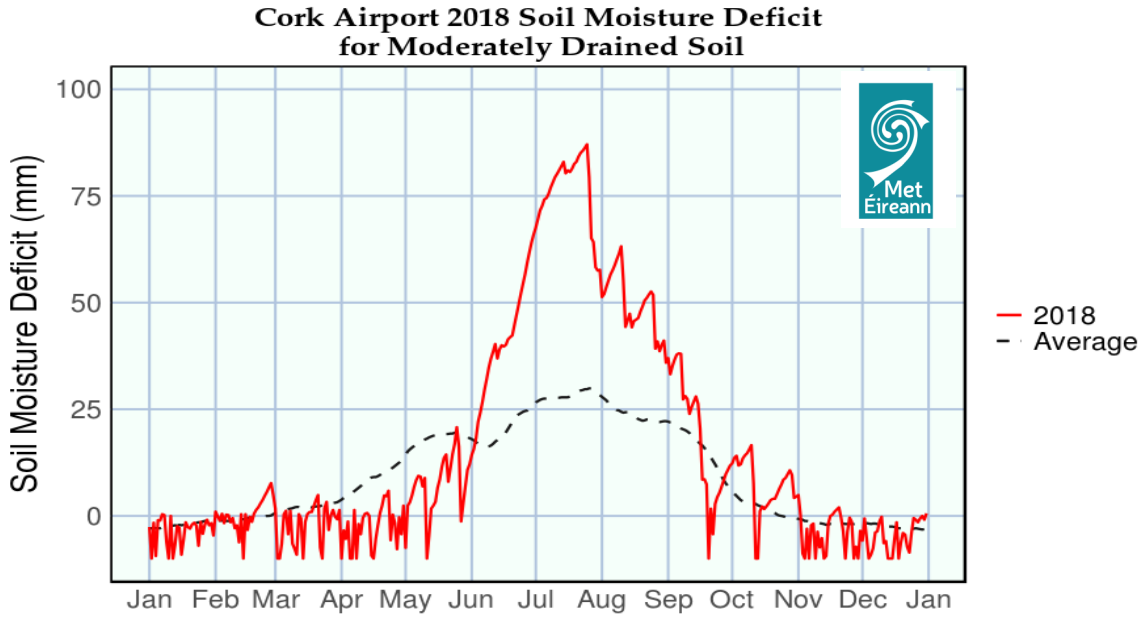

Figure 9 Cork Airport soil moisture deficit for 2018 *(Agri-Meteorological Data - Met Éireann, 2020)*

3. Rainfall, Droughts and Heatwaves

3.1 Rainfall

For the combined June-July period all stations reported rainfall below the LTA. This was particularly the case in midland, eastern and southern areas with between one third and one half of the LTA rainfall reported. At the Phoenix Park it was the second driest June-July period (behind 1887, which had 29 mm) in the available digital record since 1880. Indeed much of the South and East of the country had below average rainfall for 6 continuous months between May and October 2018. This lead to numerous absolute droughts, partial droughts, and dry spells across the country between May and July with very high soil moisture deficits being reported *(Falzoi et al., 2019).*

Station Name	June (mm)	June (% LTA)	July (mm)	July (% LTA)	June & July (mm)	June & July (% LTA)
Phoenix Park, Dublin	4.1	6%	30.5	56%	34.6	28%
Mace Head	31.6	38%	47.9	57%	79.5	48%
Oak Park	5.2	9%	42.5	72%	47.7	40%
Shannon Airport	13.6	19%	57	86%	70.6	52%
Dublin Airport	4.8	7%	40	71%	44.8	36%
Moore Park	32.4	46%	42.9	69%	75.3	57%
Ballyhaise	40.9	60%	69.2	94%	110.1	78%
Sherkin Island	17.2	23%	48.8	63%	66.0	43%
Mullingar	27.1	37%	33.5	47%	60.6	42%
Roches Point	12.4	19%	47.2	75%	59.6	47%
Newport	65.9	73%	58.5	58%	124.4	65%
Markree	39.6	48%	71.2	77%	110.8	63%
Dunsany	11.4	16%	41.9	68%	53.3	40%
Gurteen	22.8	32%	24.1	36%	46.9	34%
Malin Head	51.1	73%	60.3	75%	111.4	74%
Johnstown Castle	12.7	17%	53.3	73%	66.0	45%
Athenry	25.2	32%	69.7	81%	94.9	57%
Mount Dillon	82.2	111%	42.2	58%	124.4	84%
Finner	47.7	66%	84	92%	131.7	81%
Claremorris	43.1	58%	62.7	84%	105.8	71%
Valentia Observatory	39.2	41%	50.1	51%	89.3	46%
Belmullet	40.1	56%	64.1	81%	104.2	69%
Casement	18.5	30%	30.1	56%	48.6	42%
Cork Airport	10.4	13%	40.1	51%	50.5	32%
Knock Airport	54.1	59%	82.6	86%	136.7	73%

Table 2 Rainfall totals and % of LTA for June and July 2018

3.2 Meteorological Droughts

There were absolute drought conditions recorded at 21 stations at various times between the 22nd May and the 14th July. There were partial drought conditions recorded at 10 stations at various times between the 28th May and the 25th July. There were dry spells recorded at 5 stations at various times between the 18th June and the 14th July.

