Meteorological Data recorded at Armagh Observatory: Vol 2 - Daily, Mean Monthly, Seasonal and Annual, Maximum and Minimum Temperatures, 1844-2004

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1 Introduction

At Armagh Observatory, daily readings of air temperature and pressure started in 1795, to be joined in 1838 by wet and dry temperatures and rainfall. During the late 18th and early 19th centuries, maximum and minimum thermometers were developed and came into general use (Knowles Middleton, 1966). The principal advantage that these new instruments bestowed was that readings were relatively insensitive to the time of observation as the extrema in temperature normally occurred at times well removed from the observation time. Also, it was only necessary to read them once per day whereas to determine a mean temperature from simple thermometers required a minimum of two readings daily which must be equally spaced throughout the 24 hour day. Observations of maximum and minimum temperatures at Armagh commenced in August 1843 and have continued to the present day.

The raw maximum and minimum temperatures have been extracted from the original Meteorological Record Books in the Observatory Archives (M117.2 Butler and Hoskin 1987). Scanned images of these records may be inspected via the Armagh Observatory Climate Website http://climate.armagh.ac.uk.

After verification, the raw data have been standardised and corrected for various instrumental and exposure effects. Here, we describe the correction procedures and list the corrected daily, mean monthly, seasonal and annual data. This series of temperature data from Armagh, has been referred to as *Series II* by Butler and Johnston (1996) and Butler et al. (2005) and was supplied to the SNIFFER project team in 2003 for inclusion in their discussion of temperature series for Scotland and Northern Ireland.(see Jones and Lister, 2004).

2 Standardisation of the data

There are three general categories into which the corrections applied to the maximum and minimum temperatures fall: (1) instrumental corrections relating to the thermometers in use at any one time; (2) corrections which relate to the time of observation, and (3) corrections relating to the exposure of the thermometers. For the current series the second category of correction is minimal for the reasons given above. However, a small correction is required to the monthly and seasonal means when the time of reading is switched from morning to evening. The third category, namely exposure, is the most difficult to correct for as detailed information concerning the exact location and exposure of instruments is sometimes not available, particularly for the early data and, even when we know what the exact location was, it may no longer be possible to reconstruct the conditions prevalent at the time in order to determine a correction. One of the most important corrections of this type arises from the switch from the north wall screen type of exposure common in the early 19th century to the Stevenson Screen which became standard in many parts of the world from the late 19th century on. In the following sections we discuss each of the above types of correction separately.

2.1 Instrumental correction

Due to the physical disturbance required in reading and resetting maximum and minimum thermometers, they are more often broken than ordinary thermometers. In addition, maximum thermometers occasionally suffer from the detachment of parts of the mercury column which can give rise to appreciable errors. Such errors may not be noticed for some time, with the result that a systematic error is introduced into the temperature series. Errors of this nature are more common in the early to mid-19th century before regular inspection by Met. Office personnel was implemented.

Two maximum thermometers in use at Armagh prior to 1883 have given rise to concern. One, a thermometer by Newman, introduced in August 1843 and broken in May 1860, has no calibration data. For this thermometer we have made no correction for instrumental error. It was replaced in December 1860, after an interim period when a garden maximum on the roof was used, by a maximum thermometer by Casella of Phillips type. We believe that, when first used, this thermometer had only a small error which we have assumed to be zero (Whipple, 1921). It appears to have functioned satisfactorily until May 1863 when, from comparison with the parallel temperature series, Series I (Butler et al 2005), we see a sudden shift in level. When the readings of this thermometer were later checked by Dreyer for April/May 1881 against the maximum and minimum readings of a self-recording thermograph (SRT) set up by the Board of Trade in Armagh in 1868 (see Butler et al. 2005) he found an error of 3.2 degs F, and, by comparison with earlier SRT data, he was able to show that a similar systematic error had existed in 1871. In view of the uncertainty as to when the error developed, we have adopted a zero correction from December 1860 to May 1863 and a stepped temperature dependent correction which commences in June 1863 and is assumed to be stable from January 1872 until the thermometer was taken out of service in September 1882.

