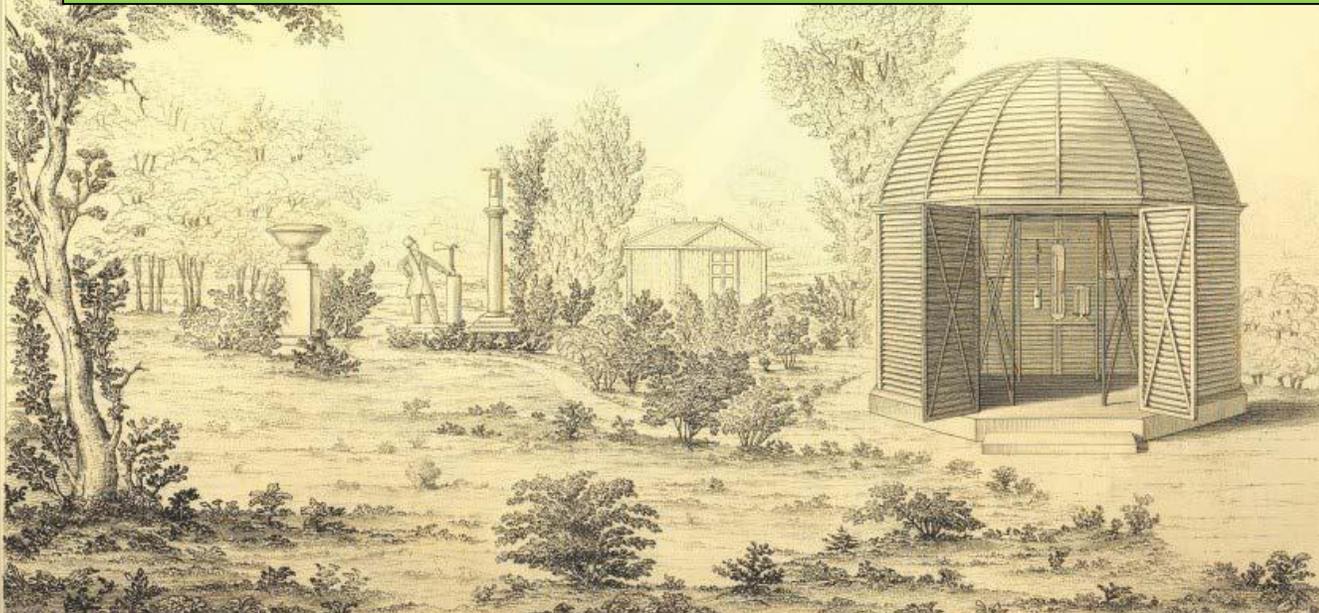


Digitisation and Homogenisation of the Long Term Daily (Max/Min) Summer and Winter Air Temperature Records in Ireland



No. 13 METEOROLOGICAL OBSERVATIONS, taken at *Roches Point* during

2 p.m.