RECORDED ABSOLUTE DROUGHTS 2018			
STATION	**START DATE**	**END DATE**	**LENGTH (Days)**
Belmullet	22-May-18	12-Jun-18	22
Phoenix Park	30-Jun-18	14-Jul-18	15
Mace Head	21-Jun-18	06-Jul-18	16
Oak Park	21-Jun-18	14-Jul-18	24
Shannon Airport	21-Jun-18	13-Jul-18	23
Dublin Airport	21-Jun-18	14-Jul-18	24
Sherkin Island	21-Jun-18	14-Jul-18	24
Ballyhaise	21-Jun-18	10-Jul-18	20
Mullingar	21-Jun-18	14-Jul-18	24
Roches Point	21-Jun-18	05-Jul-18	15
Dunsany	21-Jun-18	14-Jul-18	24
Gurteen	21-Jun-18	14-Jul-18	24
Johnstown Castle	21-Jun-18	14-Jul-18	24
Athenry	21-Jun-18	07-Jul-18	17
Mount Dillon	21-Jun-18	10-Jul-18	20
Finner	21-Jun-18	09-Jul-18	19
Claremorris	21-Jun-18	10-Jul-18	20
Valentia	21-Jun-18	13-Jul-18	23
Casement	21-Jun-18	14-Jul-18	24
Cork Airport	21-Jun-18	05-Jul-18	15
Knock Airport	21-Jun-18	10-Jul-18	20
RECORDED PARTIAL DROUGHTS 2018			
Oak Park	28-May-18	19-Jul-18	53
Cork Airport	21-Jun-18	25-Jul-18	35
Moore Park	14-Jun-18	14-Jul-18	31
Roches Point	21-Jun-18	25-Jul-18	35
Casement	03-Jun-18	19-Jul-18	47
Dublin Airport	28-May-18	19-Jul-18	53
Phoenix Park	28-May-18	19-Jul-18	53
Dunsany	21-Jun-18	19-Jul-18	29
Gurteen	21-Jun-18	25-Jul-18	35
Johnstown Castle	18-Jun-18	20-Jul-18	33
RECORDED DRY SPELLS 2018			
Belmullet	21-Jun-18	13-Jul-18	23
Moore Park	18-Jum-18	14-Jul-18	27
Newport	21-Jun-18	10-Jul-18	20
Markree	21-Jun-18	14-Jul-18	24
Malin Head	21-Jun-18	10-Jul-18	20

Table 3 Absolute Droughts, Partial Droughts and Dry Spells recorded during late Spring and Summer 2018

A **heat wave** occurs where there are 5 consecutive days or more with maximum temperature over 25° C (that is, a daily maximum screen air temperature > 25° C).

A **dry spell** is a period of 15 or more consecutive days with daily precipitation of less than 1.0mm (that is daily rainfall < 1.0mm).

A **partial drought** is a period of at least 29 consecutive days where the mean daily rainfall does not exceed 0.2mm (that is, a mean for period ≤ 0.2 mm per day).

An **absolute drought** is a period of 15 or more consecutive days with daily precipitation of less than 0.2mm (that is, a daily rainfall total < 0.2mm).

3.3 Heatwaves

Heatwaves occur in Ireland in summer during high pressure conditions, and especially under the influence of tropical continental air masses. Slow moving anticyclones, which persist for prolonged periods of time in summer, often result in dry and settled weather. In anticyclones, cool air descends from aloft, warms and diverges outwards at lower levels. When a high pressure system develops over Ireland, the jet stream is usually located to the north of the country, which keeps low pressure systems away. Heatwaves in Ireland are infrequent compared to other European countries, but can be prolonged if the conditions are right. In August 1976, Birr recorded heatwave conditions lasting 14 days. More recently, heatwave conditions occurred in the summers of 2017, 2013, 2006, 2003, 1995, 1989 and 1983. There were official heat wave conditions recorded at 15 stations at various times between the 24th June and the 4th July 2018 (See table below).

