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Long-term air temperature averages for Ireland 1991-2020

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Acknowledgements

We would like to thank Dan Hollis and Mark McCarthy of the Met Office, United Kingdom for the provision of data for Northern Ireland and their valuable advice and assistance. Also thanks to Seamús Walsh for his technical help and software scripts which formed a basis for much of the calculations that were made throughout this work. Particular thanks and recognition to the Met Éireann climate and rainfall voluntary observers without whom this work would not have been possible.

Disclaimer

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Abstract

Climate long-term averages (LTAs) or Climate Normals are the mean or average values of a climate variable over a standard reference period. They are used to describe the current climate of a specific location and to place current weather in context. The World Meteorological Organization established that the length of the reference period should be 30 years, with a recommendation to update the climate averages every 10 years to provide representative reference values for recent climatic conditions.

In accordance with WMO guidelines (WMO, 2017), Met Éireann has compiled a set of annual, seasonal, and monthly climate averages for Ireland for the period 1991-2020 for a range of parameters including air temperature and precipitation, using high-quality data obtained from Met Éireann's observation network.

This report details the process used to generate the annual, seasonal and monthly long-term averages for mean, maximum and minimum air temperatures from the initial recording of the air temperature measurements, quality control and homogenisation of the data to the production of gridded maps and climatological statistics. To facilitate a comparison with the previous 30-year period (1961-1990), a consistent high-quality dataset spanning the entire 60-year period was developed.

Analysis shows that the annual mean air temperature for Ireland for the 1991-2020 period is 9.8°C, which is an increase of approximately 0.7°C compared to the 1961-2020 period. Information on the variability of air temperature across different months and seasons, as well as the decadal trends in air temperature are highlighted in the report.

Going forward, weather and climate statistics will reference the new long-term average period 1991-2020, unless otherwise stated. The historical baseline period of 1961-1990 will be retained for use in climate change assessments.

1. Introduction

Climate long- term averages, sometimes referred to as 'climate normals', are the mean or average values of a climate variable over a standard reference period. Since the early 1900s, the World Meteorological Organization (WMO) and its predecessor, the International Meteorological Organization (IMO), have been coordinating the publication of global climate averages on a triennial basis (once every 30 years, e.g., 1901–1930, 1931–1960, 1961–1990). In 2015, the WMO, through the Seventeenth World Meteorological Congress (Cg-17), changed the definition of a Climatological Standard Normal to the most recent 30-year period finishing in a year ending with zero (1981–2010, 1991–2020 etc) rather than to non-overlapping 30-year-periods (1931–1960, 1961–1990 etc).

Climate averages are used for two principal purposes. They provide information about typical weather conditions at a particular time and location, and they serve as a benchmark against which recent or current observations can be compared, including providing a basis for many anomaly-based climate datasets. They are also widely used as a reference baseline to provide context for future climate projections.

This report describes the production of Ireland's monthly, seasonal, and annual mean, maximum and minimum air temperature averages for the period 1991–2020. These averages have been calculated for climate observing stations in Met Éireann's climate data archive and for a high resolution 1 km by 1 km grid of points covering Ireland. Much of the methodologies applied here are based on the approach previously applied by Walsh (2016).

Observational datasets of air temperature over the period 1961 to 2020 were collated for 168 stations. Of these 28 are from UK Met Office weather stations located in Northern Ireland. The time span allows the 1991 to 2020 averages to be compared with an earlier 30-year period from 1961-2020 while the geographic spread gives a good representation of air temperature across the island of Ireland.

Following the application of quality control techniques, the data are examined to determine the homogeneity of the long-term series. A homogeneous climate time series is defined as one where variations are caused only by variations in climate (Freitas et al., 2013). Most long-term climatological time series have been affected by non-climatic factors that, if not accounted for, can make these data unrepresentative of the actual climate variation occurring over time.

These factors may include changes in instruments, observing practices, station locations, and station environment. Some changes cause sharp discontinuities while other changes, particularly changes in the environment around the station, can cause gradual biases in the data. Homogenisation methods use statistical techniques and metadata to identify inhomogeneities in data series and adjust the series to remove any non-climatic factors so that the temporal variations in the corrected data reflect only the variations due to climatic processes (Aguilar et al., 2003). Multiple Analysis of Series for Homogenisation (MASH) software was used to homogenise as many as possible of the stations' maximum and minimum data sets over the period 1961 to 2020. Previous calculations of the LTAs were generated using data which was not homogenised, therefore the LTAs generated in this work should be used as the reference datasets for meteorological products based on Irelands recent and future climate.

To address gaps in data series, algorithms based on nearest neighbour observations were used to estimate missing monthly values. Due to a sufficiently high density of weather stations recording air temperature across Ireland, it has been possible to interpolate the station data on to a 1 km by 1 km grid covering the country, a process known as gridding. Gridding was performed using a regression-IDW (inverse distance weighting) algorithm. The grids produced allow area statistics of air temperature to be generated, such as the average maximum air temperature LTA for Ireland.

Using the same methodology, 30-year averages for the preceding period from 1961-1990 were also calculated allowing the difference between the two averaging periods to be determined.

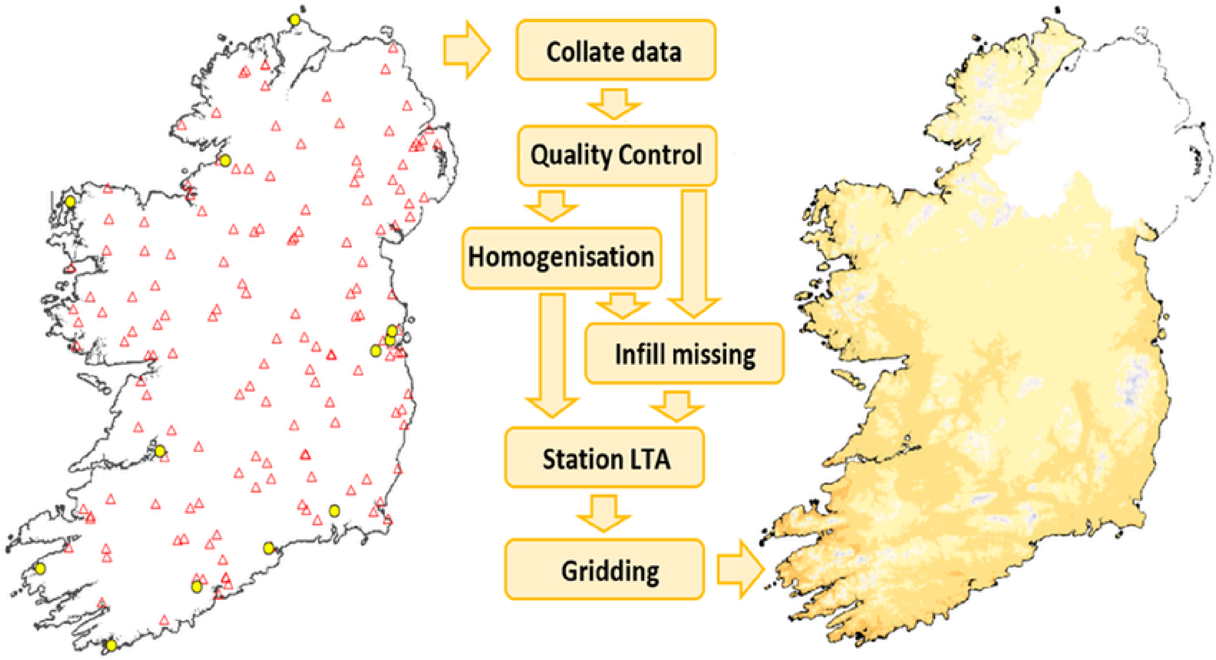

Figure 1: Outline of the LTA generation process using air temperature data from stations across Ireland.

2. Data & Methods

2.1 Air temperature observations

Approximately 140 weather stations in the Met Éireann network measure air temperature, the number of stations can vary as stations close or open over time. Daily maximum and minimum air temperature values over a 24-hour period to 09:00UTC from these stations and 28 stations located in Northern Ireland and operated by The Met Office, UK are used to calculate the LTAs. The mean temperature is defined as (maximum temperature + minimum temperature) / 2.

The majority of stations recording temperature are called climate stations where a daily maximum and minimum temperature as well as the dry bulb temperature is manually read once per day at 09:00 hours UTC. In the case of the minimum temperature the reading made at 09:00 hours is assigned to the current day whilst for the maximum temperature it is assigned to the previous day. Synoptic stations which were manned until automation in the 1980s or the early 2000s (TUCSON) make up the rest of the air temperature network with data from these stations also collated at 09:00 hours UTC. The data from these stations has been quality controlled (QC) and stored in the National Climate Database. In total, approximately 2.2 million daily temperature observations recorded over the period 1961 to 2020 were used to generate the temperature LTAs.

2.2 Quality control

All data used was extracted from the Met Éireann National Climatological database. Whilst all the temperature records had previously undergone basic QC checks previously, the QC system developed by S. Walsh (2016) which included the use of spatial techniques (Hubbard, 2005) was applied to all air temperature data. These QC checks (Table 1) ensure that outliers are flagged and can then be examined using a nearest neighbour comparison test with the value amended if necessary.

QC check	Details
Extreme values	Tmax and Tmin within ± 1°C of the absolute values for the period
Inconsistent values	Tmax < Tmin
Step changes	Day-to-day step change within limits defined by the long-term climatology
Repeated values	More than two consecutive days with identical Tmax or Tmin values
Dry bulb comparison	Tmax ≥ dry bulb read on day of observation and the previous day. Tmin ≤ dry bulb on the day of observation

Table 1: List of QC checks applied to Met Éireann air temperature data from the station network.

An automated spatial regression technique is used to determine whether flagged outlier values need to be amended or can be accepted as they are. The technique involves comparing 20 days of data before and after the suspect temperature measurement was recorded at the particular station, with equivalent data from its 20 nearest neighbouring stations. A linear regression is fitted between the suspect station and each of its neighbours with the goodness of this fit, measured using the RMSE of the regression residuals calculated. If the outlier observation fits the regression within acceptable limits, then the value can be accepted, otherwise the observation is removed and replaced by a predicted value based on a weighted average of neighbouring station regression fits.

2.3 Homogenisation

Long-term series are often affected by non-climatic influences such as station relocations, instrumental and observational changes, and changes in the local environment. Such changes can adversely impact the quality of the time series through the introduction of inhomogeneities (Begert et al., 2005; Trewin, 2010). Some of these factors can cause abrupt shifts, while others cause gradual changes over time. Since these shifts are often of the same magnitude as the climate signal (Auer et al., 2007), the quality of long-term climate analysis depends on the homogeneity of the underlying time series (Vertačnik et al., 2015). The aim of homogenisation techniques is the removal or reduction of any spurious non-climatic signal introducing inhomogeneities to the time series so that variability is caused only by changes in weather or climate (Freitas et al., 2013).