Table 1a - Instrumental Corrections for Maximum Thermometers. Corrections are in Fahrenheit up to 31 Dec 1971, subsequently in Celsius. * Correction is time dependent; interpolated

Therm. Type(Manufact.ID No.)	Period of use	Temp.RangeF	Cor.Applied[a]
Newman	1/12/1843 - 8/5/1860	Full	0.0
Casella Garden	10/5/1860 - 6/12/1860	$\leq$ 40	0.0
(on roof)		41-60	-0.1
		61-68	0.0
		$\geq$68	-0.1
Casella	7/12/1860 - 31/5/1863	Full	0.0
Casella	1/6/1863 - 31/12/1871	$\leq$48	-1.6*
		50	-1.7*
		60	-2.1*
		70	-2.6*
		$\geq$74	-2.9*
Casella	1/1/1872 - 30/9/1882	$\leq$32	-1.9
		40	-2.5
		50	-2.4
		60	-3.4
		70	-4.2
		$\geq$80	-3.8
Negretti 3404	1/10/1882 - 31/12/1882	$\leq$23	0.0
	and	30	-0.4
	1/1/1884 - 19/10/1899	40	-0.6
		50	-0.6
		60	-0.7
		70	-0.5
		$\geq$80	-0.5
Self-Rec.Therm.	1/1/1883 - 31/12-1883	Full	0.0
MO.1770	20/10/1899 to 31/12/1903		0.0
	1/1/1904 to 31/12/1907[c]		-0.1
	1/1/1908 to 31/12/1909		-0.2
	1/1/1910 to 1/6/1910		-0.1
	1/7/1910 to 31/6/1912		0.0
	1/7/1912 to 31/12/1913		-0.1
	1/1/1914 to 31/6/1917		0.0
	1/7/1917 to 31/12/1917		-0.1
	1/1/1918 to 31/12/1918		0.0
	1/1/1919 to 31/12/1919		0.1
	1/1/1920 to 31/6/1920		0.2
	1/7/1920 to 31/12/1920		0.3
	1/1/1921 to 25/5/1921		0.4
MO.14431	26/5/1921 to 31/12/1933		0.0
	1/1/1934 to 31/12/1937		-0.1
	1/1/1938 to 31/12/1946		-0.2
	1/1/1947 to 31/12/1947		-0.3
	1/1/1948 to 31/12/1948		-0.2
	1/1/1949 to 31/12/1949		-0.1
	1/1/1950 to 12/8/1969		0.0
MO. 28402	13/8/1969 to 31/12/1971		0.0
No.62271/69	(spare) 1/1/1972 to 11/4/1988		-
No. 29536	1/1/1972 to 31/12/1973		0.0
	1/1/1974 to 30/4/1986		0.1
	1/5/1986 to 31/12/1991		0.0
No. 51235	1/1/1992 to 15/7/1997		0.0
	16/7/1997 to 6/1/1998		-0.1
No. 55335	14/1/1997 to 26/10/1998		-0.1
	27/10/1998 to 27/4/1999		0.0
No. 56070/95	28/4/1999 to 23/8/1999		0.0
No. 55664/90	24/8/1999 to 27/10/1999		0.0
	28/10/1999 to 31/12/1999		0.1
	1/1/2000 to 30/11/2000		0.0
No. 55280	1/12/2000 to 30/6/2000		0.0
	1/7/2001 to 28/11/2001		-0.2
No. 256546/98	28/11/2001 to 31/12/2004		0.0

Table 1b - Instrumental Corrections for Minimum Thermometers. Corrections are in Fahrenheit up to 31 Dec 1971, later in Celsius.