Station Name	Start Date	End Date	Length (Days)
Cavan	04-Aug-03	08-Aug-03	5
Glengarriff	09-Jul-05	13-Jul-05	5
Cavan	15-Jul-06	21-Jul-06	7
Navan	24-Jul-06	28-Jul-06	5
Cashel	06-Jul-13	14-Jul-13	9
Kilkenny	17-Jun-17	21-Jun-17	5
Oak Park	24-Jun-18	4-Jul-18	11
Mullingar	24-Jun-18	29-Jun-18	6
Gurteen	24-Jun-18	30-Jun-18	7
Athenry	24-Jun-18	30-Jun-18	7
Mount Dillon	24-Jun-18	30-Jun-18	7
Shannon Airport	24-Jun-18	30-Jun-18	7
Casement	24-Jun-18	28-Jun-18	5
Moore Park	26-Jun-18	4-Jul-18	9
Ballyhaise	25-Jun-18	29-Jun-18	5
Newport	25-Jun-18	29-Jun-18	5
Dunsany	24-Jun-18	29-Jun-18	6
Claremorris	25-Jun-18	30-Jun-18	6
Knock Airport	26-Jun-18	30-Jun-18	5
Markree	26-Jun-18	30-Jun-18	5
Finner	26-Jun-18	30-Jun-18	5

Table 4 Recorded Heat Wave periods since 2000

4. Impacts

The impacts of the high temperatures and droughts during the summer of 2018 in Ireland were widespread across the country and especially for the farming community where grass growth was well below normal. The fodder deficit was highest in the South-east where the soil moisture deficit was highest.

Farming:

- Teagasc, The Agriculture and Food Development Authority, said the average farm income was down by 15% in 2018 and dairy farming was down by 31% from 2017 due to feed costs. *(Dillon et al., 2018)*
- Teagasc revealed in their 'Outlook 2019' report that the long winter and summer drought "has had a significant negative impact on Irish farm income in 2018". *(Dillon et al., 2018)*
- Teagasc also indicated that tillage farmers had "serious difficulty with spring sown crops in 2018, with yields well down on normal". *(Dillon et al., 2018)*
- The Irish Farmers Association found that the "The country's prolonged drought spell had devastating consequences for Irish field vegetable producers". *(Irish Farmers' Association, 2018)*

Water Restrictions:

- The droughts of 2018 put the Irish water network under stress with widespread water restrictions and hosepipe bans in place across the country, especially in the East.
- Restrictions were introduced by Irish Water in early July which were not fully lifted until late September as Irish Water warned there were likely to be "serious deficiencies" of water available.
- Irish water said "The prolonged hot weather during the summer caused a huge increase in water usage across the country. As demand for water rose to critical levels, our supplies were put under severe stress as we were using more water than we could produce. It was, therefore, necessary to introduce restrictions". *(Water Shortages & Restrictions, 2018)*

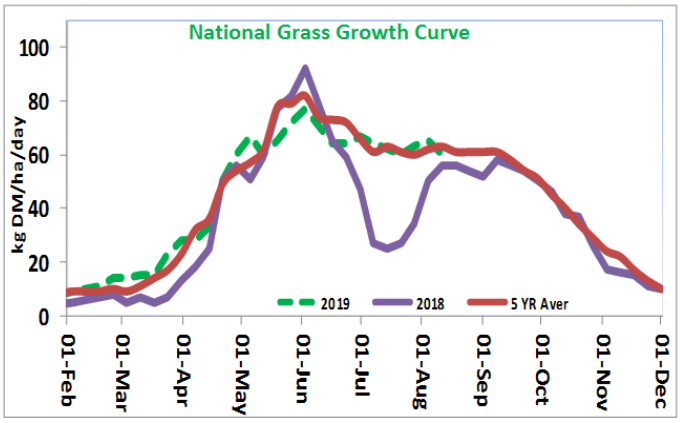

Figure 10 Teagasc grass growth curve *(Grass Curve - Teagasc, 2020)*

Figure 11 Lambs *(Moore, 2018)*

Figure 12 Irish water logo

5. Summer 2018 in Europe

The World Meteorological Organization (WMO) statement on the State of the Global Climate in 2018, said "Large parts of Europe experienced exceptional heat and drought through the late spring and summer of 2018. Temperatures were well above average and rainfall well below average from April onwards in much of northern and western Europe."