Sophisticated algorithms have been developed to detect and correct inhomogeneities in the observational time series. Corrections are made such that historical measurements are aligned with the current station observations. In this work Multiple Analysis of Series for Homogenisation (MASH) software has been used for this purpose. MASH is developed and maintained by Szentimrey, previously at the Hungarian Meteorological Service (Szentimrey, 2017).

Homogenisation was carried out on both the maximum and minimum data series separately. In order to homogenise as large a data set as possible, homogenisation was carried out in 5 iterations. The method used was similar to that devised by Iszak et al., (2021). The time periods used and the order in which they were homogenised was 1961-2020, 1965-2020, 1980-2020, 1990-2020 and 2000-2020. A total of 101 stations, 73 from Ireland and 28 located in Northern Ireland, were homogenised for both maximum and minimum temperature.

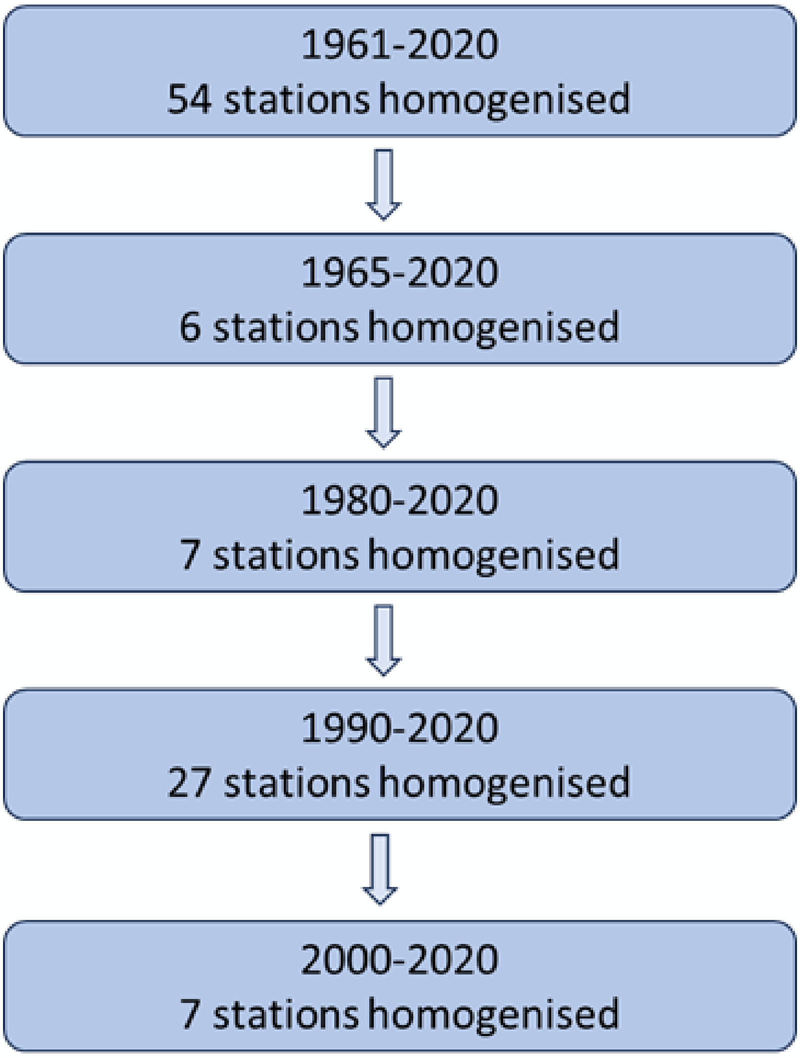

Figure 2: Iterations of air temperature station data homogenisation using MASH.

2.4 Infilling missing station data

Over the period the LTAs have been calculated, from 1961 to 2020, stations have opened, closed, have periods when observations may not have been taken. Missing station data can be infilled at a monthly level provided that the station to be infilled has at least 3 years of station observations. This is achieved using an algorithm which determines the relationship between the station with missing data and observations of its nearest neighbours over a period when overlapping observations are available.

The infilling algorithm uses a spatial regression of air temperature observations at the station which has data to be infilled, and each of its neighbours in turn. Neighbouring stations which have a better fit to the target station, based on the regression RMSE, are weighted more than stations where the regression fit is poor. For periods where there is missing monthly data for the station, the neighbouring stations regression fits are applied to generate temperature values at the target station, weighted by how well they match the target station. Infilling ensures that there is a monthly temperature value at a station location over the whole of the time period, here from 1961 to 2020. This aids the production of grids, maps and the calculation of temperature parameter statistics as will be outlined in the next section. Infilling was carried out on the 101 homogenised data series and a further 67 series which had 3 or more years of data. The resulting data set for the 1961 to 2020 period consisted of complete data sets for 168 stations.

2.5 Generation of gridded datasets

To produce a map of air temperature LTAs, the station temperature values are interpolated over a 1 km by 1 km grid across the island of Ireland, approximately 84,000 points. The grid is based on the Irish National Grid (ING) geographic coordinate system (OSI, 2000). At each station and at each grid point, geographical parameters such as easting and northing, elevation, distance and exposure to the sea are known. While the interpolated or gridded values within Northern Ireland are removed from the final maps, it is important that these are calculated as they ensure an accurate representation of the temperature parameter in areas near the border.

Interpolating the station data to the grid proceeds in a two-step process where firstly a stepwise regression fit between station geographical parameters and the temperature parameter is made. The stepwise methodology ensures only the most descriptive or important geographical parameters are included in the regression. An example of the regression of mean air temperature is given by;

$$Tmean_i = Tmean_{mean} + a_1 east_i + a_2 north_i + a_3 elevation_i + a_i geo\_param1_i \ldots + \boldsymbol{residual}$$

Here 〖Tmean〗_i is the mean air temperature at station i, 〖Tmean〗_mean is the average of the mean air temperature across all stations, a are the coefficients of the geographic variables (station easting, northing, elevation, distance to sea etc) and residual is the error or information not captured by the regression.

The regression fit is not exact and the difference between the regression value at the station locations and the actual station values, the residuals, are then modelled using an Inverse Distance Weighting (IDW) algorithm. IDW involves using the regression residuals of stations near to a particular grid point to predict the residual at that grid point; the closer a station is to the grid point the more weight is given to that station residual value, the further a station is the less influence it has on the predicted grid point residual value.

The IDW algorithm cross-validates station level predictions using different numbers of neighbouring stations and differing weighting with distance to determine the optimised predicting combination of these two factors. The interpolated grid temperature value is then a combination of the regression and IDW predictions.

For the LTA grid of air temperature parameters, a monthly grid is calculated separately for each month and year across the LTA period and then averaged to create the LTA grid. To improve the efficiency of the gridding model, station and grid baseline datasets are generated using the 1991-2020 average of mean, maximum and minimum air temperature at stations and grid points. The baselines use the air temperature lapse-rate, 6.5°C per kilometre elevation, to capture the change in temperature with increasing elevation. These baseline datasets serve to account for the long-term characteristics of the distribution of temperature across the stations and grid, with the regression-IDW applied to the difference between the baseline and the temperature values at the particular month of interest. When the regression and IDW steps are complete, the baseline grid is added back to the calculated grid values.

Performance statistics are generated using a leave one out cross validation technique (LOOCV) where the regression and IDW is applied to predict the temperature parameter at a station location, a station which has been left out of the regression-IDW step, and this calculated value compared with the actual station temperature. This is repeated with each station in turn left out and its interpolated temperature compared with its observed temperature. The calculated statistics are shown below in table 2.

		Maximum Air Temperature				Minimum Air Temperature			
Month	**No. of stns**	**ME**	**MAE**	**RMSE**	**RMSEr**	**ME**	**MAE**	**RMSE**	**RMSEr**
Jan	168	-0.01	0.13	0.21	0.01	0.01	0.20	0.27	0.28
Feb	168	0.01	0.13	0.22	0.00	0.00	0.22	0.29	0.30
Mar	168	0.01	0.14	0.25	0.00	0.00	0.19	0.24	0.27
Apr	168	0.00	0.17	0.29	0.00	0.00	0.20	0.26	0.30
May	168	0.00	0.19	0.31	0.00	0.00	0.19	0.26	0.32
Jun	168	0.00	0.18	0.28	0.00	0.00	0.19	0.26	0.34
Jul	168	0.00	0.17	0.26	-0.01	-0.01	0.18	0.25	0.34
Aug	168	0.00	0.17	0.26	0.01	0.01	0.18	0.25	0.33
Sep	168	0.00	0.15	0.26	0.00	0.00	0.20	0.27	0.29
Oct	168	0.00	0.12	0.23	0.00	0.00	0.20	0.27	0.27
Nov	168	0.00	0.13	0.22	0.00	0.00	0.21	0.28	0.27
Dec	168	0.00	0.13	0.22	0.00	0.00	0.23	0.30	0.28

Table 2: The number of stations and measures of the quality of the regression-IDW fit are shown for each month. ME (mean error), MAE (mean absolute error), RMSE (root mean square error) and RMSEr (RMSE divided by the standard deviation of the error) are also presented here.

The final statistic in table 2, the RMSEr, is the RMSE divided by the standard deviation of the LOOCV errors and has values in the range of approximately 0.2-0.3 meaning that 90%-95% of the variation in the temperature values are captured by the regression-IDW model [Hengl. 2007].

Comparing the 1991 to 2020 LTA station temperature values with the equivalent station temperatures generated using the gridded data shows that the maximum, minimum and mean station air temperatures calculated using the grid are within 0.14°C to 0.19°C of the actual station values, based on the RMSE difference measure. The minimum air temperature is less well modelled by the grid with RMSE between 0.17°C and 0.19°C, while the mean and maximum air temperatures show better agreement between grid and station values – see table 3 below.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Tmean (°C)	5.4	5.6	6.8	8.7	11.2	13.7	15.3	15.1	13.3	10.4	7.5	5.7	9.9
ME (°C)	-0.02	-0.02	-0.02	-0.02	-0.02	-0.01	-0.02	-0.02	-0.02	-0.01	-0.01	-0.02	-0.02
MAE (°C)	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.08
RMSE (°C)	**0.15**	**0.15**	**0.15**	**0.14**	**0.15**	**0.15**	**0.14**	**0.15**	**0.15**	**0.15**	**0.14**	**0.15**	**0.14**
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Tmax (°C)	8.3	8.8	10.4	12.8	15.5	17.8	19.2	19	17.1	13.7	10.5	8.6	13.5
ME (°C)	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02
MAE (°C)	0.09	0.09	0.1	0.1	0.11	0.1	0.09	0.1	0.1	0.09	0.09	0.1	0.08
RMSE (°C)	**0.15**	**0.14**	**0.15**	**0.15**	**0.16**	**0.16**	**0.14**	**0.15**	**0.15**	**0.15**	**0.14**	**0.15**	**0.14**
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Tmin (°C)	2.5	2.5	3.3	4.7	7.1	9.7	11.5	11.3	9.6	7.1	4.5	2.9	6.4
ME (°C)	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
MAE (°C)	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.11	0.12	0.11
RMSE (°C)	**0.18**	**0.18**	**0.18**	**0.17**	**0.17**	**0.18**	**0.17**	**0.18**	**0.19**	**0.18**	**0.17**	**0.19**	**0.17**

Table 3: The mean, maximum and minimum air temperatures for stations used to create the grid are shown by month and annual average for the 1991 to 2020 period on the top row of this table. Rows below this show the mean error (ME), the mean absolute error (MAE) and the RMSE difference between the station value and a value based on nearest interpolated grid-points.