Therm. Type(Manufact.ID No.)	Period of use	Temp.Range F	Cor.Applied
Newman	12/1843 - 30/9/1882	≤16	0.8
		20	1.0
		30	1.6
		40	1.0
		50	0.0
		≥60	-0.7
Casella 427	1/10/1882 - 31/12/1882	Full	0.0
Self. Rec. Therm.	1/1/1883 - 31/12/1883	Full	0.0
Casella 427	1/1/1884 - 1/11/1899	Full	0.0
MO 78	2/11/1899 - 12/1902		0.0
	1/1/1903 to 31/12/1903		-0.1
	1/1/1904 to 31/6/1904		0.0
	1/7/1904 to 31/12/1904		0.1
	1/1/1905 to 31/12/1905		0.0
	1/1/1906 to 31/12/1906		0.1
	1/1/1907 to 31/12/1907		0.0
	1/1/1908 to 31/12/1908		0.1
	1/1/1909 to 31/12/1909		0.0
	1/1/1910 to 31/12/1910		0.1
	1/1/1911 to 31/12/1911		0.2
	1/1/1912 to 31/12/1912		0.1
	1/1/1913 to 31/8/1913		0.0
	1/9/1913 to 31/12/1913		0.1
	1/1/1914 to 31/12/1917		0.2
	1/1/1918 to 31/12/1918		0.1
	1/1/1919 to 31/12/1928		0.0
	1/1/1929 to 31/12/1938		0.1
	1/1/1939 to 31/12/1950		0.0
	1/1/1951 to 31/12/1951		-0.1
	1/1/1952 to 31/12/1952		-0.2
	1/1/1953 to 31/6/1953		-0.1
	1/7/1953 to 31/6/1954		0.0
	1/7/1954 to 31/12/1954		0.1
	1/1/1955 to 31/6/1955		0.2
	1/7/1955 to 28/1/1957		0.3
MO.31479	29/1/1957 to 31/12/1971		0.1
No.62131	1/1/1972 to 22/5/1978		-0.1
	23/5/1978 to 29/4/1986		0.1
No. 62510/70	30/9/1986 to 19/12/1989		0.4
	20/12/1989 to 31/8/1990		0.2
	1/9/1990 to 30/9/1991		0.0
	1/10/1991 to 31/12/1991		0.1
No. 7897	1/1/1992 to 11/10/1993		0.1
	12/10/1993 to 28/10/1994		0.0
	29/10/1994 to 9/11/1995		0.2
	10/11/1995 to 15/7/1997		0.1
No.71411 (spare)	16/7/1997 to 29/10/1997		0.0
No. 68479/86	30/10/1997 to 5/1/1998		0.0
No. 71650/96	6/1/1998 to 23/8/1999		0.0
No. 71652	24/8/1999 to 27/10/1999		0.0
	28/10/1999 to 29/11/2000		0.1
	30/11/2000 to 28/11/2001		0.0
	29/11/2001 to 31/12/2001		-0.1
	1/1/2002 to 31/12/2004		0.0

The temperature dependent corrections for this thermometer have been derived by comparison of the daily maximum readings from the thermometer and the maximum temperatures recorded by the SRT for the same days (p42, Coughlin, 1998). For all other maximum thermometers that have subsequently been used at Armagh

Observatory, detailed thermometer corrections are available from archived meta-data (García-Suárez et al, 2004a).

For all minimum thermometers except the first by Newman (employed from August 1843 to September 1882) calibration data is available from the archived meta-data. Using the same procedure adopted for the Casella Maximum thermometer outlined above, a temperature-dependent correction for the Newman minimum has been determined (Coughlin, 1998). Details of the instrumental corrections for all maximum and minimum thermometers are given in Table 1.

For the calendar year 1883, whilst the SRT was still in operation, no conventional maximum or minimum thermometers were used. For this year alone, the maximum and minimum data in Series II are taken from the published SRT data with no further instrumental corrections applied.