Therm.	WIND	OF	OF																		
Dry Bulb	Wet Bulb	Direction	Force																		
1 30.09	63	57	54	53	N	1	3	NW	8	0	—	2									
2 29.98	64	58	58	67	52	SW	3	3	SW	9	f	0.02	3								
3 29.61	63	55	54	64	55	W	3	6	SSW	9	0	0.18	4	29.64	64	59	53	SW	4	5	
4 29.62	63	52	50	60	50	W	3	4	SW	3	fine	0.07	4	29.75	64	61	57	SW	3	3	
5 29.55	64	61	60	68	52	WSW	1	3	SW	9	0	0.09	3	29.65	66	59	57	SSW	4	9	
6 29.85	64	59	56	66	50	W	4	7	NW	4	C	0.12	4	29.93	68	60	56	SW	4	8	
7 29.88	64	59	58	68	55	SSW	5	5	SSW	9	0	—	4	29.96	64	59	51	S	7	9	
8 30.02	63	58	57	62	54	SW	3	7	SSW	8	0	0.25	3	30.09	66	62	57	SW	4	3	
9 30.15	65	59	56	70	55	SW	3	4	SW	7	C	—	3	30.11	66	62	60	SW	3	7	
10 29.95	64	57	54	68	54	W	4	3	SSW	8	0	0.28	4	29.94	65	62	59	WSW	3	7	
11 29.88	62	57	54	63	53	WSW	3	4	W	7	C	—	3	29.80	65	63	51	WSW	4	5	
12 29.67	64	58	55	66	52	SW	3	4	WSW	6	C	—	3	29.63	65	56	51	WSW	3	9	
13 29.60	64	57	55	65	49	SSW	1	4	W	6	C	0.42	2	29.58	65	58	57	SW	2	7	
14 29.63	62	56	54	64	48	S	1	3	NW	8	0	0.40	2	29.55	63	58	57	NW	3	8	
15 29.81	62	57	53	62	51	NW	3	3	NW	5	C	0.28	3	29.90	65	63	56	NW	4	3	
16 30.12	62	54	51	65	48	NW	1	4	NW	2	fine	—	2	30.13	66	64	64	SSW	3	8	
17 29.99	65	59	58	67	53	SW	4	4	SW	9	h	0.10	3	29.92	68	60	59	SSW	4	9	
18 29.95	64	57	55	68	56	NW	4	5	SSW	8	0	0.02	4	30.12	65	61	56	NW	4	6	
19 30.21	62	59	59	64	52	SW	3	4	NW	8	0	—	3	30.19	65	62	57	SW	3	8	
20 30.13	66	59	57	67	50	S	3	4	SW	9	fog	0.13	3	30.15	67	60	62	SW	2	9	
21 30.08	68	61	58	68	59	SW	3	3	SW	2	fb	0.05	3	30.03	69	68	64	SW	4	2	
22 30.00	68	62	60	74	59	SE	2	4	SE	6	fog	—	3	30.01	69	66	64	SSW	2	9	
23 30.07	67	61	57	70	54	NW	3	4	NW	5	C	—	3	30.07	69	66	63	SSW	3	6	
24 29.70	68	61	60	73	59	SSW	4	4	SSW	9	0	0.20	3	29.91	69	63	62	SSW	4	9	
25 29.93	68	60	57	68	55	SW	3	5	S	9	0	0.22	3	29.92	68	65	64	WSW	4	3	
	66	58	56	69	55	W	3	4	WSW	7	B	—	3	29.97	64	62	51	NW	4	7	
	63	57	55	66	53	WSW	4	5	NW	8	P	0.08	4	30.00	67	60	57	NW	4	8	
	65	59	57	64	55	W	2	4	NW	6	C	—									
	64	57	58	67	56	SSW	4	4	SSW	9	0	—									

Carla Mateus¹

Aaron Potito¹

Mary Curley²

¹Department of Geography, National University of Ireland Galway

²Met Éireann

Dr Tony Ryan Research Scholarship

NUIG Geography Postgraduate Travel Bursary

GSI – Postgraduate Travel/Fieldwork Award



Geographical Society of Ireland
An Cúnamh Tíreolaíochta na hÉireann
9th Seminar for Homogenization and Quality Control in Climatological Databases
4th Conference on Spatial Interpolation in Climatology and Meteorology