The statement also describes how "Some of the most abnormal conditions affected northern Europe from May to July. This period was the driest and warmest on record in many parts of central and southern Scandinavia and Finland; rainfall for May to July at Lund in southern Sweden, with observations dating back to 1748, was only about half the previous lowest recorded. Denmark had its hottest summer and driest May to July on record, and Norway and Finland their hottest Julys. This culminated in a prolonged heatwave in late July and early August, which included numerous record high temperatures north of the Arctic Circle, and record long runs of warm temperatures, including 25 consecutive days above 25 °C at Helsinki-Vantaa, Finland, and 8 consecutive days above 30 °C at Lääne-Nigula, Estonia. Warm nights and high humidity were also a feature of this period, with records including seven consecutive nights above 20 °C at Riga, Latvia, and a national record dew point of 24.8 °C on 1 August at Karlskrona, Sweden. It was also an exceptionally warm and dry period in the United Kingdom and Ireland."

It goes on to say that "Conditions in these regions moderated from mid-August, but it remained unusually warm and dry further south. Dry conditions were especially persistent in Germany, where the April–September period was the second driest on record, leading to heavy agricultural production losses, and eastern Switzerland (driest April to November on record), with western Poland, Czechia (with its driest January to August on record), the Netherlands and north-eastern France also amongst the areas affected. Latvia went on to have its driest year on record (29% below average) and Czechia its second driest (24% below average), while further north, Stockholm had its driest year since 1892."

The statement also reveals that "The most significant heatwave in central Europe was in late July and early August; in France it was of similar duration to the heatwave of 2003 but less intense; still, 1500 excess deaths were reported. In Germany, some sites in the Frankfurt area had 18 consecutive days above 30 °C from 23 July to 9 August. Further south-west, a short but intense heatwave affect-

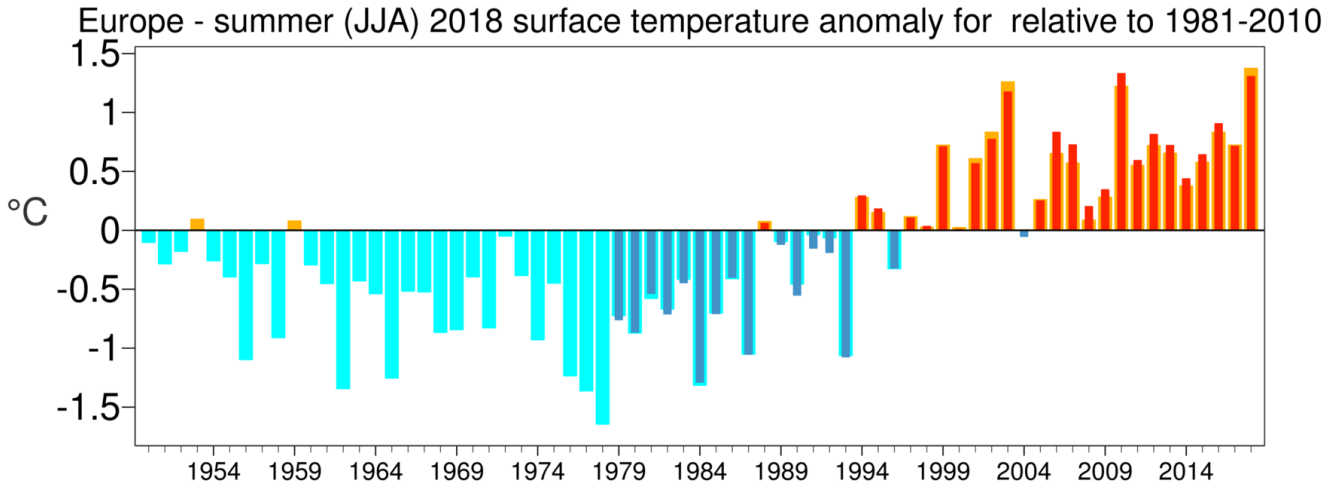

Figure 13 European surface temperature anomaly for the period April-August, with respect to 1981-2010 averages. Credit: Copernicus Climate Change Service (C3S)/ECMWF/KNMI. *("European temperature | Copernicus", 2019)*