2.2 Correction for time of observation

The principal advantage of maximum and minimum thermometers for the determination of mean temperature derives from the relative insensitivity of their readings to the time the reading is made. Nevertheless, substantial changes in the time of observation can have a small and systematic effect on the derived mean monthly, seasonal and annual values. Thus long term averages of evening readings can differ slightly from averages of morning readings. At Armagh, readings of maximum and minimum temperatures were initially made in the morning, but later, from around 1865 till December 1958, readings were made in the evening. Subsequently, through instruction from the Met. Office, readings reverted to the morning. An empirically determined correction for the effect of this twelve hour change in the time of reading was made using the SRT data for 1875/6 (Coughlin, 1998). The corrections required were +0.08 degs F for the maximum and +0.19 degs F for the minimum, to be applied over the period (1865-1958) when observations were made in the evening (Coughlin, 1998). These corrections have been applied here to the monthly, seasonal and annual means, but not to daily values.

2.3 Correction for exposure

Parker (1994) has discussed the differences between exposure effects using north wall screens and the, now more common, Stevenson Screen. He concludes that, for the determination of mean temperatures, there is little systematic difference between the two types of screen, provided direct radiation has been shielded. However, for maximum and minimum temperatures, appreciable corrections are required because of the influence of the buildings adjacent to to the north wall screen. Thus maximum and minimum series that have switched from a north wall screen type of exposure to a Stevenson Screen must be corrected.
From detailed descriptions of the order in which instruments were read (M117, Butler and Hoskin, 1987; García-Suárez et al. 2004a) written in 1846 and 1865, we can

surmise that the maximum and minimum thermometers in use at those times were fixed in a horizontal position close to, or possibly on the sill of, the north window of the East (1827) Tower. This was essentially a north wall screen type of exposure. It would not have been possible for the maximum and minimum thermometers to have been placed inside the bright metal box which housed the external thermometer (used for Series I) and the hygrometer (used for Series III). Therefore we do not know whether screening from early morning summer sunshine was provided. However, considering the care taken to screen the other thermometers, we would be surprised if similar provision was not made for the maximum and minimum thermometers. As, after this lapse of time, it seems unlikely that we can fully resolve this issue, we decided to standardise our maximum and minimum data over the period 1843-1882 against the SRT. The SRT also used a north wall screen type of exposure (see Figure 1 Butler et al, 2005, for an illustration) and was situated on the north wall of the adjacent Meteorological Building, approximately 4 metres east and 8 metres south of the north window of the East Tower. From a comparison of the published readings of the SRT for 1874, 1876, 1881 and 1882 at the time of reading of the external thermometer, we have found only a very small systematic difference (0.16 degs F, $\sim$0.1 degs C) between the mean temperatures for both sites. Therefore, we believe the mean temperature at the position of the north wall screen of the SRT was very close to that at the north window of the East Tower, that is the exposure for the two sites was similar. However, even if there was a small difference in exposure between the two sites, this is likely to have been removed by our adoption of temperature dependent thermometer corrections determined from comparison with the SRT, as discussed earlier.

A much more significant difference in exposure occurred when the maximum and minimum thermometers were moved in 1884 into a Stevenson Screen situated well away from the influence of neighbouring buildings (see Figure 1). Parker (1994) found that although mean temperatures determined from maximum and minimum thermometers in north wall screens were not substantially different from those housed in Stevenson Screens, the diurnal temperature range was significantly lower for north wall screens than Stevenson Screens. This is evidently due to the proximity of masonry with a substantial thermal inertia.