The gridding algorithm is applied to each month over the period of interest, and the grids then aggregated to produce LTA grids periods such as for the 1991 to 2020 timeframe. Gridding allows air temperature statistics such as the mean, median or 95th percentile of air temperatures for Ireland to be determined. Difference grids can be calculated by simply subtracting one grid from another, for example allowing the minimum air temperature anomaly between 1961 to 1990 LTA and the current LTA period to be mapped and statistics calculated. The infilling and homogenisation of the station data minimises the occurrence of 'bullseyes' or areas on the maps where the difference is not climate related, but due to the presence or absence of a station at a particular location.

3. Results and Discussion

Grids were generated for each month of every year from 1961 to 2020 for maximum, minimum and mean air temperature. From this dataset LTA annual, seasonal and monthly maps were generated for the 30-year periods 1991-2020, and 1961-1990 along with difference maps which compare the long-term averages for the two periods.

3.1 1991-2020 Mean air temperature LTAs

The annual mean air temperature for Ireland over the period 1991-2020 is 9.8°C. The annual mean air temperature ranges from approximately 8.5°C to 10.8°C across the country.

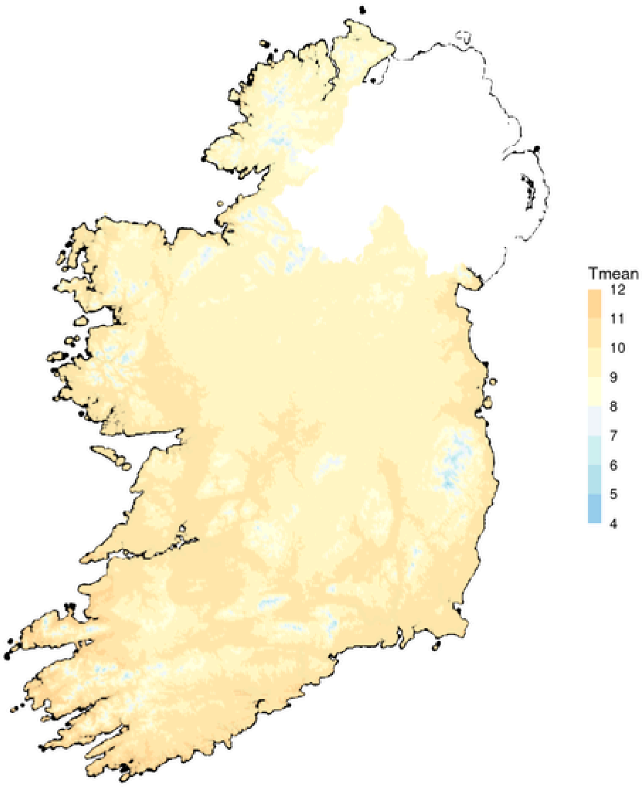

Figure 3: Annual mean air temperature (°C) 1991-2020

Summer is the warmest season in the 1991-2020 period with a mean air temperature for Ireland of 14.6°C. Autumn is the second warmest season with a mean air temperature of 10.3°C, followed by spring at 8.8°C. Winter is the coldest season with a mean air temperature of 5.4°C.

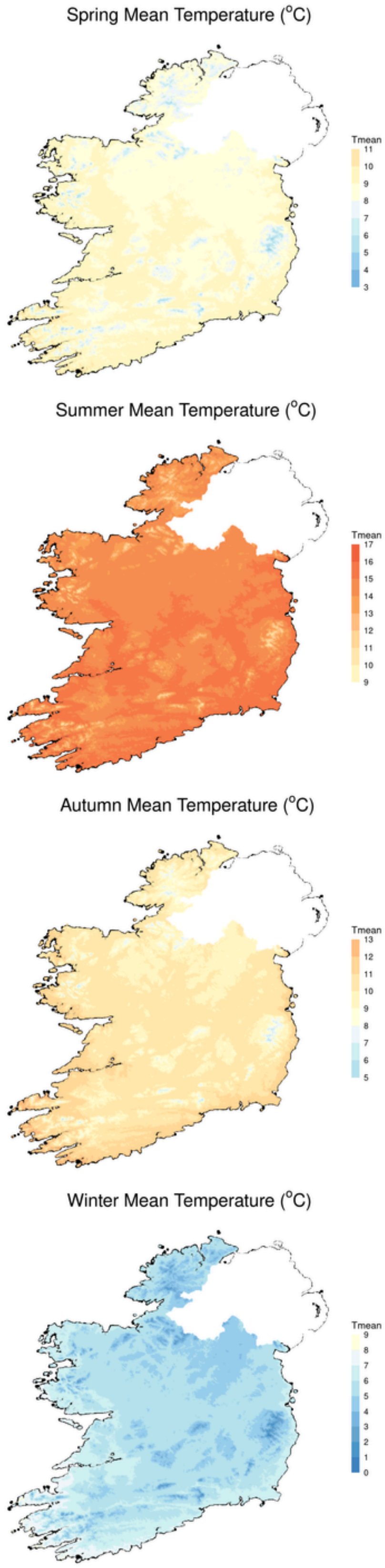

Figure 4: Seasonal mean air temperature (°C) 1991-2020

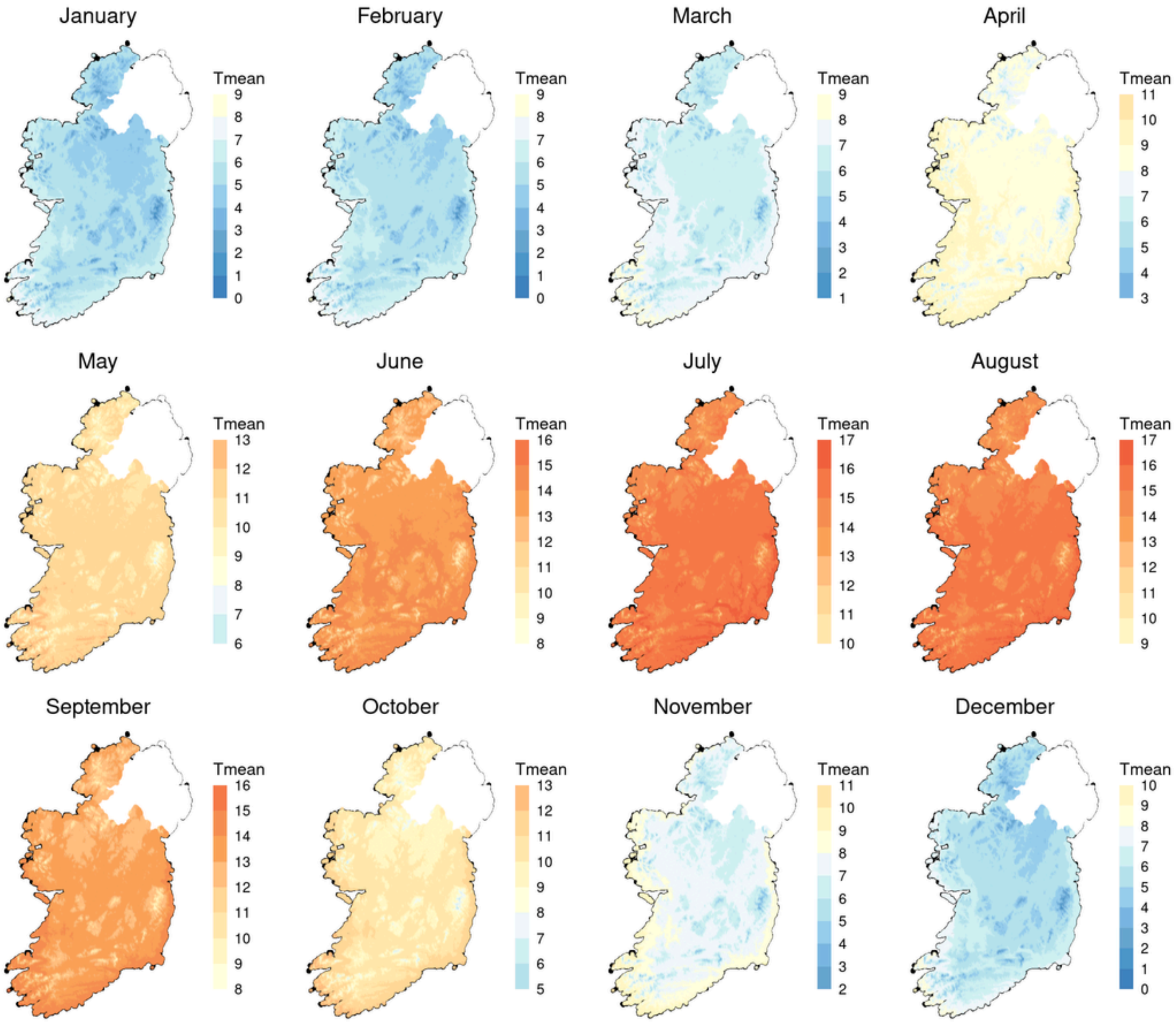

Figure 5: Monthly mean air temperature for the 1991-2020 LTA period.

The highest monthly mean air temperatures for Ireland are observed in July and August, with monthly mean air temperature of 15.2°C and 15°C, respectively. June has the third highest monthly mean air temperature at 13.6°C. The winter months are the coldest over the 30-year period, with the lowest monthly mean air temperatures observed in January at 5.3°C. February is the second coldest month with a monthly mean air temperature of 5.5°C, followed by December at 5.6°C.

Higher elevation areas are clearly cooler than lower lying areas throughout the year. There is a coastal effect evident where areas within 10 km of the sea are more than 0.5°C warmer from November to February, but these same coastal areas are slightly cooler than inland areas during July and August by about 0.2°C.

3.2 Comparison between the 1991-2020 and 1961-1990 mean air temperature LTAs

Comparing the 1991-2020 annual mean air temperature for Ireland with that of the 1961-1990 period, there has been an increase of approximately 0.7°C.