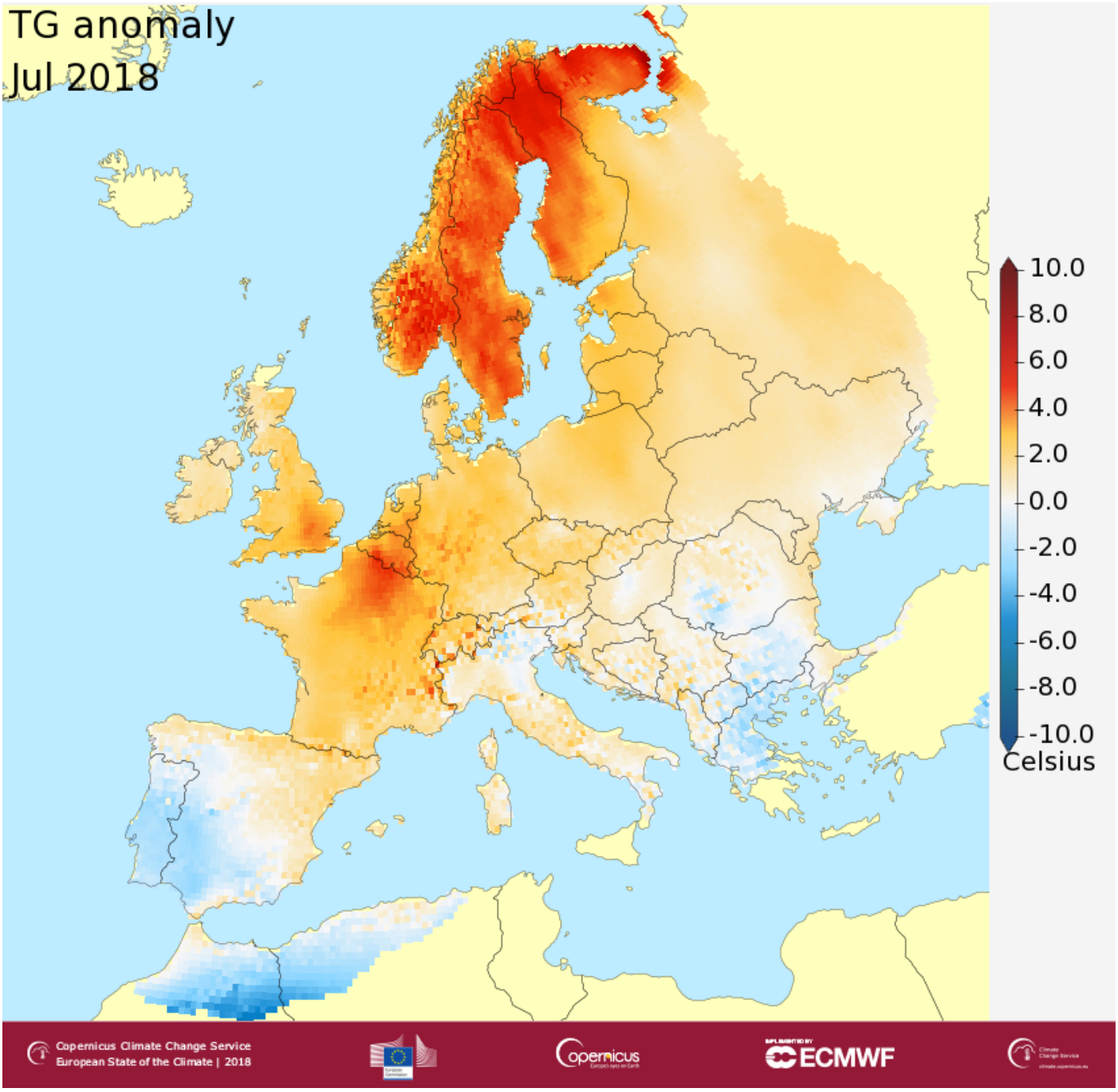

Figure 14 Mean temperature anomaly for July 2018 with respect to 1981-2010 averages. Data source: E-OBS. Credit: Copernicus Climate Change Service (C3S)/KNMI. *("European temperature | Copernicus", 2019)*

ed Spain and Portugal in early August. In Portugal, 4 August was the country's hottest day of the 21st century with 40% of stations setting records, including Lisbon – Gago Coutinho (44.0 °C). Armenia had its warmest July with 43.7 °C being recorded in Yerevan, the highest temperature on record."

While discussing wildfires and rivers in Europe it says "Wildfires reached an unprecedented extent in Sweden, with over 25 000 hectares burned, and abnormal wildfire activity also occurred in Latvia, Norway, Germany, the United Kingdom and Ireland. The dry conditions also led to very low flows on some central European rivers, with the Rhine approaching record low flows by mid-October, before some recovery during December. This severely disrupted river transport with the weight of goods carried reduced by 20% to 25% compared with 2017. There were also disruptions to river transport on the Danube in Serbia." *(WMO Statement on the State of the Global Climate in 2018, 2019)*

6. Summer 2018 and Climate Change

6.1 Attribution

The Fifth Assessment report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) concluded that "human influence on the climate system is clear" and that "changes in many extreme weather and climate events have been observed since about 1950". Societies around the world are faced with increasing climate change risks *(IPCC PRESS RELEASE, 2013).*

There are a large number of studies showing that human induced global warming has increased the likelihood of extreme events occurring across the planet such as heatwaves, droughts and floods. Therefore when we have a heatwave or drought it is scientifically correct to point to the increased risk of such events due to human activities. With an event such as the heatwaves and droughts across Europe during the summer of 2018, we can say that events of this nature have been made more likely by climate change, or that climate change has loaded the dice on the frequency of such events happening.

