Met Éireann

Climatological Note No. 16

Long-term temperature averages for Ireland 1981-2010

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Title: Long-term rainfall averages for Ireland, 1981-2010.

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1. ABSTRACT

Long-Term Averages (LTA) or Climate Normals are 30-year averages of weather elements. They are used to describe the current climate and to place current weather in context. Met Éireann has produced a suite of LTAs covering the period 1981-2010 which have replaced the 1961-1990 LTAs for day-to-day comparison purposes. LTAs of monthly maximum, minimum and mean temperature have been generated for 138 locations; using these data and data for Northern Ireland, provided by the United Kingdom Meteorological Office (UKMO), gridded values covering the Island of Ireland have been produced at resolution of $1km^2$.

The paper details the process involved in generating the new LTAs, from data collection through the network of climatological observers, to quality control and estimation of missing values, and finally the geo-statistical methods used to produce the gridded datasets. A comparison is also made between the LTAs for 1961-1990 and 1981-2010, which shows an increase of approximately 0.5 degrees Celsius in Average Mean Temperature, and other seasonal and monthly changes.

2. INTRODUCTION

It is usual to place current weather events in context by comparing them to long-term averages or 'normals'. LTAs are also used for as a benchmark for climate models and across a wide range of environmental disciplines.

Climate Normals or long term averages are 30 year averages of a particular parameter, usually produced in 10 year cycles, 1951-1980, 1961-1990 etc. There is a need for up to date sets of LTAs to reflect the most recent 30-year period, and as GIS systems are now widely in use there is also a need for quality gridded datasets at high spatial resolution.

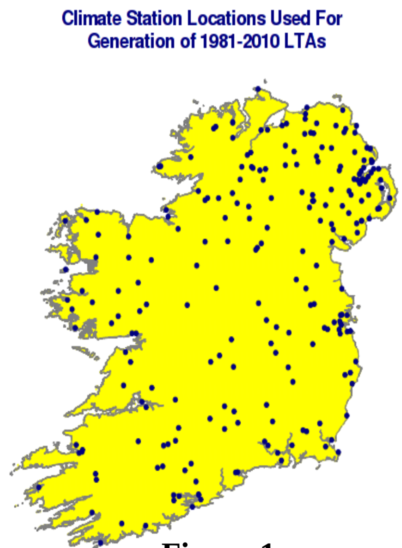

Figure 1
Climatological Station Locations

Temperature is a basic meteorological and climatological parameter. This paper describes the production of new sets of monthly and annual long-term temperature averages for climatological observing sites in the Republic of Ireland (ROI) covering the period 1981-2010, and the production of gridded data sets for the Island of Ireland including data for Northern Ireland provided by the United Kingdom Meteorological Office (UKMO). Figure 1 shows the station locations for which LTAs were calculated. Station values for the 1961-1990 period are also produced for ROI stations using a consistent analysis method to allow for comparison with the new LTA period.

The compilation of the new averages involves data collection and quality control, statistical techniques for data and analysis infilling, and geo-statistical techniques for the generation of gridded data sets (See Figure 2). These LTAs define the temperature regime of Ireland and are used in the production of monthly, seasonal and annual weather statistics.

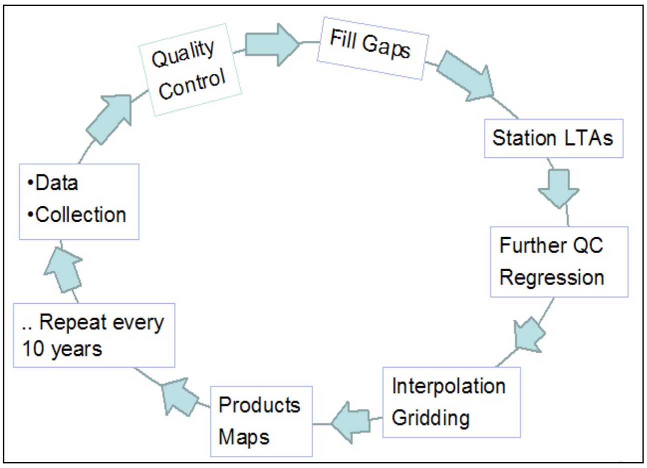

Figure 2
Procedure to produce long-term averages

3. DATA

3.1 The Climatological Network

At climatological stations a daily maximum, minimum and dry bulb temperature reading is taken every day at 0900UTC. Data are recorded manually and returned to Met Éireann at the end of each month where the data are quality controlled and entered into the National Climate Database. This database contains daily air temperature records from 1961. In the case of the minimum temperature the temperature is assigned to the current day and in the case of the maximum temperature the reading is assigned to the previous day. If no reading is recorded on a particular day a null value is returned. The network is, for the most part, operated by voluntary observers, the number of locations varies from year to year.