Regrettably, no simultaneous readings were obtained in Armagh between the earlier NWS exposure of the SRT (or the bright metal box in the north window of the East Tower) and the Stevenson Screen - the latter simply replaced the former. However, a very similar set of meteorological equipment had been set up at the Valentia Island Observatory in County Kerry and there an identical SRT to that formerly at Armagh, continued in operation in parallel with maximum and minimum thermometers in a Stevenson Screen until the 1960s. In Table 2 we show the comparison of mean monthly maximum and minimum temperatures from the SRT with the mean monthly maximum and minimum from thermometers in the Stevenson Screen at Valentia for the years 1955-59. There is a significant and consistent annual cycle in the differences between the two sets of readings with a substantially larger diurnal variation evident in readings from the Stevenson Screen. On average, in the Stevenson Screen, the maxima are approximately 1.0 deg. F (0.56 deg C) warmer and the minima 1.6 deg F (0.89 deg C) cooler than the NWS of the SRT. These findings are broadly consistent with those of Marriott (1879) and Parker (1994) for other types of NWS.

As the SRT in Valentia (which still survives) is identical to that formerly at Armagh and the general conditions of the site broadly similar to that at Armagh (though Valentia is wetter and windier) we decided to adopt the Valentia data as the basis of our correction for exposure of the maximum and minimum data from Armagh prior to the introduction of the Stevenson Screen in January 1884. The correction for exposure to the daily maximum and minimum temperatures in the interval 1843-1883 is shown in Figure 2. It is based on the mean monthly difference Stevenson Screen - SRT of the maximum and minimum temperatures at Valentia over the five year period 1955-59. This correction has been applied to the Armagh maximum and minimum temperature data from 1843-1883. On average, this has the effect of raising the mean maximum temperature by 0.55 degs C, lowering the mean minimum by 0.93 deg C, and lowering the mean temperature by 0.19 deg C over this period compared to the uncorrected data.

Table 2. Mean monthly differences in maximum and minimum temperatures recorded in a Stevenson Screen and by the Self-Recording Thermograph (SRT) in a North Wall Screen at Valentia Observatory, 1955-1959

Stevenson Screen - North Wall Screen (degs F)

	Maximum						Minimum					
	1955	1956	1957	1958	1959	Mean	1955	1956	1957	1958	1959	Mean
Jan	1.0	0.6	1.2	1.0	1.2	1.00	-0.7	-1.3	-1.3	-1.3	-1.8	-1.28
Feb	1.2	1.1	1.3	1.1	0.7	1.08	-1.3	-1.6	-1.6	-1.3	-1.6	-1.48
Mar	2.1	1.0	0.9	0.9	1.3	1.24	-1.5	-1.6	-1.3	-1.9	-1.8	-1.62
Apr	1.7	1.2	1.0	1.3	0.6	1.16	-1.6	-1.4	-1.9	-2.8	-1,8	-1.90
May	0.7	0.6	0.7	1.0	1.2	0.84	-1.8	-2.0	-2.3	-1.8	-1.9	-1.96
Jun	0.4	0.0	1.0	0.6	0.1	0.40	-1.9	-1.8	-2.2	-2.0	-1.9	-1.96
Jul	0.6	0.0	0.9	0.5	0.7	0.59	-2.3	-2.1	-2.0	-2.1	-1.9	-2.08
Aug	0.7	0.7	1.3	1.1	1.8	1.12	0.3	-1.4	-2.0	-1.8	-1.6	-1.30
Sep	1.4	1.3	1.1	1.8	2.9	1.70	-1.3	-1.6	-1.8	-1.8	-1.2	-1.54
Oct	1.2	1.6	0.9	0.9	1.6	1.24	-1.1	-1.4	-2.0	-1.7	-1.7	-1.58
Nov	1.1	0.5	1.3	0.9	1.3	1.02	-1.9	-1.6	-1.7	-2.0	-1.1	-1.66
Dec	0.8	0.4	0.7	0.8	1.1	0.76	-1.0	-1.7	-1.7	-1.5	-2.4	-1.66

Over the period December 2003 to October 2004, we tested these results by monitoring the temperature inside the light metal box in the north window of the East Tower with a *Gemini Datalogger Tinytag Temperature Sensor* incorporating a 10KΩ *NTC* encapsulated thermistor previously calibrated in the Stevenson Screen. Readings were recorded automatically every half hour and read out at the end of the run. The results imply a mean correction of 0.42°C to the maximum and -0.95°C to the minimum, closely similar to those derived from the Valentia data. As the latter were derived from a more extended period, covering all seasons, we have used these corrections to correct the Armagh maximum and minimum temperatures from 1843 to 1883 for exposure.