The Atmospheric patterns which led to the European heatwaves in the summer of 2018 do occur in the natural cycles of the weather, and some will remember the summer of 1976 for its heatwaves in northwest Europe, but as shown in figure 15 below, only a few parts of the globe had above normal temperatures in June 1976, whereas the majority of the globe had above normal temperatures in June 2018.

The study of attribution of individual weather events to climate change, although relatively new, has advanced greatly in recent years. Giving an evidence based estimate of whether an event can be attributed to climate change is achieved by running a model with only natural influences in it, such as the solar cycle and volcanoes. Then the real world model is run - this includes human influences, such as greenhouse gas emissions, expanding cities, deforestation and many other things, along with natural influences. The two model outputs are then compared. By running an ensemble of models it is then possible to give a percentage probability of how more/less likely a particular event is. Results of attribution studies have statements like "the event is 30% more likely to have occurred in a warmer climate".

One such study by a team of scientists at the World Weather Attribution Network found that the heatwaves that affected much of Northern Europe during the 2018 summer were as much as "five times more likely" due to human-caused climate change *(Climate change made 2018 European heatwave up to 'five times' more likely, 2018).* Another study by the Met Office Hadley Centre found that the heatwave in the UK "was made up to 30 times more likely by climate change" *(Met Office: Climate change made 2018 UK summer heatwave '30 times more likely' | Carbon Brief, 2018).*

The next goal in the scientific attribution sphere is to operationalise the attribution methodologies. Met Éireann is involved in a European project, EUPHEME, the goal of which is to develop a "toolbox for attribution studies" *(Climate change and extreme weather events in Europe - Met Éireann, 2020).*

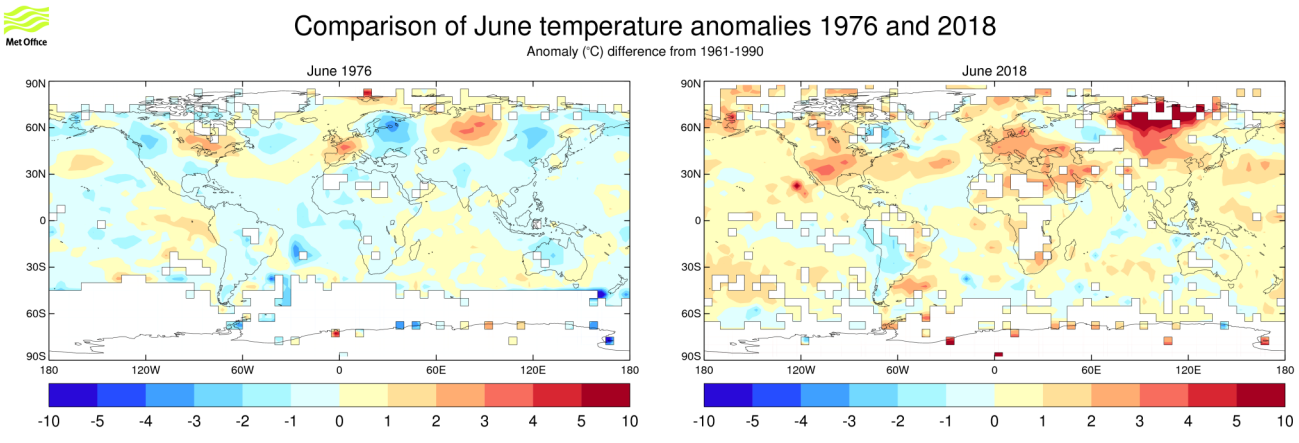

Figure 15 Comparison of 1976 and 2018 June temperature anomalies, based on Met Office HadCRUT4 data set *("Summer temperature 2018 – the 'new normal'?", 2018)*

6.2 Current State of the Climate

"In a clear sign of continuing long-term climate change associated with record atmospheric concentrations of greenhouse gases, 2015, 2016, 2017 and 2018 have been confirmed as the four warmest years on record" *(WMO, Geneva, 6 February 2019, 2019).* WMO has since confirmed 2019 as the second warmest year on record behind 2016, and the five year period (2015-2019) the highest on record.

"A consolidated analysis by the World Meteorological Organization of five leading international datasets showed that the global average surface temperature in 2018 was approximately 1.0° Celsius (with a margin of error of ±0.13°C) above the pre-industrial baseline (1850-1900). It ranks as the fourth warmest year on record" *(WMO, Geneva, 6 February 2019, 2019).* 2018 now ranks as fifth.