3.2 Quality Control

Data used was extracted from the Met Éireann database. This contains digital temperature records from 1961. All data in the database had undergone basic quality control (QC). However as QC programs had been developed and improved over a number of years, a new QC system was developed which included the use of spatial techniques. All data were run through the new QC.

QC Checks	Summary of tests
1. Extreme Climate Values	1. Are Maximum and Minimum values within +/- 1 Degree Celsius of the absolute values for the period
2. Tmin>Tmax	2. Is the Maximum less than the Minimum
3. Day to day step Change	3. Is the step change within limits defined by the long term climatology
4. Days with same Max/Min values	4. Days with more than 2 days with consecutive Max/Min values
5. Tmax/Tmin >/< drybulb of previous/next day	5. Is Tmax >= Drybulb on day of observation and previous day Is Tmin <= Drybulb on day of observation

Table 1: Summary of Temperature Quality Control

Approximately 3 million temperature readings for the 1961-2010 period were examined, of these approximately 74,000 observations were flagged as suspect, these were checked against neighbouring observations using a spatial regression test (Hubbard, 2005). This test involves using regression relationships with neighbouring stations to predict values, if these values are within defined limits the value is accepted, if the predicted value is outside these limits the original value is rejected and the predicted value used in its place. Regression was carried out for each station against its 20 nearest neighbours for each suspect observation, using a window of +/- 20 days. The steps employed were as follows:

1. Calculate the RMSE of residuals for each regression
2. Use the regression model to predict required value
3. Take predictions from the best 5 fits (least RMSE)
4. Weight these according their RMSE to get final predicted value

The predicted value was compared to the ‘suspect’, if the difference was outside a defined tolerance, the suspect value was replaced. This methodology was applied to the 74,000 suspect values and approximately 4000 values were amended.

3.3 Estimation of missing data

Daily maximum or minimum temperature values, which were missing were in-filled using the spatial regression method, this was carried out on all stations with a minimum observation length of 3 years, an overlap or +/- 20 days was require either side of a missing observation. For stations with complete months missing data the spatially weighted method of infilling was completed as already described using monthly values.

The monthly infilling method was verified by omitting data for a number of stations with a complete record and using the method to fill in the gaps. A summary of the verification statistics for the infilling of missing monthly data is shown in Table 2. Infill was verified by cross-validation: known values were omitted and predicted by the infill methods

	Mean Error	**Mean Abs Error**	**RMSE**	**Mean**	**Number of months**
T max (C)	0.0	0.18	0.24	13.2	1260
T min (C)	-0.01	0.23	0.3	7.15	1260

Table 2: Verification for monthly infilling

4. CALCULATION OF STATION LONG-TERM AVERAGES

Following estimation of missing daily and/or monthly data it was possible to compile monthly LTAs for stations which now had a complete set of monthly values for the period. LTAs were compiled for a total of 138 stations.

5. CREATION OF GRIDDED DATASETS

Data have been gridded at 1km^2 resolution on the Irish National Grid (OSI, 1996) for maximum, minimum and mean temperatures. There are various methods for interpolation of climatological parameters; a good overview is given by Hengel (2007). Almost all methods involve detrending the data,that is removing the dependency on geographical effects by regression analysis, the regression analysis model may be customised to the parameter and month. This method produces a trend which is dependent on regression variables only (and can be calculated at each grid point), and also a residual for each data point. The regression residuals are then interpolated onto the grid, the regression model trend is evaluated at each grid point and added to the interpolated residual field to produce the final LTA product. Table 3 shows the independent variables which were used in the regression analysis. The interpolation chosen for temperature interpolation was inverse distance weighted, and was carried out using the R package gstat.