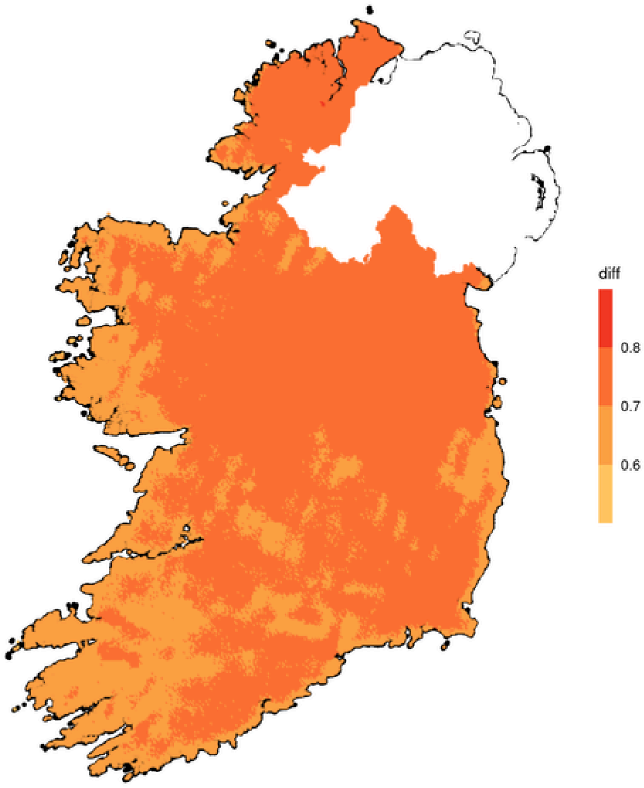

Figure 6: Annual mean air temperature comparison (°C)

Mean air temperature has increased in all seasons. Spring shows the highest increase of approximately 0.8°C. Winter has the smallest increase at 0.6°C. Summer and autumn observed an increase of approximately 0.7°C.

Tmean	Annual	Spring	Summer	Autumn	Winter
1991-2020 (°C)	9.8	8.8	14.6	10.3	5.4
1961-1990 (°C)	9.1	8.0	13.9	9.6	4.8
Difference (°C)	0.7	0.8	0.7	0.7	0.6

Table 4: Annual and seasonal mean air temperature comparison (°C)

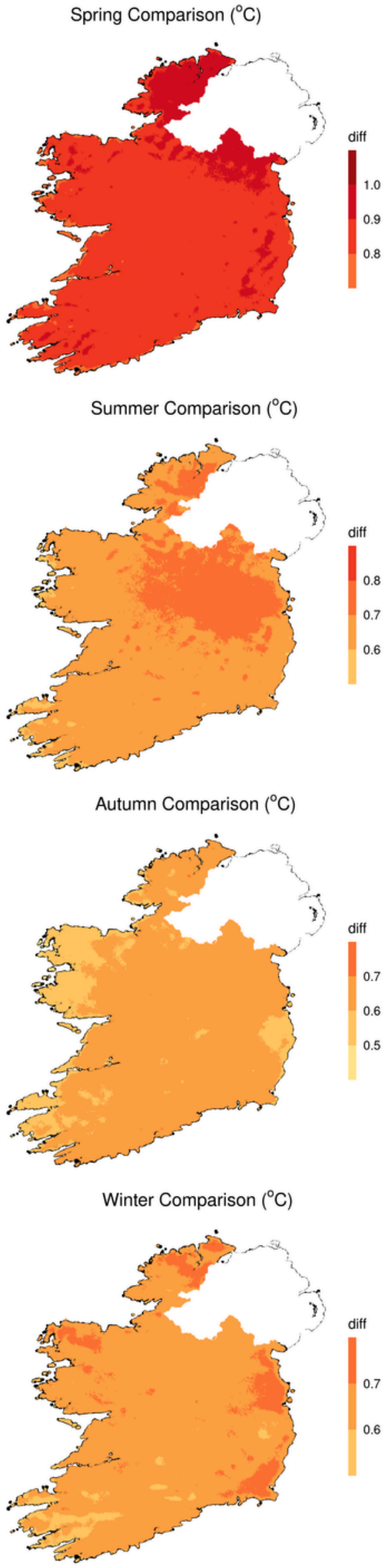

Figure 7: Seasonal mean air temperature comparison (°C)

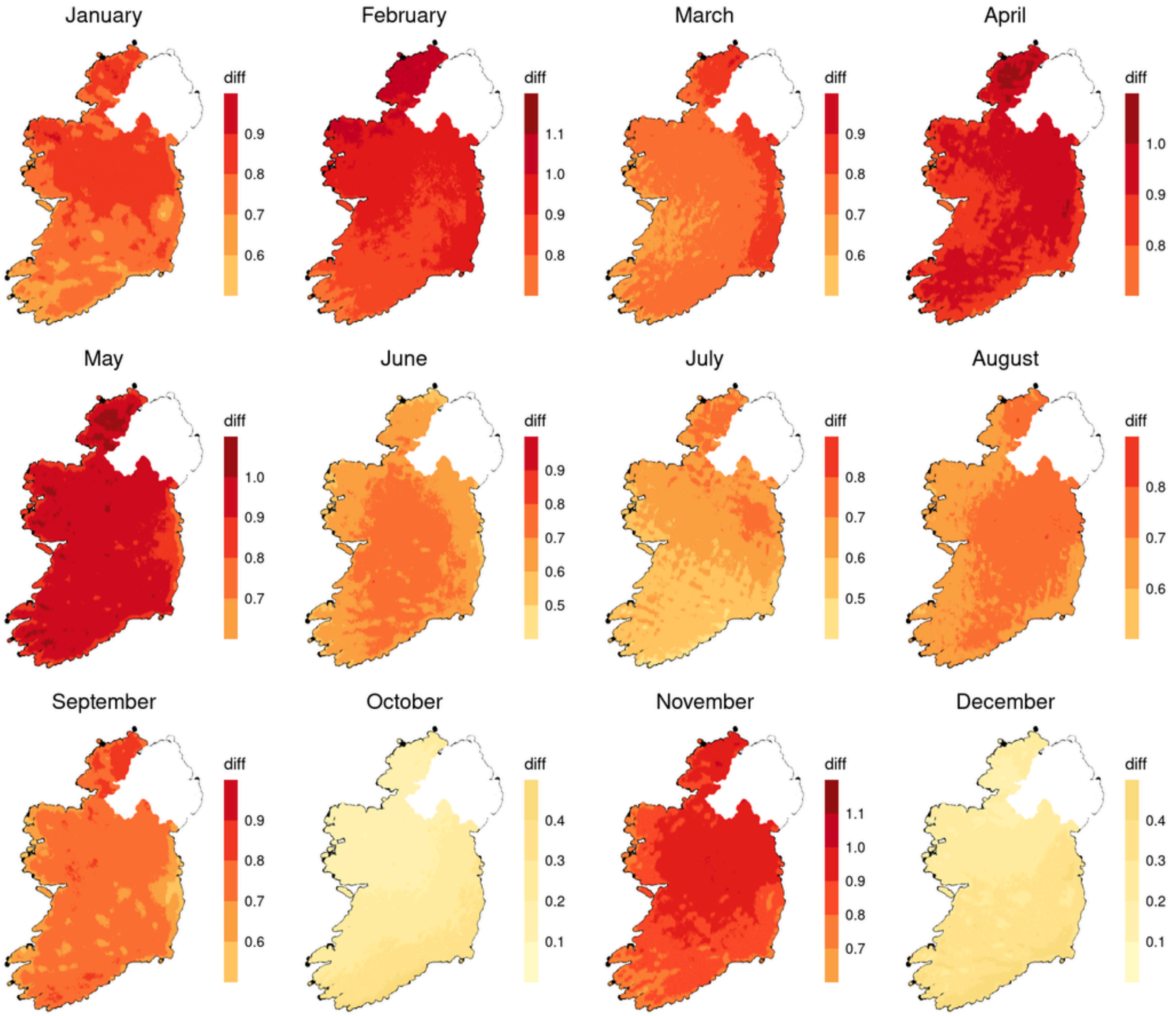

Figure 8: Monthly mean air temperature comparison between 1991-2020 and 1961-1990

All months observed an increase in mean air temperature in the 1991-2020 period when compared with the 1961-1990 period. The greatest increase at 0.9°C is observed in February, April, May and November. The smallest increase in monthly mean air temperature is in October at 0.2°C, followed by December at 0.3°C. All other months observed an increase of between 0.6°C and 0.8°C.

Tmean	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991-2020 (°C)	5.3	5.5	6.7	8.6	11.1	13.6	15.2	15	13.2	10.2	7.4	5.6
1961-1990 (°C)	4.5	4.6	6.0	7.7	10.2	12.9	14.6	14.3	12.4	10.0	6.5	5.3
Difference (°C)	0.8	0.9	0.7	0.9	0.9	0.7	0.6	0.7	0.8	0.2	0.9	0.3

Table 5: Monthly mean air temperature comparison (°C)

3.3 1991-2020 Maximum air temperature LTAs

The annual mean maximum air temperature for Ireland over the period 1991-2020 is 13.4°C. The annual maximum air temperature ranges from approximately 12.0°C to 14.2°C across the country.

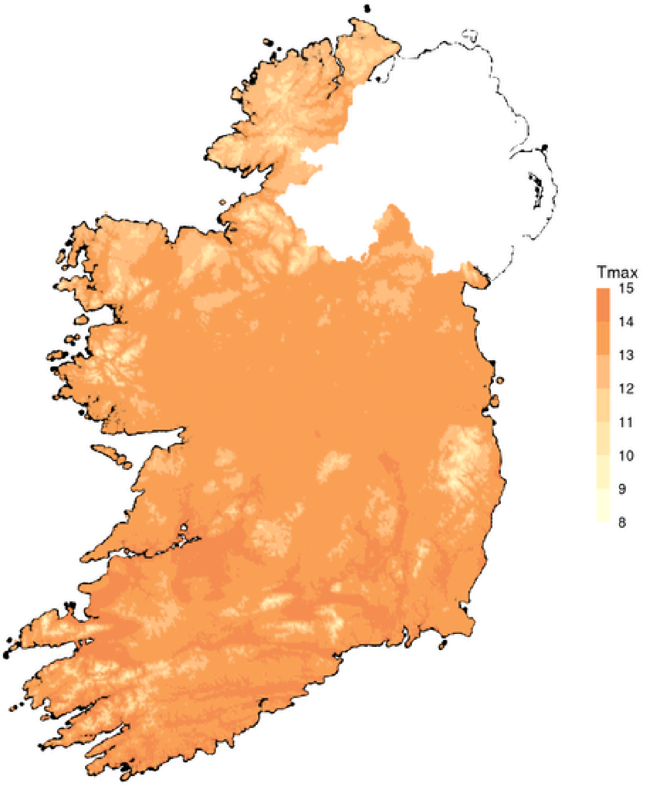

Figure 9: Annual maximum air temperature (°C) 1991-2020

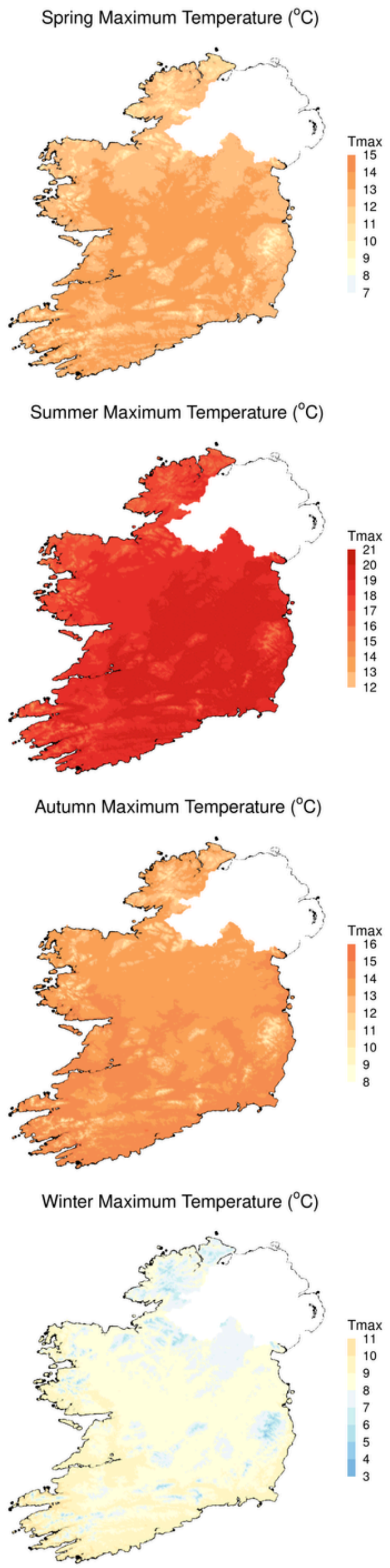

Figure 10: Seasonal maximum air temperature (°C) 1991-2020

Summer is the season with the highest mean maximum air temperature for Ireland with a value of 18.6°C. Autumn is the second highest with a mean maximum air temperature of 13.7°C, followed by spring at 12.8°C and winter at 8.5°C.