At the European Geosciences Union (EGU) General Assembly 2019, where new research on the 2018 heatwaves was presented, it was stated that the "2018 Northern Hemisphere concurrent hot extremes could not have occurred without human-induced climate change" and that "22% of populated and agricultural areas of the NH concurrently experienced hot extremes between May and July 2018". It was also declared that "Observed 2018-like heatwave areas are simulated in models and are projected to occur nearly every year for a 2°C global warming scenario" *(EGU General Assembly, 2019).*

The "warming stripe" graphics below (Figures 16, 17 and 18) are visual representations of the change in temperature as measured over the past 100+ years and are produced by Professor Ed Hawkins (University of Reading), using data from the Berkeley Earth temperature dataset, updated to the end of 2019. Each stripe represents the temperature in that country or region averaged over a year. For virtually every country or region, the stripes turn from mainly blue (below average) to mainly red (above average) in more recent years, illustrating the rise in annual temperatures in that country or region *(Hawkins, 2020).*

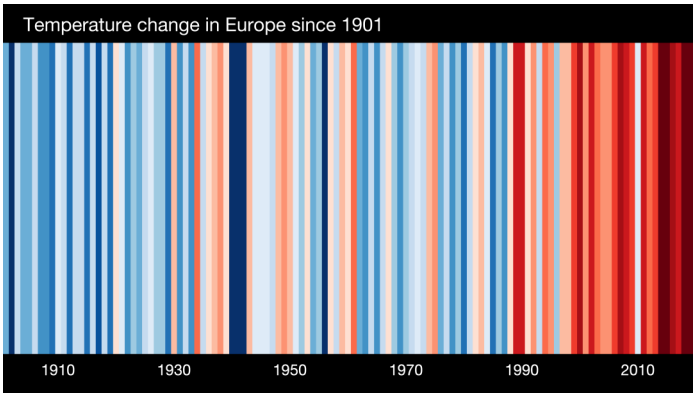

Figure 16 Warming stripes for Europe *(Hawkins, 2020)*

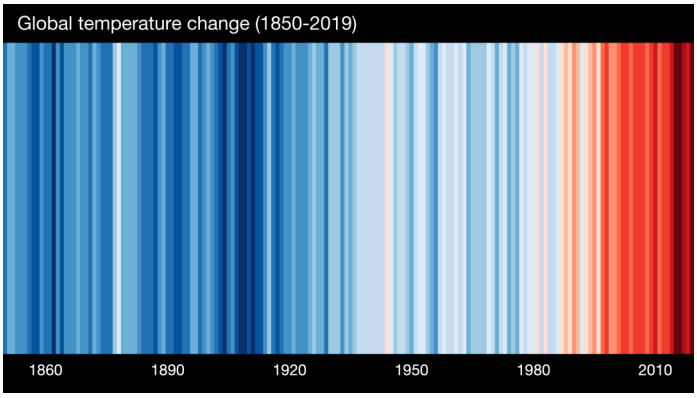

Figure 17 Global warming stripes *(Hawkins, 2020)*

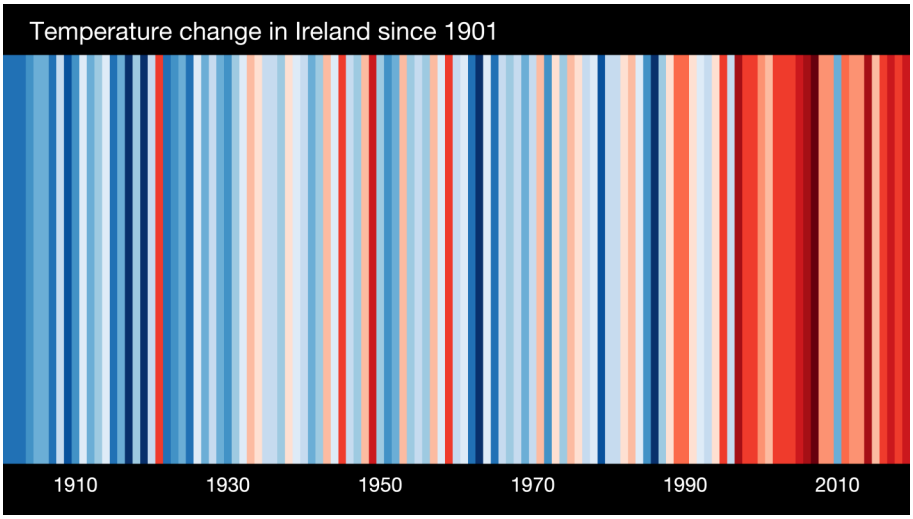

Figure 18 Warming stripes for Ireland *(Hawkins, 2020)*

7. Conclusions and Summary

Droughts can occur in Ireland at any time of the year when high pressure dominates our weather over a long period of time. However, heatwaves only occur in Ireland in summer during high pressure dominated periods. High pressure systems or anticyclones, can stall over Ireland for long periods of time, pushing the North Atlantic Jetstream away to the north and blocking Atlantic weather fronts from coming over the country. This kind of pattern, when prolonged, can lead to dry soils in summer and when combined with a lot of sunshine, increases the temperature even further, due to the sun's energy not being used up to evaporate water. The air mass most associated with this pattern is a tropical continental air mass, which can originate in North Africa.