Independent Variable	Use	Purpose
Easting and Northing	1st, 2nd order and cross product	To capture spatial trends
Coast	Percentage of land within a 5,10,15,20 or 25km radius	To model coastal effects (best fitting value)
Distance to Sea	Cartesian distance to nearest coast	To model coastal effects

Table 3: Summary of variables used in the rainfall regression model

The gridding techniques were applied to the whole Island of Ireland, this was made possible by the provision of LTA data for stations in Northern Ireland by the UKMO, these data were produced using similar techniques to those described in this paper. (Perry, 2005; Hollis D., private communication to S Walsh, 2012). Complete station LTAs were available for 138 locations in ROI and 106 for Northern Ireland, these were combined into a single dataset.

The distribution of stations with height was not sufficient to allow a regression model to fully account for the variation of temperature with altitude. To account for elevation, a standard atmosphere lapse rate of 6.5°C/km was applied to mean temperature before regression and interpolation, and reapplied when the interpolation procedures were completed. For each location the mean monthly air temperature was calculated and reduced to mean sea level (MSL) using the standard atmosphere lapse rate. Regression analysis was then applied to the station data. The trend was evaluated at each grid point (Fig 3a), the regression residuals were interpolated onto the 1km grid and added to the valuation of the regression trend at each point (Fig 3b), finally the lapse rate for elevation was applied (Fig 3c). The regression analysis was performed iteratively, successively removing outliers – those whose residuals fell outside +/- 2.5 times the standard deviation of the residuals until a smooth MSL temperature profile was achieved (by visual inspection of the gridded residuals). The IDW power, and number of nearest neighbours was chosen by varying the power from 1.5 to 3 in increments of 0.5, and number of nearest neighbours from 20 to all in increments of 20, crossvalidation statistics were used to calculate the parameter which produced the best fit and these were used to produce the final grids.

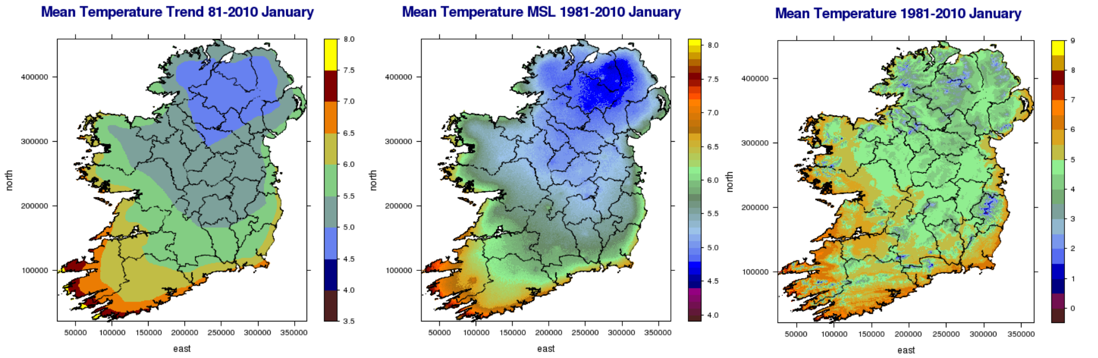

Figure 3

(a) Trend at each grid point (b) Trend plus gridded residual (c) Final grid, adjusted for elevation

This procedure was followed to produce 12 monthly mean temperature grids and an annual mean temperature for the island of Ireland. Maximum and minimum monthly and annual temperature grids were produced as follows: Monthly and annual anomalies were calculated for station temperature values from the station 1981-2010 mean temperature LTA, these anomalies were interpolated on to a 1km grid using the detrending and IDW method already described. The interpolated anomaly grid was added to the LTA to give the final monthly and annual grids. Seasonal grids were calculated by averaging over the months of each season. Mean temperature outputs are shown in Figures 4, 5 and 6.