NUI Galway
OÉ Gaillimh

3-7 April 2017
Budapest, Hungary

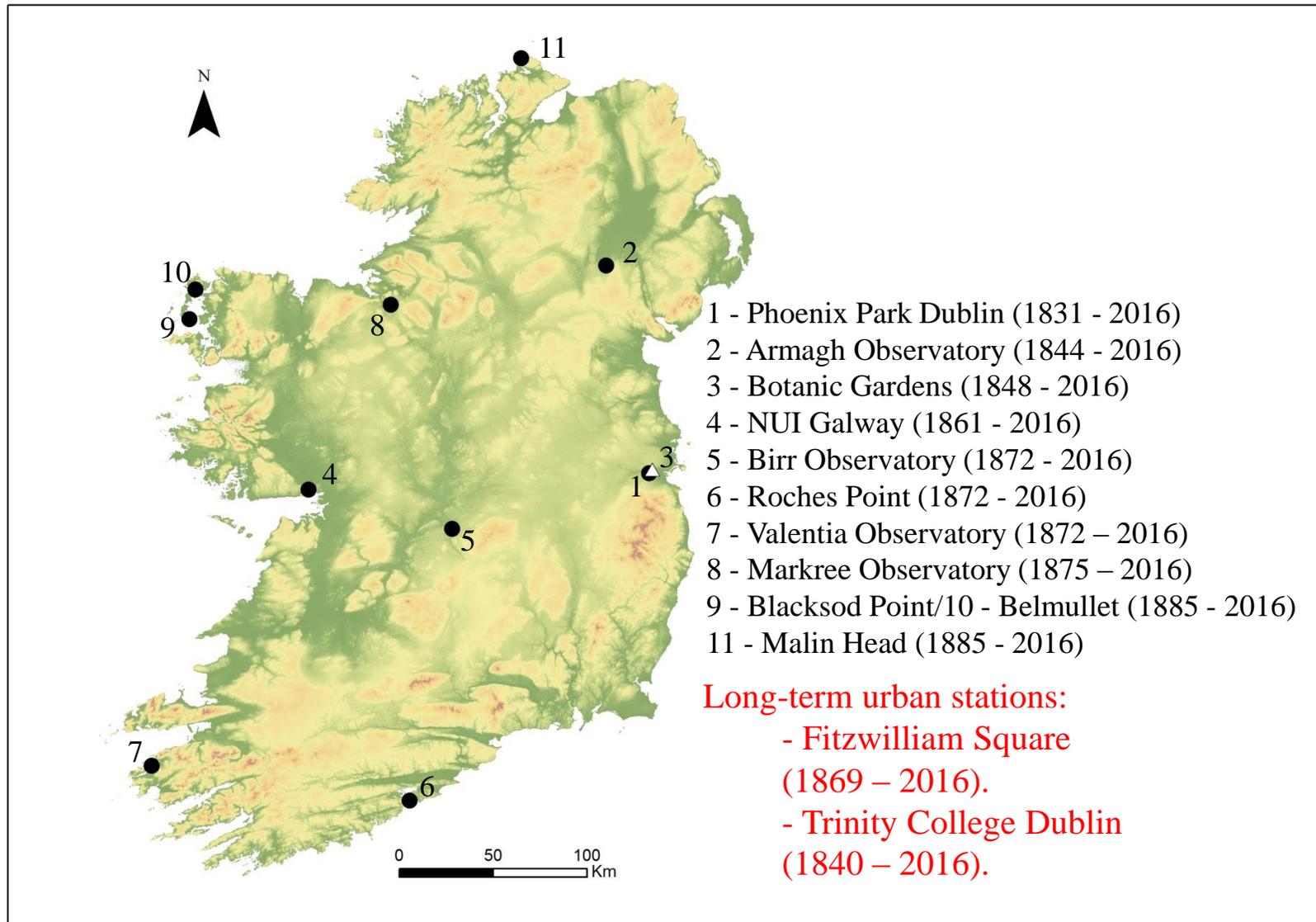
Presentation Aim: Methodology Discussion

- **HOMOGENISATION OBJECTIVE**: Identify outliers and non-climate bias/trends, perform statistical adjustments while maintaining the climate variability, climate trends and air temperature extreme events such as heat and cold waves.
- Interpolation methods to:
 - Fill missing data at the weekend/on Sunday;
 - Fill few days/long period missing data.
- Early/modern density network of reference stations:
 - e.g:1831 – 1841 (Phoenix Park Dublin without Irish reference stations?);
 - Transition from manual to automatic stations;
 - Parallel measurements.
- Corrections:
 - Different observing times;
 - Re-location;
 - Instruments and exposure changes;
 - Observing practices.
- Identification of break-points;
- Statistics to perform adjustments;
- Homogenisation software.