The dry and settled weather from the end of May 2018 continued through most of June and July. Slow moving anticyclones positioned themselves either directly over Ireland, just to the north, or over Scandinavia. There were times when low pressure broke through, especially in mid June, but rainfall amounts remained low and the weather mostly dry with a lot of sunshine. August became more unsettled in the West and Northwest of the country, but high pressure to the southeast kept the South and East of Ireland drier and warmer than normal.

This prolonged settled spell of weather led to heatwave and drought conditions in many parts of Ireland. Heatwave conditions were recorded at 15 synoptic stations for 5 or more days between the 24th June and the 4th July. Oak Park, Co Carlow had heatwave conditions for 11 consecutive days. During this period, Shannon Airport, Co Clare reached 32.0°C, the highest temperature ever recorded at a synoptic station in Ireland.

Absolute drought conditions were recorded at 21 stations at various times between the 22nd May and the 14th July. There were partial drought conditions recorded at 10 stations and dry spells recorded at 5 stations at various times between the 28th May and the 25th July. For the combined June and July period, all stations reported rainfall below the LTA. This was particularly the case in midland, eastern and southern areas, where between one third and one half of the LTA rainfall was reported. Cork Airport had its driest summer on record (record length 56 years) and the Phoenix Park had its second driest June-July period since 1880. Indeed much of the South and East of the country had below average rainfall for 6 continuous months between may and October 2018.

The summer of 2018 will stand out as one of the warmest and driest summers on record for Ireland and most of Northwestern Europe. The heatwaves and droughts experienced in Ireland during the summer of 2018 occur in the natural cycles of the weather and 1976 stands out as another summer where Ireland experienced exceptionally warm and dry conditions. However, when comparing the global temperatures of both June's (Figure 14) as an example, the clear global increase in temperatures from 1976 to 2018 is evident.

It is also clear from the 'Warming Stripes' produced by Professor Ed Hawkins (University of Reading) that the average temperatures globally and regionally are rising and that "the science on the human contribution to modern warming is quite clear. Humans emissions and activities have caused around 100% of the warming observed since 1950, according to the Intergovernmental Panel on Climate Change's (IPCC) fifth assessment report" *((IPCC) fifth assessment report, Carbon Brief, 2017).*

At the European Geosciences Union (EGU) General Assembly 2019 it was also stated that "2018 Northern Hemisphere concurrent hot extremes could not have occurred without human-induced climate change" and "Observed 2018-like heatwave areas are simulated in models and are projected to occur nearly every year for a 2°C global warming scenario" *(EGU General Assembly, 2019).*

Climate projections for Ireland show a trend towards warmer, wetter, winters and hotter, drier, summers.

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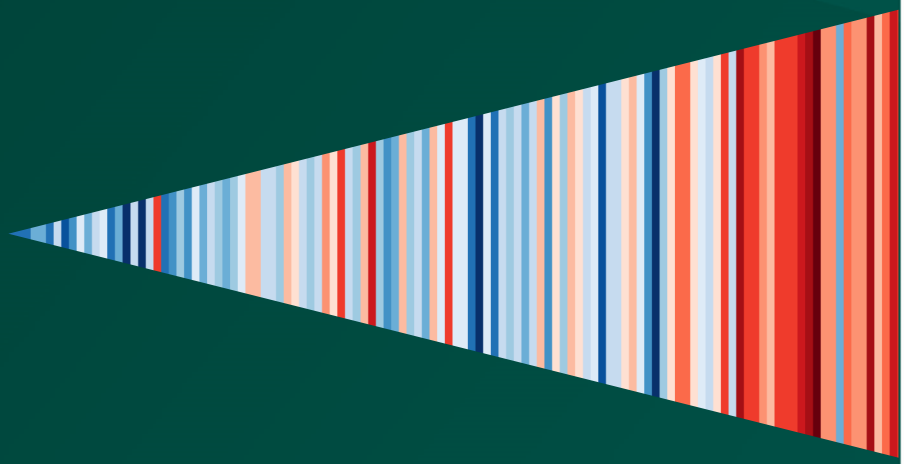

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