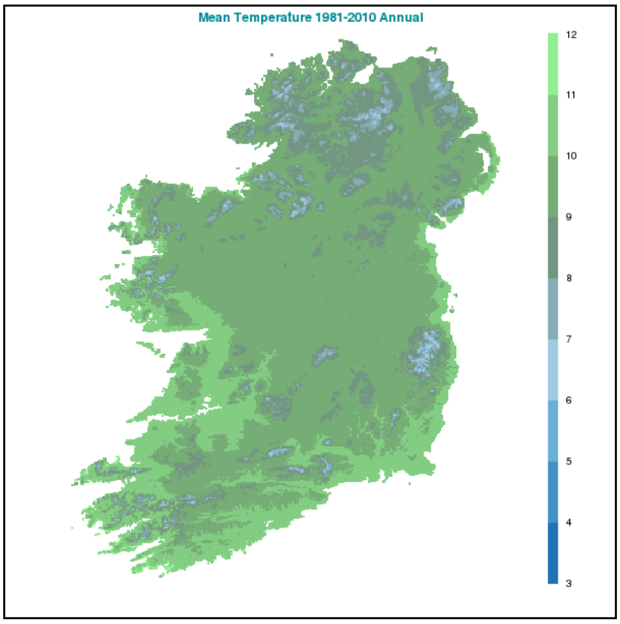

Figure 4

Average Annual Mean Temperature 1981-2010 °Celsius

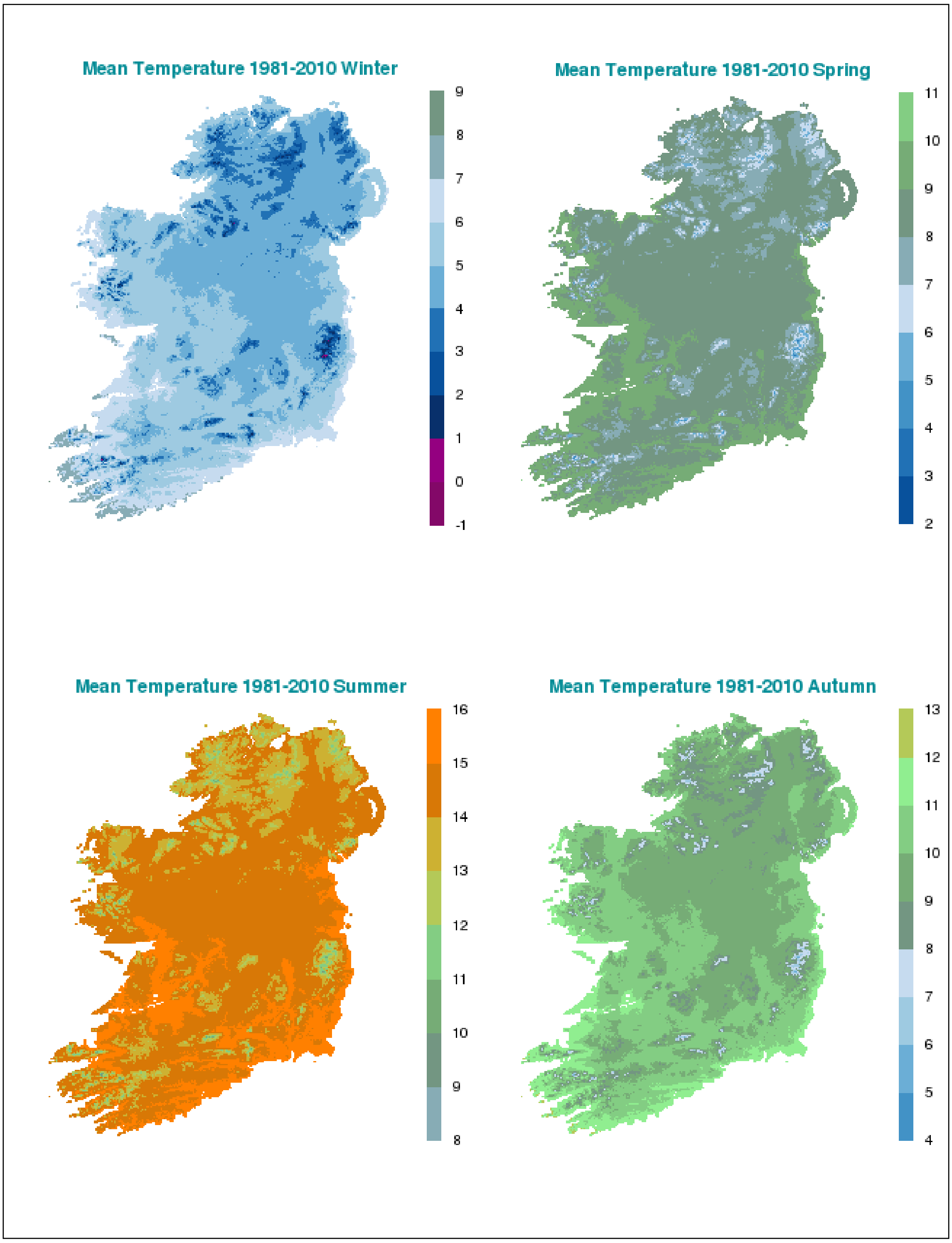

Figure 5
Seasonal Mean Temperature 1981-2010 °Celsius

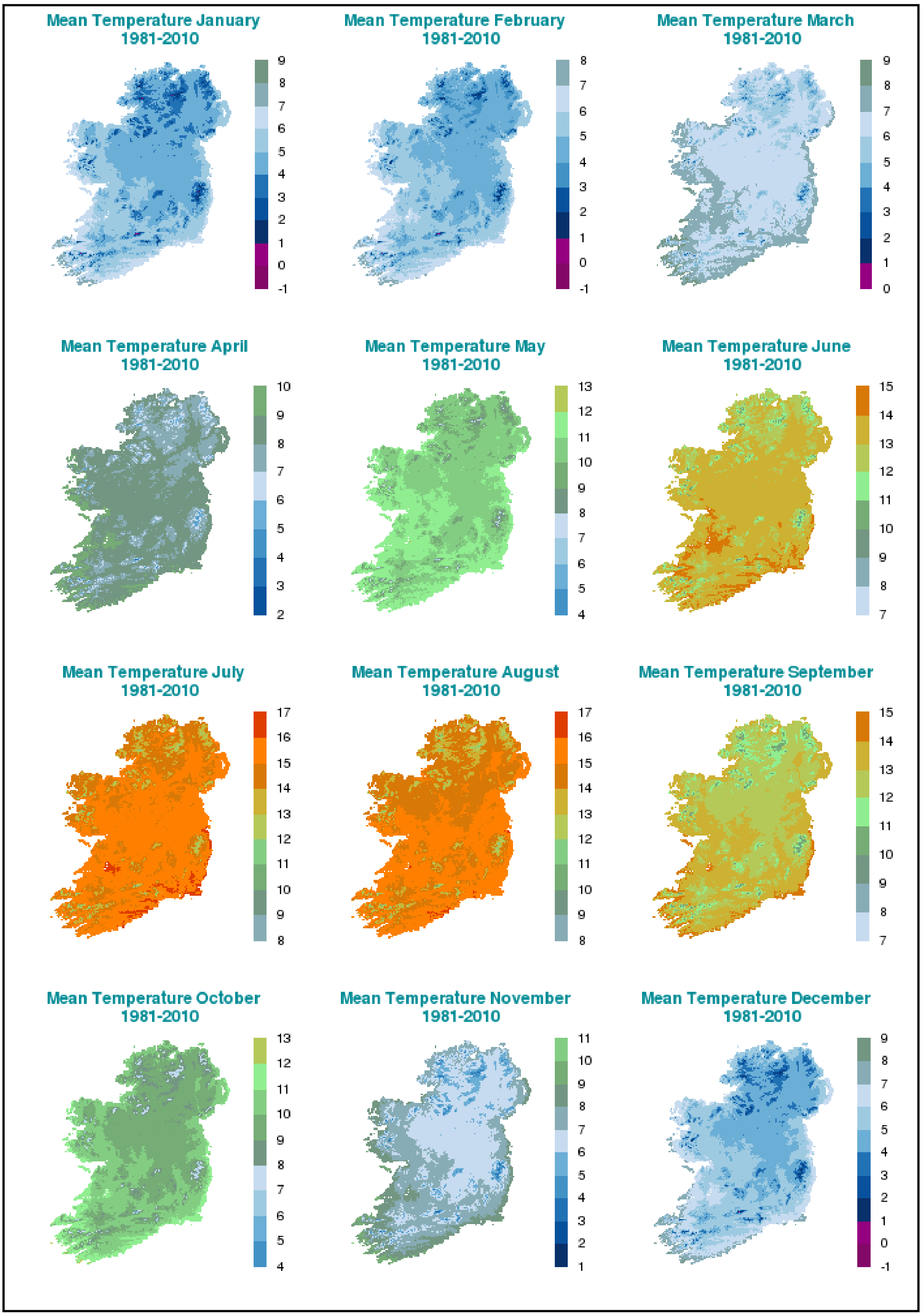

Figure 6
Monthly Mean Temperature 1981-2010 °Celsius

5.1 Verification of Gridding

Interpolation of monthly and annual temperature was verified by the leave one out cross validation method (loocv). Each observation is left out and its value predicted using the remaining members of the dataset. The verification statistics for monthly and annual mean, minimum and maximum temperatures are shown in Table 4. RMSEr is the normalised RMSE, the RMSE of the prediction errors divided by the total variation. As a rule of thumb a value of RMSEr of 0.4 or less means 85% or more of the variation is accounted for by the regression-kriging model (Hengl, 2007).

	Mean Temperature				**Minimum Temperature**				**Maximum Temperature**			