The corrected daily maximum and minimum temperatures are listed in Tables 3 and 4. These data have been corrected for the instrumental errors listed in Table 1 and the move from the North Wall Screen type of exposure to the Stevenson Screen in Table 2. Tables 5 and 6 list the mean monthly maximum and minimum temperature respectively. Table 7 contains the mean seasonal maximum and minimum temperatures and the daily temperature range, and Table 8, similar mean annual data. In addition to the corrections made for Tables 3 and 4, a small correction has been made to data from 1865 to 1958 (see Section 2.2) when readings were made in the evening rather than the morning. Thus, a straight average of the daily readings in Tables 3 and 4 for the period 1865 to 1958 will differ slightly from the mean values in Tables 5, 6, 7 and 8.

3 Mean annual maximum, minimum temperatures and the daily temperature range

In Figure 3, we plot the annual mean maximum and minimum temperatures and the daily temperature range (DTR) over the entire period they are available. On both year to year and decadal timescales the behaviour of mean maxima and mean minima is generally similar, with warm periods in the mid-19th century and in the middle and at the end of the 20th century. The coolest period in both maximum and minimum was the penultimate decade of the 19th century. There appears to be a decreasing trend in the DTR which is more pronounced at the beginning and end of the series than in the middle. Palle and Butler (2001) have remarked on the gradually increasing cloud levels over Ireland since the late 19th century that is evidenced from declining numbers of sunshine hours as well as other data. The gradual decline in DTR, seen in Figure 3, is consistent with such an increase in cloudiness. We have looked to see if there is any seasonal dependence in the DTR present in our data but we have found no significant effect.

4 Acknowledgements

Many people have contributed to this meteorological data series, most notably staff members of Armagh Observatory who, as part of their daily routine, provided the basic observations. In particular, over recent years, we acknowledge the contributions of Robert Scott, John McGinn and Shane Kelly. Likewise, we wish to acknowledge the help of the staff of the UK Meteorological Office who have regularly inspected the equipment and site since the 1860s.

For supplying data from the Self Recording Thermograph at Valentia Observatory, County Kerry, we thank Mr J. O'Sullivan of Met Eireann. Finally, we wish to thank Dr David Lister of the University of East Anglia for alerting us to some erroneous readings in an earlier compilation.

This work has been supported in part by The UK Heritage Lottery Fund (RF-98-01507) for Northern Ireland and the Soldiers and Sailors Land Trust Fund (RF. No. 46 AG 152) administered by the Department of the Taoiseach, Dublin. Armagh Observatory is grant aided by the Department of Culture, Arts and Leisure for Northern Ireland.