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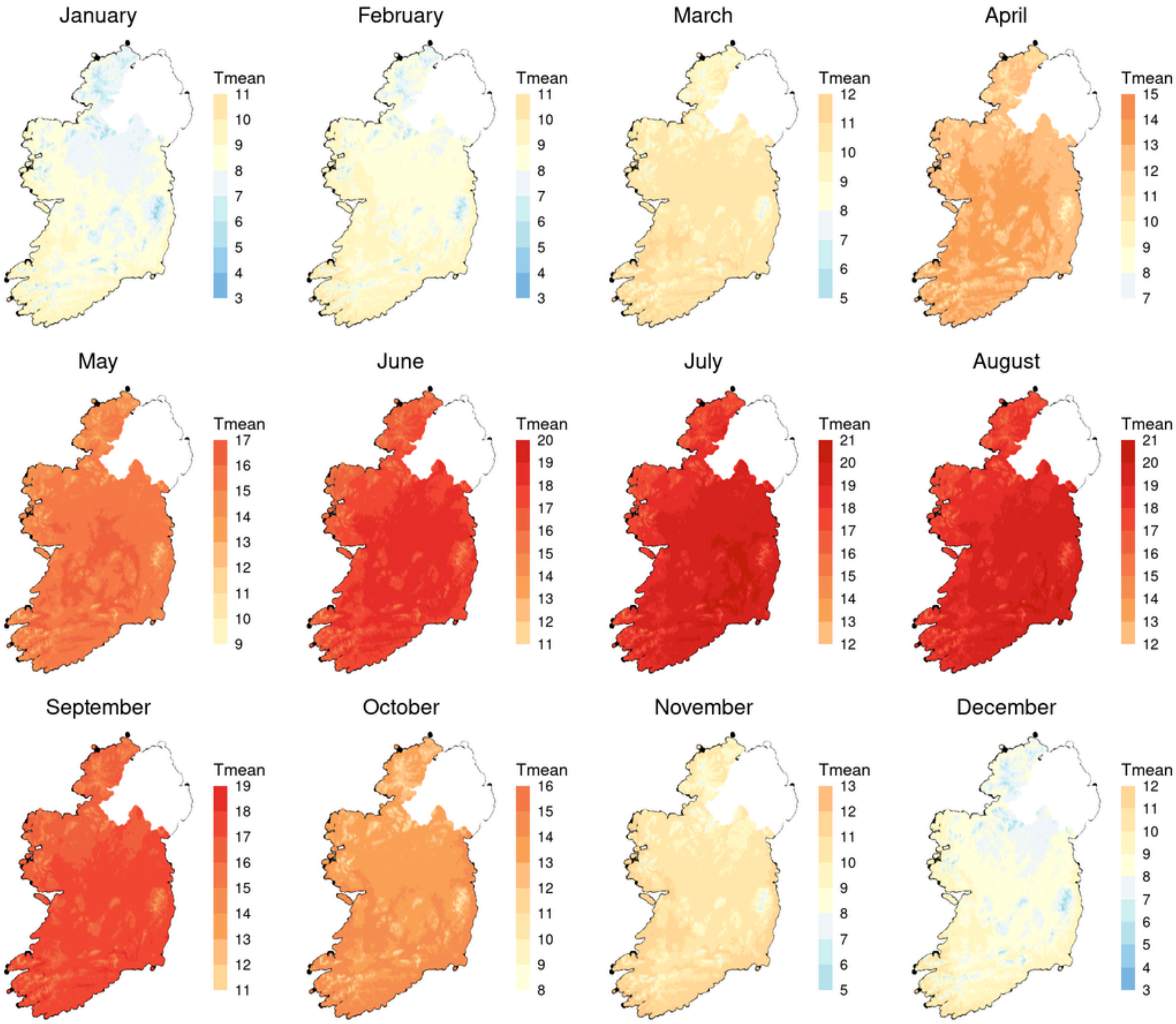


Figure 11: Monthly maximum air temperature (°C) 1991-2020

With regards to the monthly maximum air temperature, July has the highest mean maximum air temperature with a value of 19.1°C, closely followed by August at 18.9°C, and June at 17.8°C. January has the lowest mean maximum air temperature at 8.2°C, followed by December at 8.5°C and February at 8.7°C.

3.4 Comparison between the 1991-2020 and 1961-1990 maximum air temperature LTAs

There has been an increase of approximately 0.7°C when the 1991-2020 annual maximum air temperature LTA for Ireland is compared with that for the 1961-1990 period.

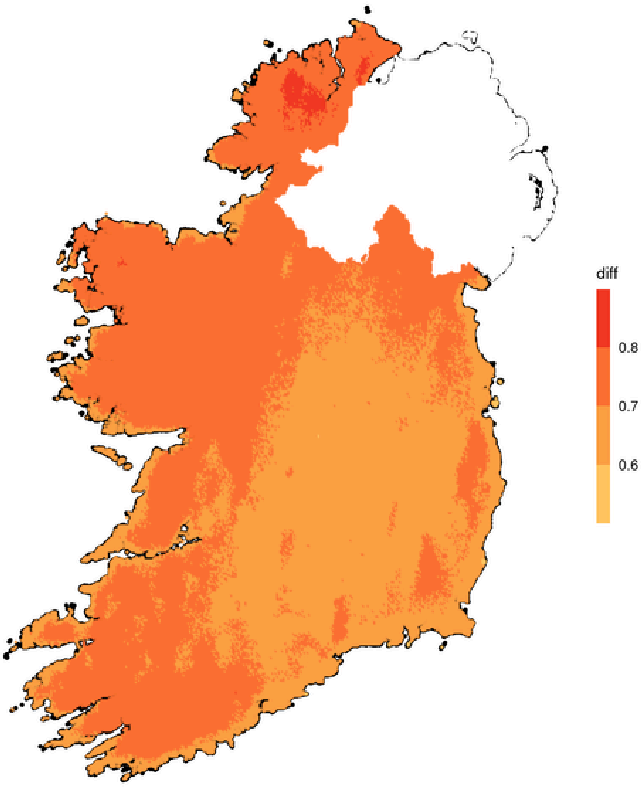


Figure 12: Annual maximum air temperature comparison (°C)

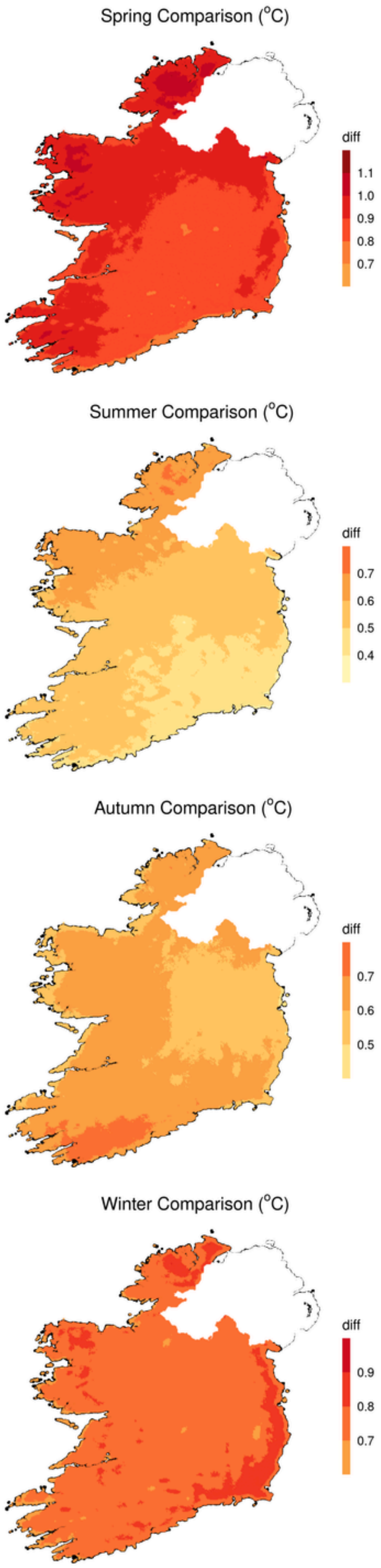


Figure 13: Seasonal maximum air temperature comparison (°C)

Maximum air temperature has increased in all seasons. Spring shows the highest increase of approximately 0.9°C, followed by winter with an increase of 0.8°C. Summer and autumn observed an increase of approximately 0.6°C.