	Merr	**MAE**	**RMSE**	**RMSEr**	**Merr**	**MAE**	**RMSE**	**RMSEr**	**Merr**	**MAE**	**RMSE**	**RMSEr**
JAN	0.00	0.14	0.17	0.22	0.00	0.14	0.17	0.20	0.00	0.14	0.17	0.22
FEB	0.00	0.14	0.18	0.24	0.00	0.15	0.18	0.21	0.00	0.15	0.18	0.26
MAR	0.00	0.14	0.18	0.27	0.00	0.16	0.19	0.25	0.00	0.16	0.19	0.29
APR	-0.01	0.15	0.20	0.34	0.01	0.20	0.25	0.34	-0.01	0.20	0.25	0.36
MAY	-0.01	0.17	0.21	0.35	0.01	0.20	0.23	0.31	-0.01	0.20	0.23	0.34
JUN	-0.01	0.18	0.22	0.37	0.02	0.19	0.23	0.34	-0.02	0.19	0.23	0.30
JUL	-0.01	0.16	0.20	0.35	0.01	0.19	0.23	0.36	-0.01	0.19	0.23	0.28
AUG	0.00	0.16	0.19	0.33	0.01	0.20	0.24	0.36	-0.01	0.20	0.24	0.31
SEP	0.00	0.15	0.18	0.29	0.02	0.21	0.26	0.34	-0.02	0.21	0.26	0.37
OCT	0.00	0.14	0.17	0.26	0.01	0.18	0.22	0.26	-0.01	0.18	0.22	0.33
NOV	0.00	0.14	0.17	0.23	0.00	0.16	0.19	0.21	0.00	0.16	0.19	0.26
DEC	0.00	0.14	0.18	0.21	0.00	0.15	0.18	0.19	0.00	0.15	0.18	0.22
ANN	0.00	0.14	0.17	0.27	0.01	0.16	0.20	0.27	-0.01	0.16	0.20	0.30

Table 4

Verification statistics for Temperature: Merr: mean Error MAE, Mean Absolute Error, RMSE: Root Mean Squared Error, RMSEr: Normalised RMSE.

6. COMPARISON WITH 1961-1990 LTAS

Comparisons were made between the LTAs of 1981-2010 period and those of 1961-1990 period which had been in general use. To enable such a comparison, the datasets covering both periods need to be consistent. Station LTAs were generated for the 1961-1990 period using the same methods as for the 1981-2010 period, including quality control and infilling methods. Comparisons were made between stations which had over 25% coverage (before infilling) in both LTA periods for monthly, seasonal and annual temperatures, 64 stations fulfilled these criteria. (Republic of Ireland stations only). Mean annual temperature showed an average increase of approximately 0.5 Celsius. The changes in annual and monthly temperatures are shown in Table 5.