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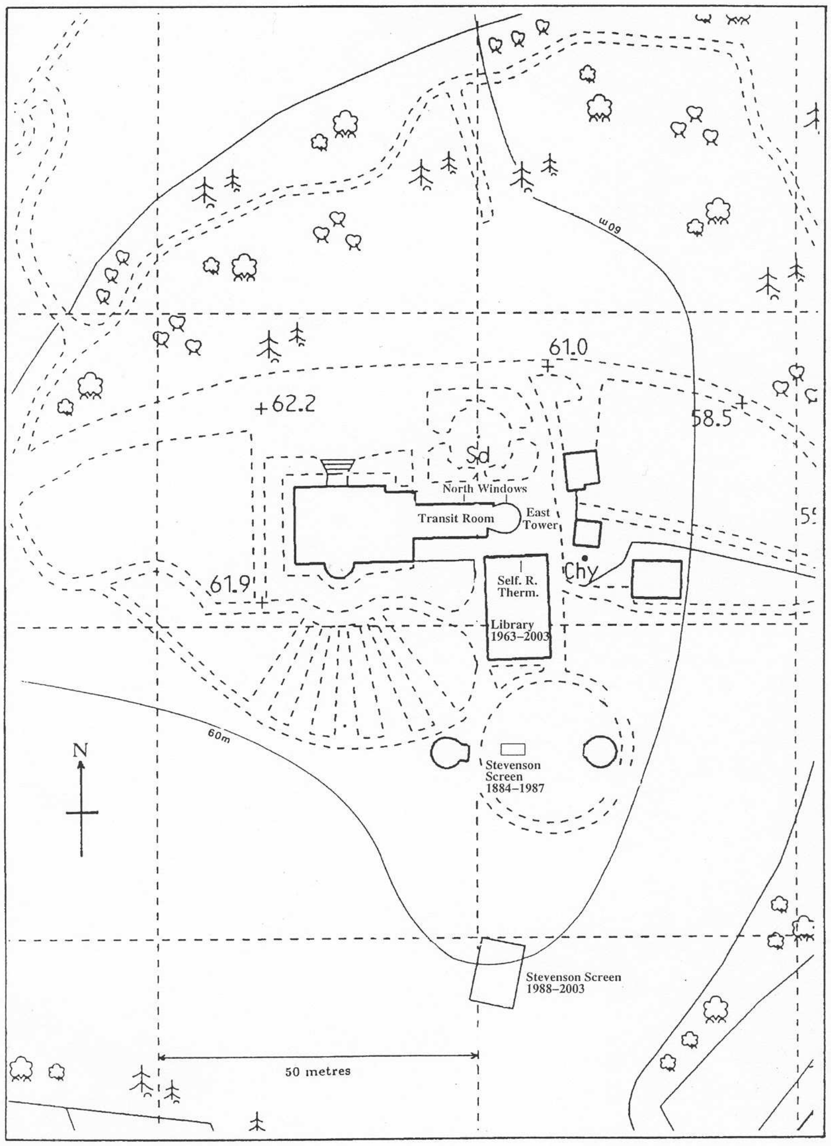

Figure 1: Plan of Armagh Observatory grounds, circa 2000 AD, showing the locations of thermometers used in this study. The East Tower was built in 1827 and the Library in 1963. The north wall screen of the Self-Recording Thermograph was located close to the north wall of the current Library