Tmax	Annual	Spring	Summer	Autumn	Winter
1991-2020 (°C)	13.4	12.8	18.6	13.7	8.5
1961-1990 (°C)	12.7	11.9	18.0	13.1	7.7
Difference (°C)	0.7	0.9	0.6	0.6	0.8

Table 6: Annual and seasonal max air temperature comparison (°C)

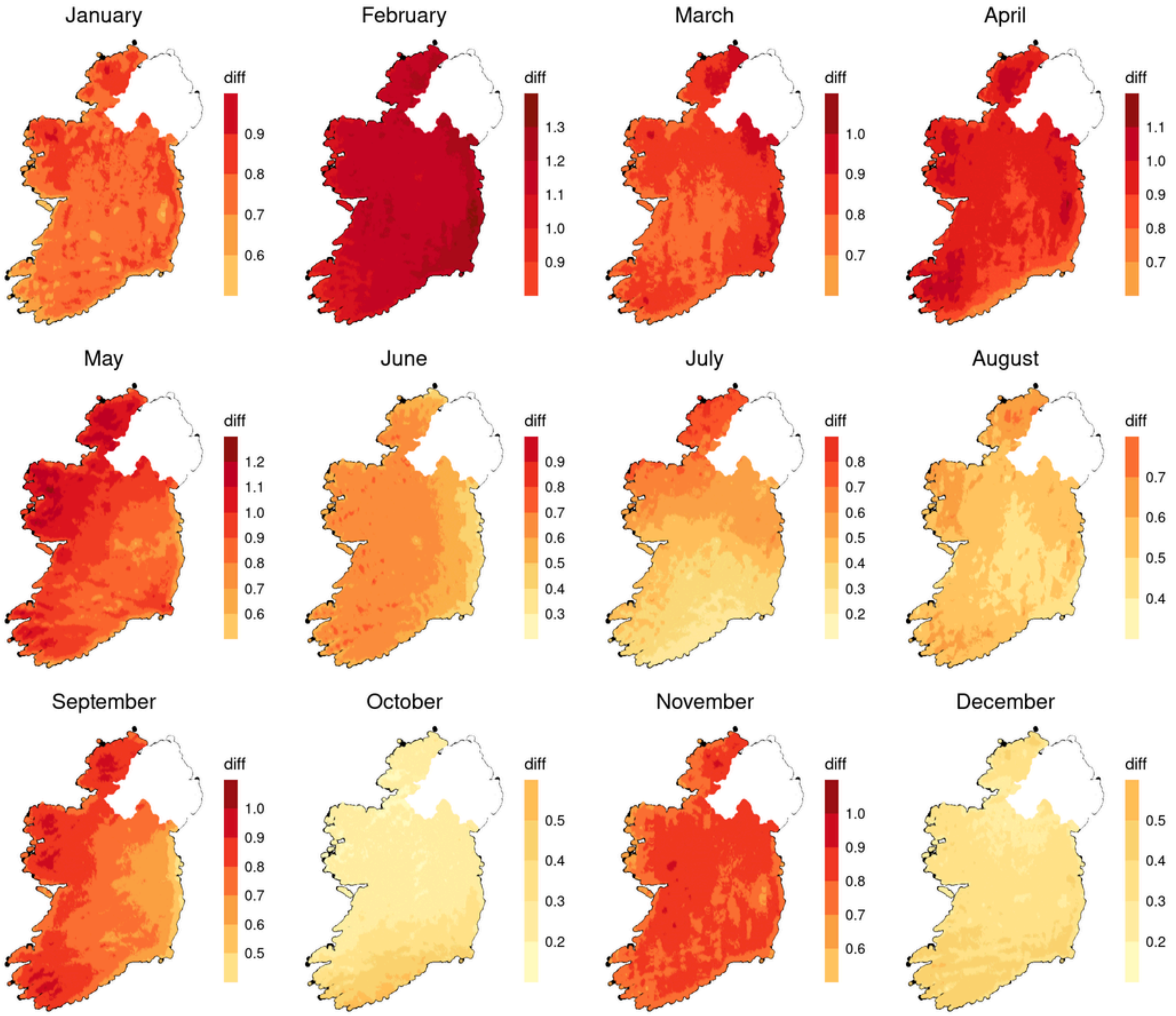


Figure 14: Monthly maximum air temperature comparison between 1991-2020 and 1961-1990

All months observed an increase in maximum air temperature in the 1991-2020 period when compared with the 1961-1990 period. February had the biggest increase with a value of 1.2°C, followed by April and May with increases of 0.9°C in each month. The smallest increase in monthly mean air temperature is in October at 0.3°C, followed by December at 0.4°C. All other months observed an increase of between 0.5°C and 0.8°C.

Tmax	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991-2020 (°C)	8.2	8.7	10.3	12.7	15.4	17.8	19.1	18.9	17.0	13.6	10.4	8.5
1961-1990 (°C)	7.4	7.5	9.5	11.8	14.5	17.1	18.6	18.3	16.2	13.3	9.6	8.1
Difference (°C)	0.8	1.2	0.8	0.9	0.9	0.7	0.5	0.6	0.8	0.3	0.8	0.4

Table 7: Monthly maximum air temperature comparison (°C)

3.5 1991-2020 Minimum air temperature LTAs

The annual mean minimum air temperature for Ireland for the period 1991-2020 is 6.2°C. The annual minimum air temperature ranges from approximately 4.9°C to 7.6°C across the country.

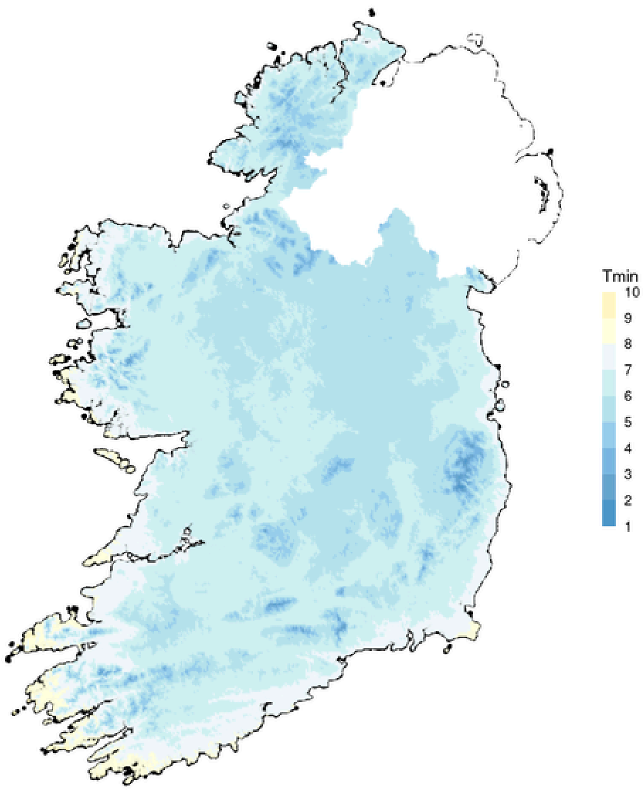


Figure 15: Annual minimum air temperature (°C) 1991-2020

Winter has the lowest mean minimum air temperature for Ireland with a value 2.4°C. Spring has the second lowest mean minimum air temperature at 4.8°C, followed by autumn at 6.8°C. Summer has the highest mean minimum air temperature at 10.7°C.

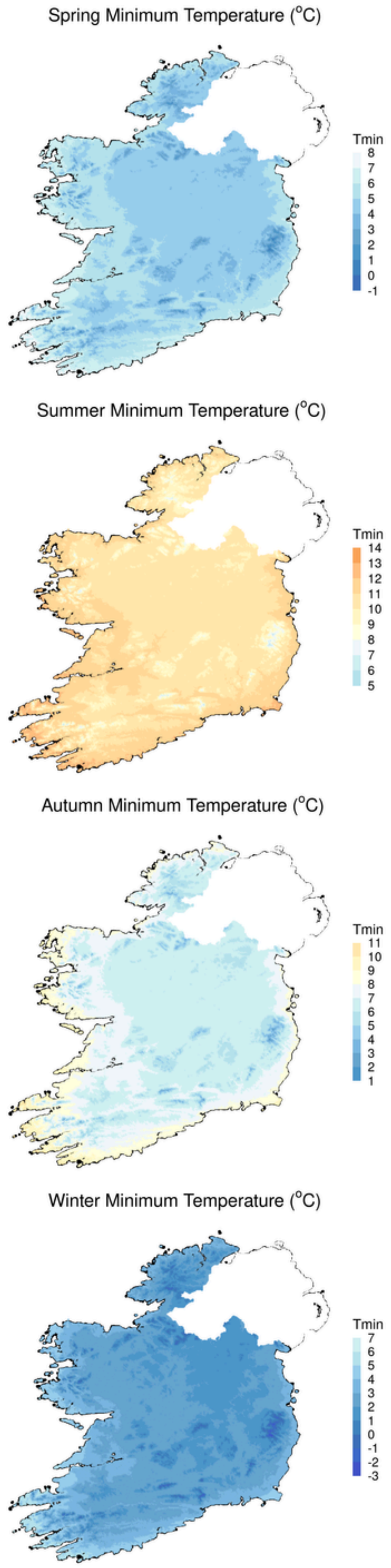


Figure 16: Seasonal maximum air temperature (°C) 1991-2020

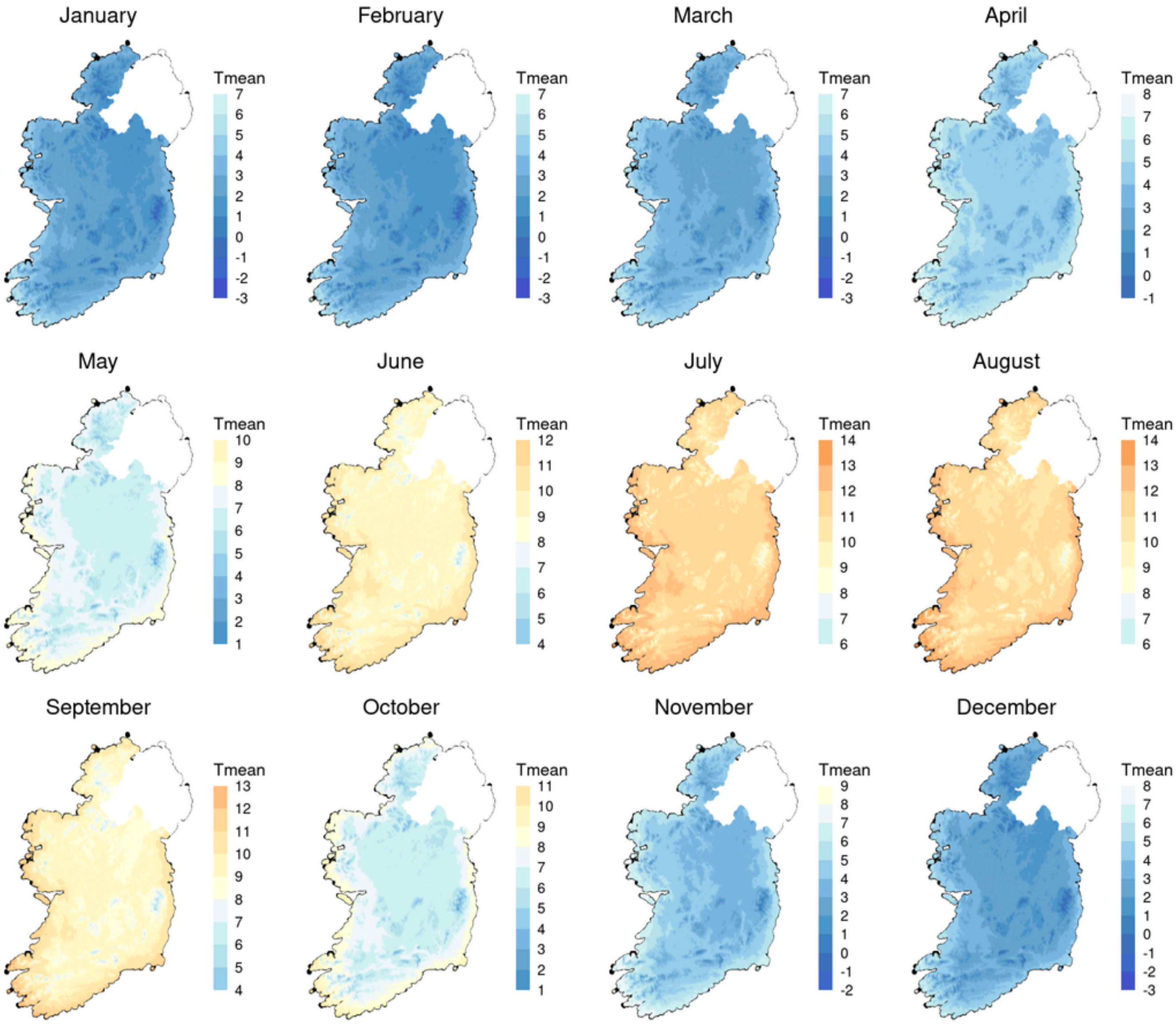


Figure 17: Monthly minimum air temperature (°C) 1991-2020

January and February have the lowest monthly mean minimum air temperature at 2.3°C, followed by December at 2.7°C. The summer months have the highest monthly mean minimum air temperatures. Minimum temperatures are at their highest in July and August, with mean minimum air temperatures of 11.4°C and 11.2°C, respectively.