Difference between 1981-2010 and 1961-1990 LTAs			
Month	**Mean T**	**Min T**	**Max T**
JAN	0.55	0.48	0.62
FEB	0.60	0.42	0.78
MAR	0.71	0.68	0.74
APR	0.56	0.51	0.61
MAY	0.65	0.57	0.72
JUN	0.44	0.50	0.38
JUL	0.56	0.60	0.51
AUG	0.58	0.63	0.54
SEP	0.51	0.43	0.59
OCT	0.04	-0.04	0.13
NOV	0.67	0.71	0.63
DEC	0.05	-0.02	0.11
ANNUAL	0.49	0.46	0.52

Table 5
Average difference between LTA temperatures, 1981-2010 less 1961-1990 °Celsius

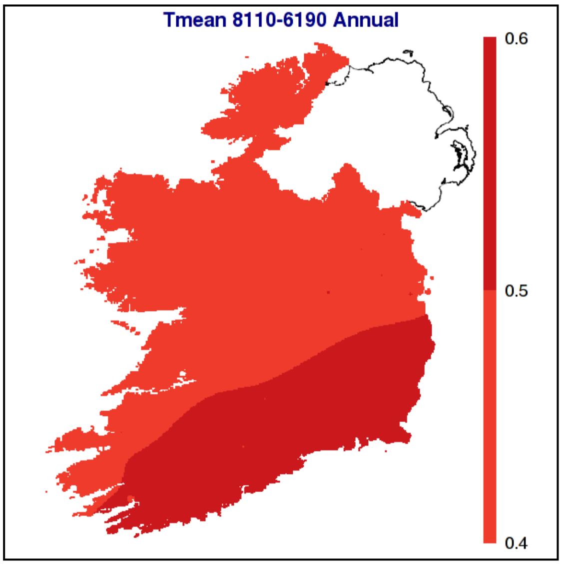

Figure 7
Annual Mean Temperature Difference 1981-2010 less 1961-1990 °Celsius

Smoothed maps of the changes for annual, monthly and seasonal mean temperatures derived from the station data are shown in Figures 7, 8 and 9. Most months show an average increase mean temperature of approximately 0.5 Celsius. There are also significant regional differences in some months. Seasonal differences reflect the monthly with all seasons on average recording an increase in mean temperature.