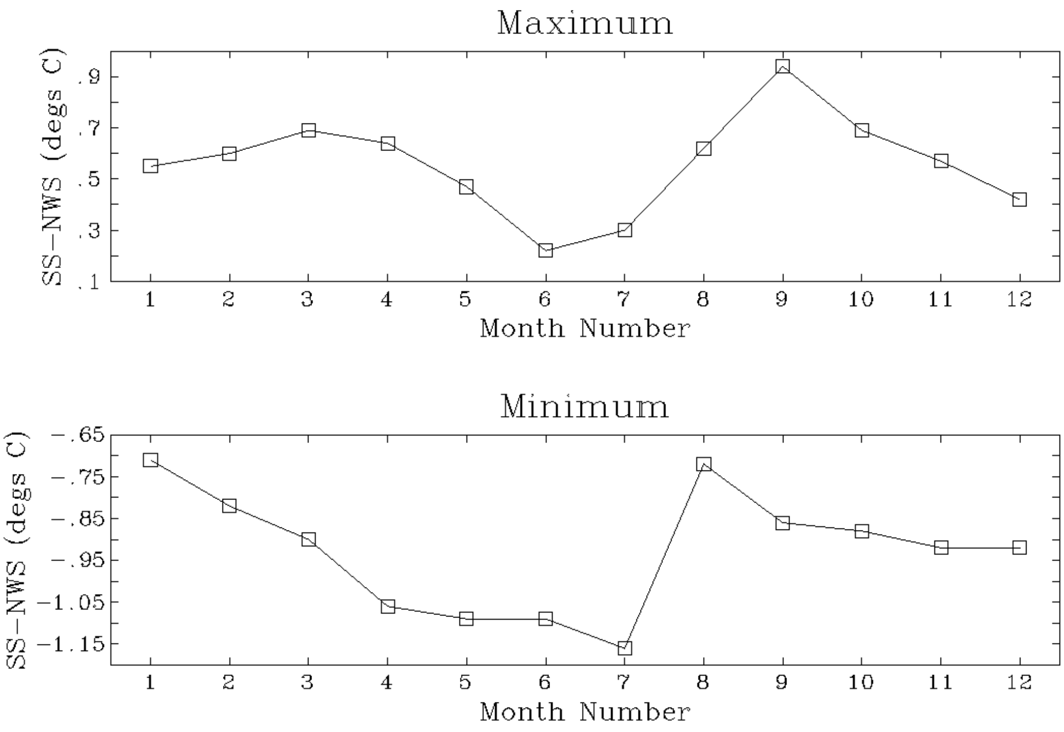

Figure 2: The difference between the mean monthly temperature extrema measured by the Self-Recording Thermograph in a north-wall screen and the standard maximum and minimum thermometers in a Stevenson Screen at Valentia Observatory from 1955 to 1959.

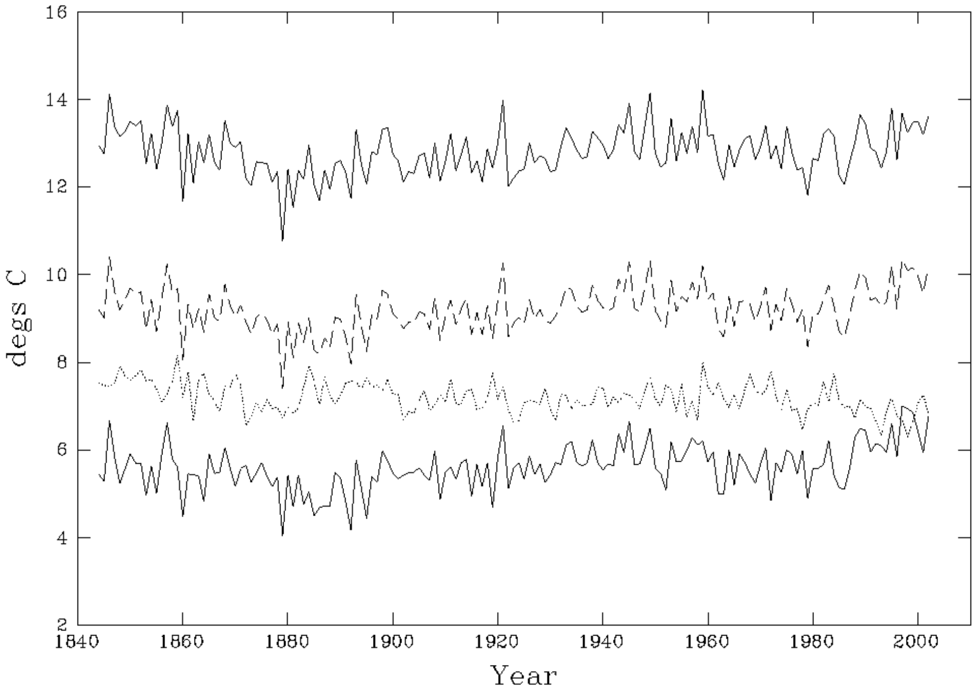

Figure 3: Mean annual maximum, minimum and mean temperatures and the daily temperature range (maximum minus minimum) at Armagh, 1844-2002. Maximum (top continuous line), Minimum (bottom continuous line), Mean (dashed line), DTR (dotted line).