3.6 Comparison between the 1991-2020 and 1961-1990 minimum air temperature LTAs

Comparing the 1991-2020 annual minimum air temperature for Ireland with that of the 1961-1990 period, there has been an increase of approximately 0.7°C.

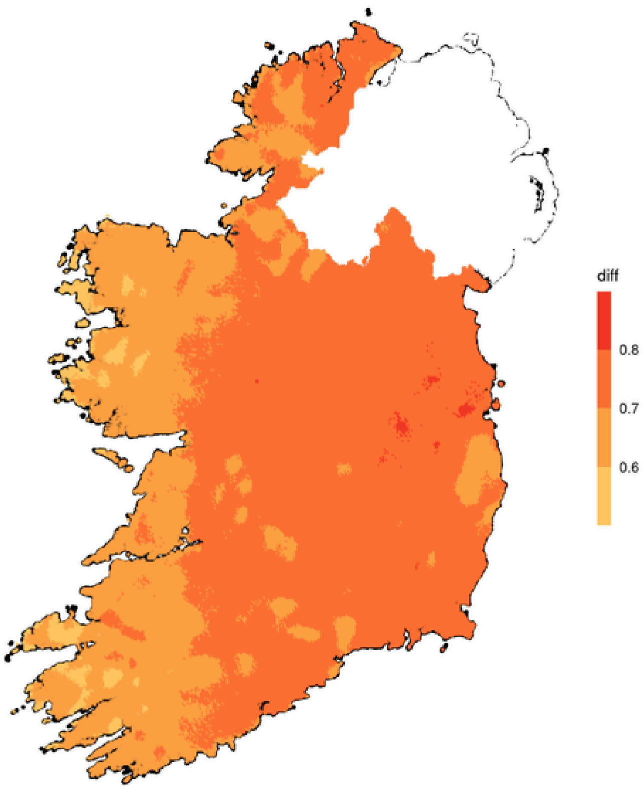


Figure 18: Annual minimum air temperature comparison (°C)

Minimum air temperature has increased in all seasons. Spring and summer show the highest increase of approximately 0.8°C. Winter shows the smallest increase at 0.5°C. Autumn observed an increase of approximately 0.6°C.

Tmin	Annual	Spring	Summer	Autumn	Winter
1991-2020 (°C)	6.2	4.8	10.7	6.8	2.4
1961-1990 (°C)	5.5	4.0	9.9	6.2	1.9
Difference (°C)	0.7	0.8	0.8	0.6	0.5

Table 8: Annual and seasonal min air temperature comparison (°C)

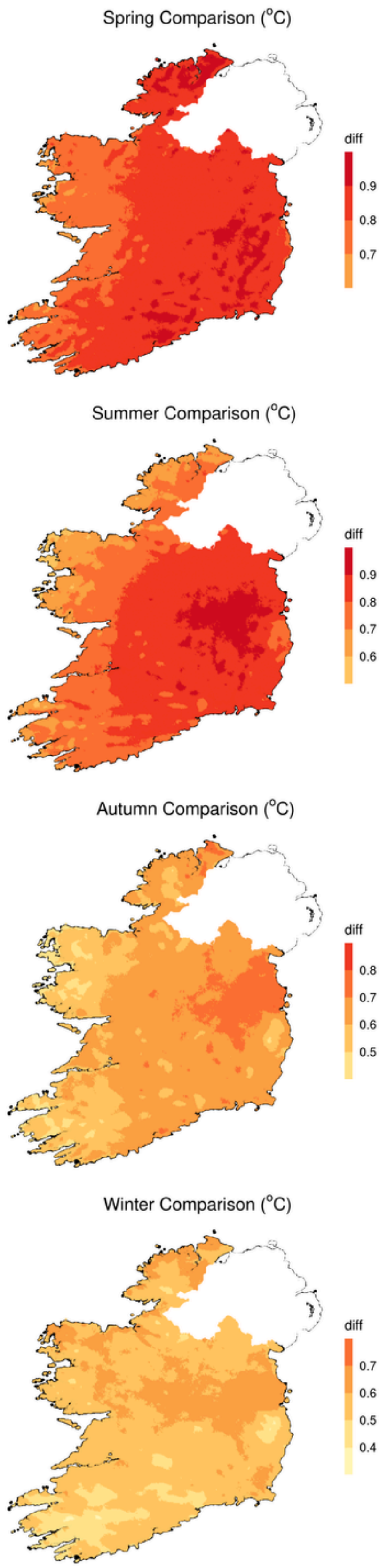


Figure 19: Seasonal minimun air temperature comparison (°C)

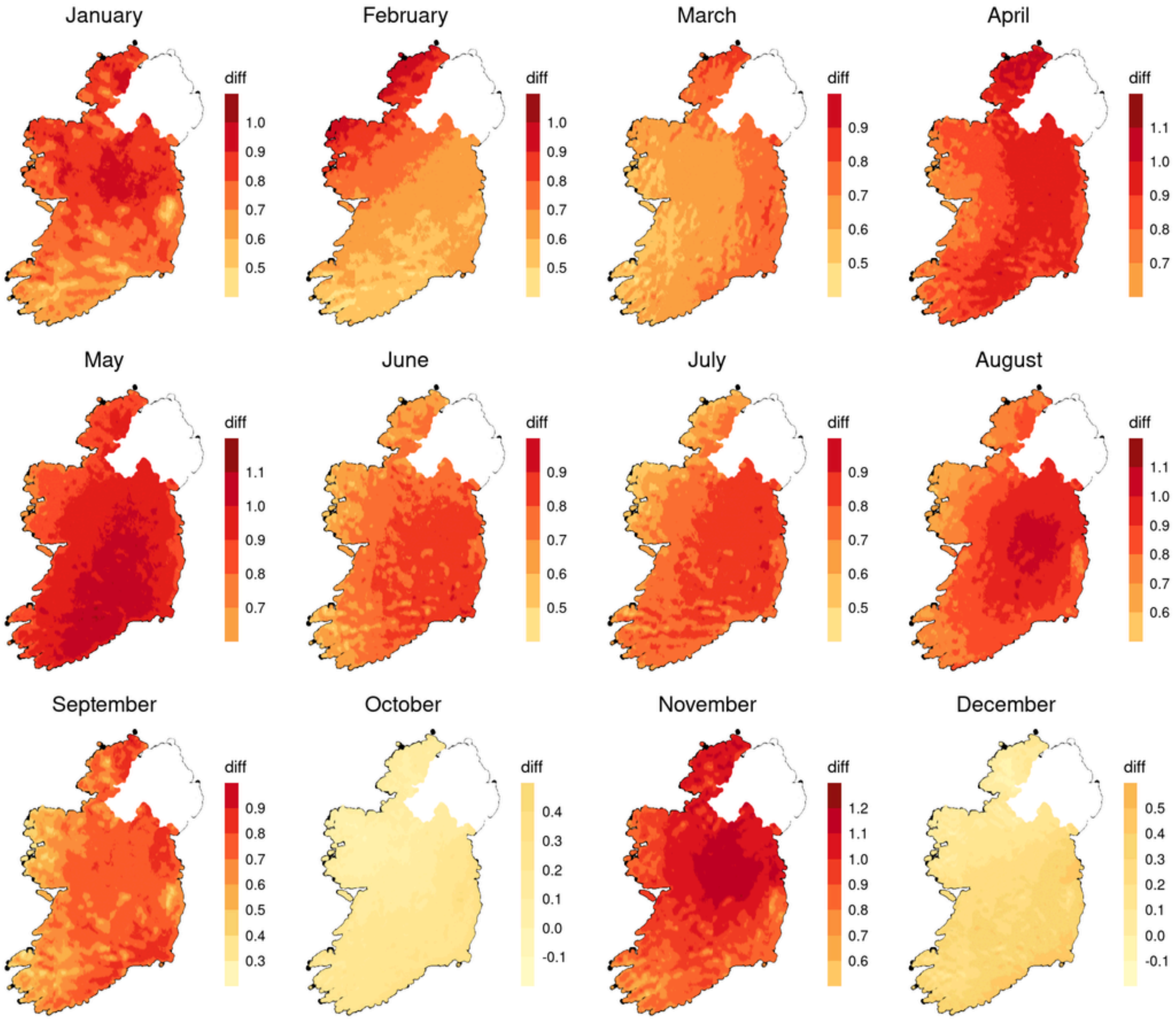


Figure 20: Monthly minimum air temperature comparison between 1991-2020 and 1961-1990

All months observed an increase in minimum air temperature in the 1991-2020 period when compared with the 1961-1990 period. The greatest increase at 1°C is observed in May and November, followed by April and August which show an increase of 0.9°C. The smallest increase in monthly mean air temperature is in October at 0.2°C, followed by December at 0.3°C. All other months observed an increase of 0.7°C or 0.8°C.

Tmin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991-2020 (°C)	2.3	2.3	3.1	4.5	6.9	9.5	11.4	11.2	9.4	6.9	4.3	2.7
1961-1990 (°C)	1.5	1.6	2.4	3.6	5.9	8.7	10.6	10.3	8.7	6.7	3.3	2.4
Difference (°C)	0.8	0.7	0.7	0.9	1.0	0.8	0.8	0.9	0.7	0.2	1.0	0.3

Table 9: Monthly minimum air temperature comparison (°C)

3.7 Summary of monthly and annual air temperatures over the period 1961-2020

Tables 4 to 9 summarise the LTA annual, seasonal and monthly values for mean, maximum and minimum air temperature for the 1991-2020 LTA with the difference between this LTA and the period 1961-1990 also tabulated. While all months have recorded an increase in temperature between the recent LTA and the period 1961 to 1990, the change varies from month to month. For example, October has seen just a 0.2-03°C increase across all air temperature measures, but the following month, November, has a 0.8°C-1.0°C increase recorded.