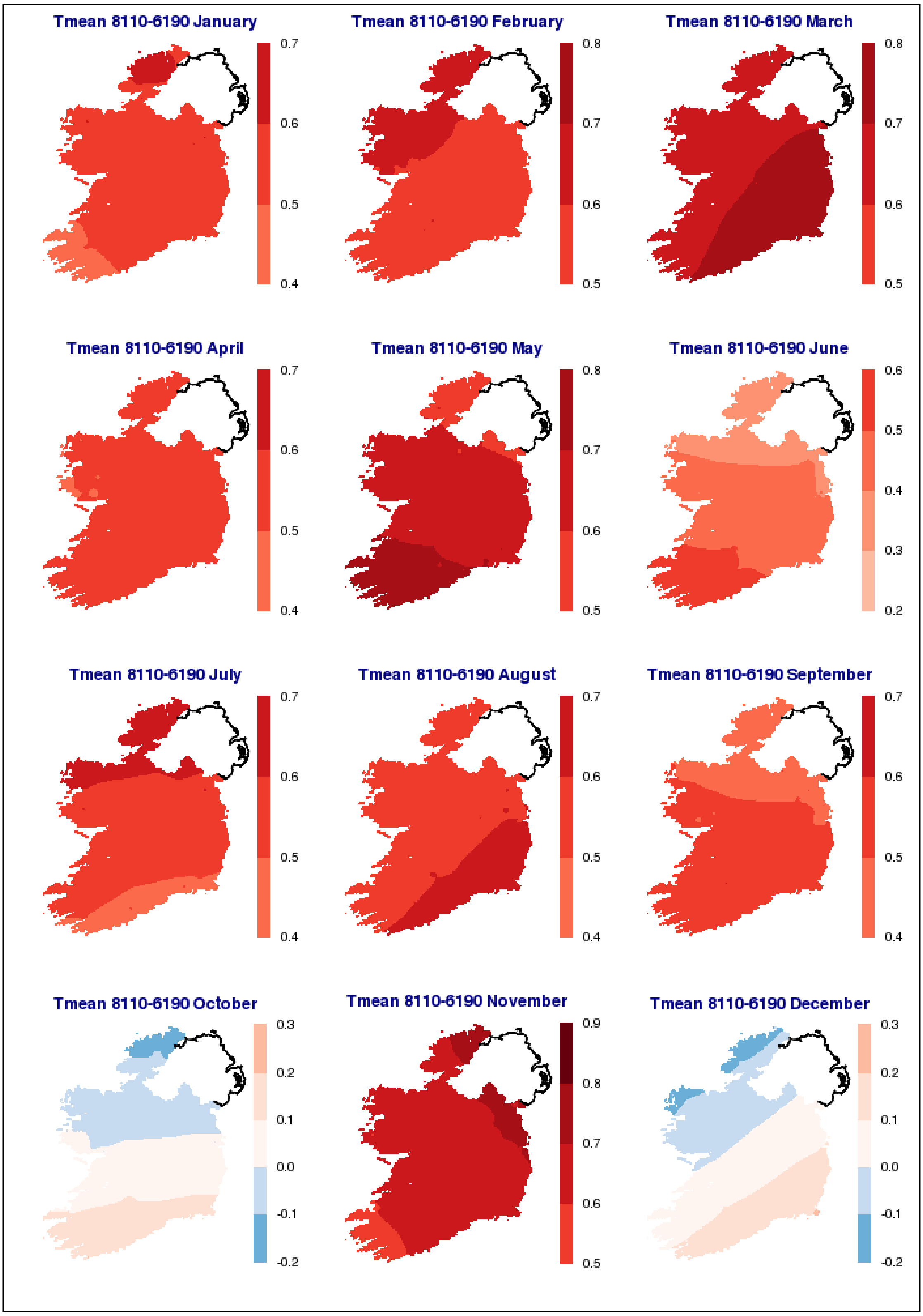

Figure 8
Monthly Mean Temperature Difference
1981-2010 less 1961-1990 °Celsius

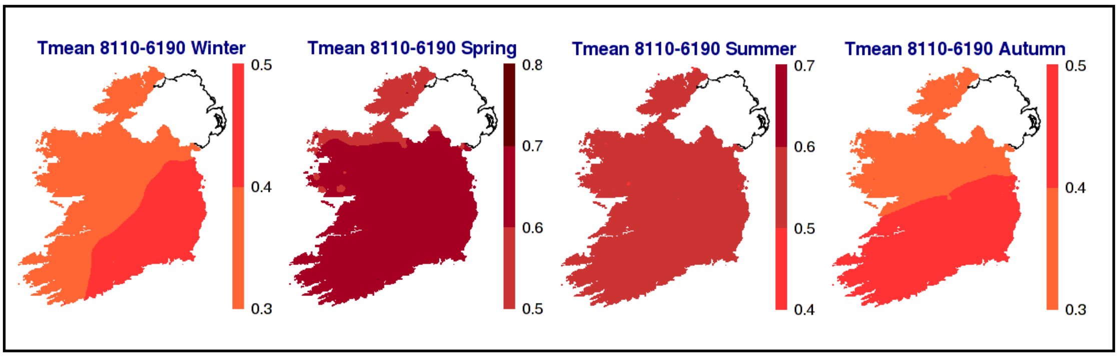

Figure 9

Seasonal Mean Temperature Differences 1981-2010 less 1961-1990 °Celsius

7. SUMMARY AND CONCLUSIONS

Long-term averages of monthly, seasonal and annual mean, minimum and maximum temperatures have been generated for stations in the Republic of Ireland for the 30-year period 1981-2010. These data have been combined with the corresponding data for Northern Ireland to produce gridded datasets for the island of Ireland at $1km^2$ resolution using geo-statistical methods. Comparisons with the 1961-1990 station LTA point to an approximately 0.5 % rise in average annual temperature between the two LTA periods.

8. ACKNOWLEDGEMENTS

Particular thanks are due to the Met Éireann voluntary observers without whom this work would not have been possible. Thanks to my colleagues in Met Éireann for valuable help, assistance and advice. Thanks also to John Prior and Dan Hollis of the United Kingdom Meteorological Office for provision of data for Northern Ireland.

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