3.8 Annual variability in mean air temperature from 1961-2020

Whilst the annual maximum, minimum and mean air temperatures have each increased by 0.7°C between 1961-1990 and 1991-2020, there is variability from year to year. Figure 21 shows the mean air temperature anomaly from 1961 to 2020 from the 1961-1990 LTA. All years since 1988, except 2010, show annual average temperatures above the 1961-1990 LTA, however the increase in temperature is not a gradual and uniform trend.

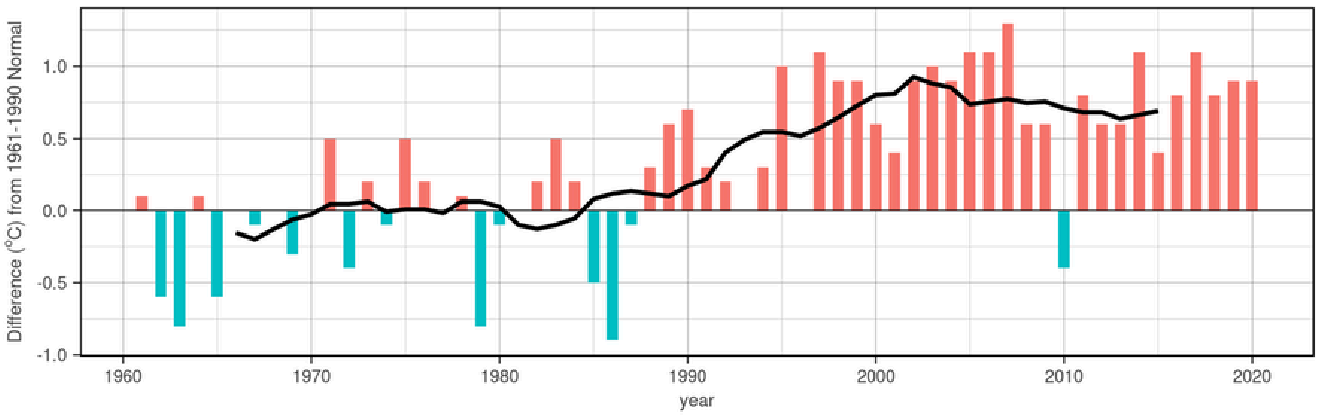


Figure 21: The difference between annual mean temperatures for each year from 1961 to 2020 and the 1961-1990 LTA. The solid line is an 11-year rolling average of the temperature anomaly.

Looking at the mean temperature anomaly for each month from 1961 to 2020, with the 1961-1990 LTA serving as a baseline, shows the variability of temperature from year to year, (Figure 21). Though the annualised increase in mean air temperature is 0.22°C per decade, there are differences in the decadal change in monthly data, see Figure 22 below. May shows the largest rise in air temperature per decade from 1961 to 2020 of 0.29°C, with October showing the lowest increase of 0.08°C per decade. All increasing monthly trends in mean air temperature are significant based on a Mann-Kendall ($p < 0.05$) except for October.

Year on year variability in the annual temperature data is also clear in monthly temperature data. There are notable instances where significantly lower temperatures have been recorded more recently, for example December 2010, when the lowest December average mean air temperature between 1961 and 2020 was recorded.

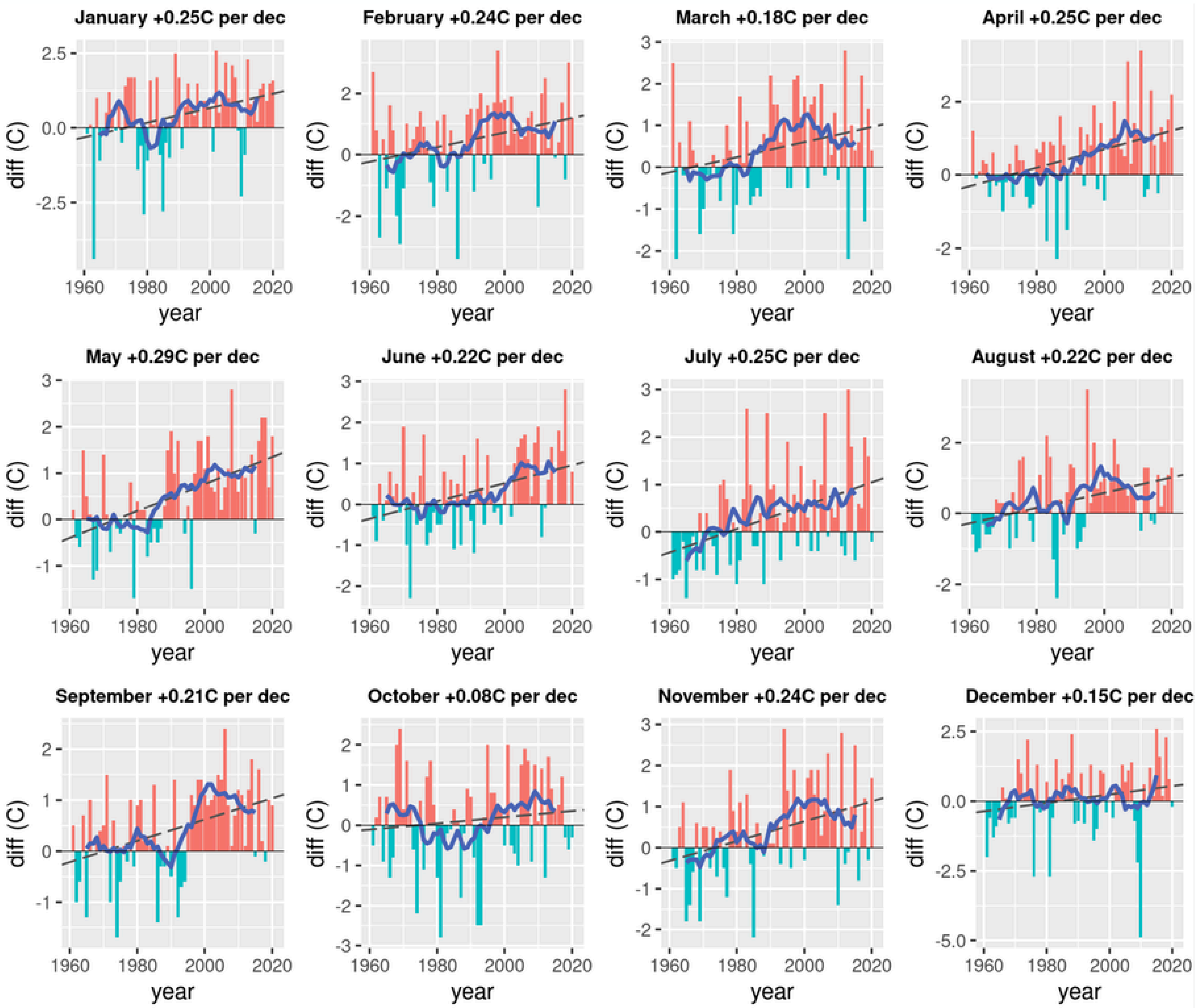
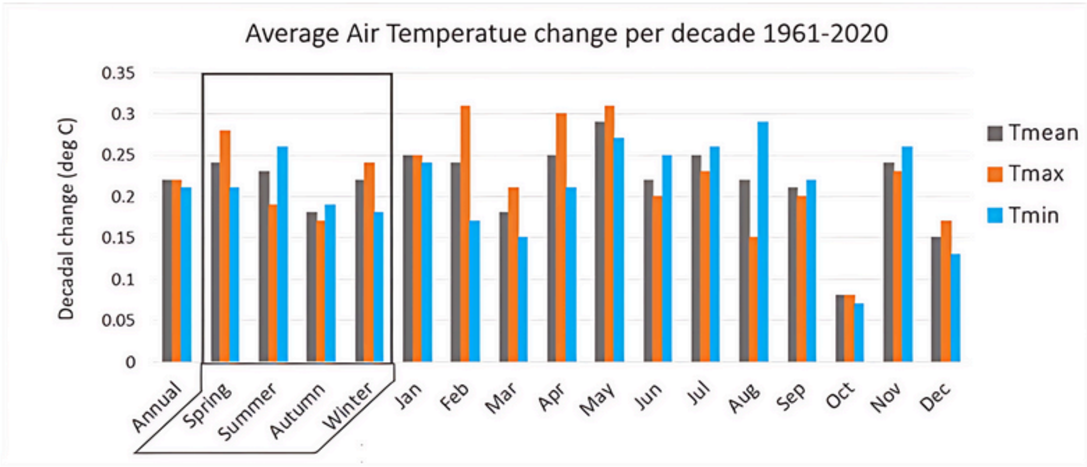


Figure 22: Difference between the monthly LTA based on 1961 to 1990 mean air temperature and the monthly average for each year 1961 to 2020 is shown here with the decadal trend in temperature and 11-year rolling average also presented.

Whilst the increasing decadal trend in maximum, minimum and mean air temperature is very close on an annual basis, differences can be seen at a seasonal or monthly level (Figure 23). In summer months the minimum air temperature is tending to increase faster than the maximum air temperature, but in spring and winter the opposite is the case. Overall, air temperature has increased, but there is significant variability from year to year.



	Annual	Spring	Summer	Autumn	Winter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tmean	0.22	0.24	0.23	0.18	0.22	0.25	0.24	0.18	0.25	0.29	0.22	0.25	0.22	0.21	0.08	0.24	0.15
Tmax	0.22	0.28	0.19	0.17	0.24	0.25	0.31	0.21	0.3	0.31	0.2	0.23	0.15	0.2	0.08	0.23	0.17
Tmin	0.21	0.21	0.26	0.19	0.18	0.24	0.17	0.15	0.21	0.27	0.25	0.26	0.29	0.22	0.07	0.26	0.13

Figure 23: Decadal trends in maximum, minimum and mean air temperature for months, seasons and the annual value.

4. Conclusion

This report outlines the steps taken to compile the annual, seasonal, and monthly long-term 30-year averages for maximum, minimum and mean air temperature for Ireland over the period 1991-2020.

A description of the quality-control, homogenisation and infilling methods used to produce a consistent dataset spanning the period 1961-2020 is presented. This dataset was used to calculate monthly averages of air temperature from which gridded data and maps were compiled.

The annual mean, maximum and minimum air temperature for Ireland over the period 1991-2020 is 9.8°C, 13.4°C and 6.2°C respectively. A comparison with the previous 30-year period (1961-1990), shows that maximum, minimum and mean air temperatures have all increased by 0.7°C between the two periods.

Based on data from 1961 to 2020, the annualized increase in mean temperature is 0.22°C per decade. According to the Mann-Kendall test, this increasing trend is statistically significant. Decadal increases are observed for each month, but it is important to note the significant year-to-year variability.

Going forward, weather and climate statistics will reference the new long-term average period 1991-2020, unless otherwise stated. These will replace the 1981-2010 long-term averages that are currently in use. The historical baseline period of 1961-1990 will be retained for use in climate change assessments.

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