12 Long Term Candidate Meteorological Stations

Importance



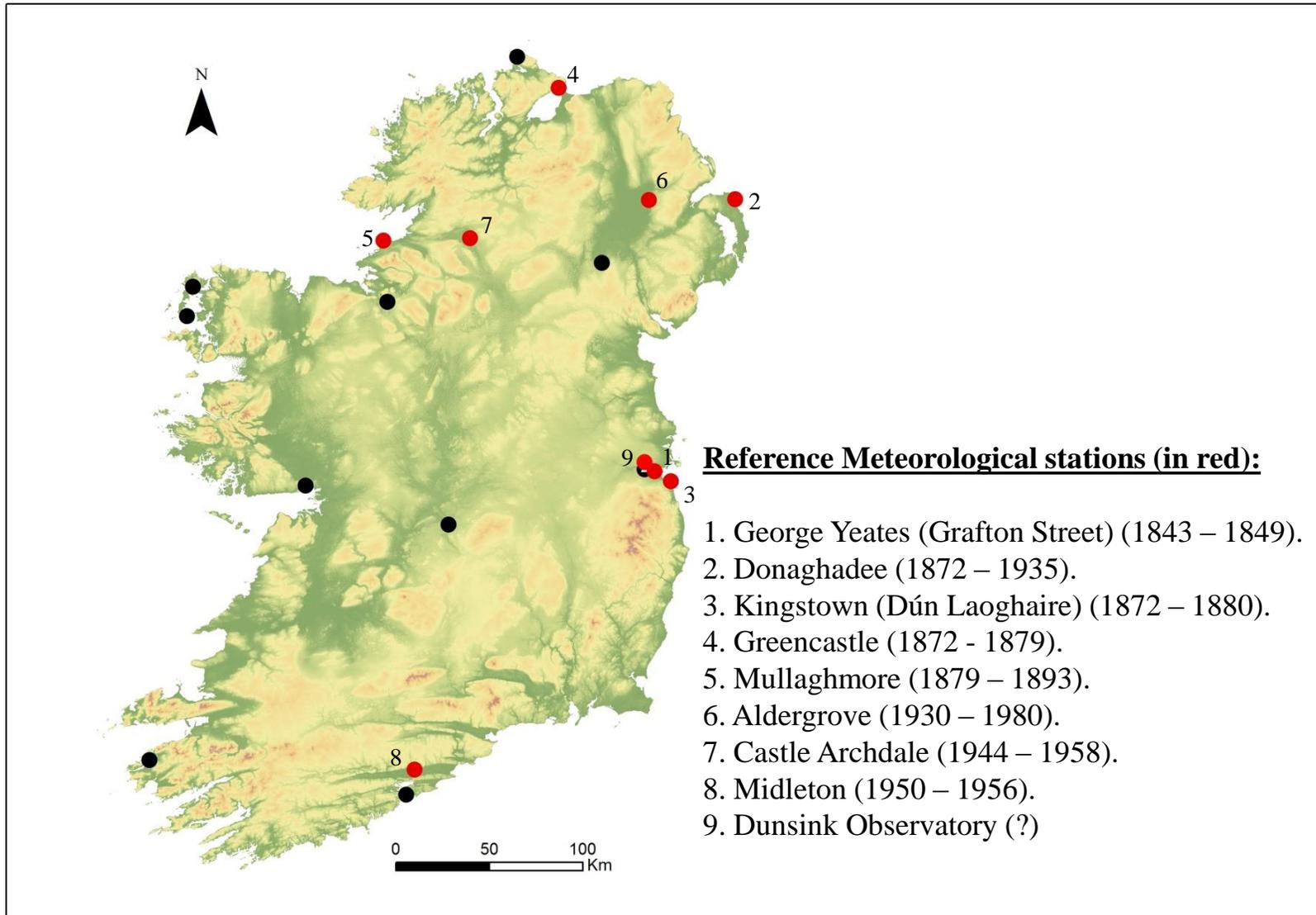
Sources:

- Daily max/min air temperature data rescue from original manuscripts and publications since the beginning of the meteorological observations until 1950's.

-1950's - 2016: Met Éireann's digital database.

- Armagh Observatory: calibrated data by BUTLER *et al.* (2003)

Possible Early Short Term Reference Meteorological Stations



Sources:

- Data rescue from the *Daily Weather Report* (DWR) and article publications.

- 1850 - 1852: Observations by RIA (Caherciveen, Dublin, Royal Dublin Observatory, Markree).

- Golddoen (1860s – 1880s).

- Note: Searching for private manuscript meteorological register/journal.

CURRENT NETWORK: dense.

Station Metadata: Rescue & Digitisation

- Opening/closing date;
- Location/re-location (latitude, longitude; level);
- Instruments type (and number) and its exposure;
- Screen type and size;
- Observer;
- Instruments maintenance;
- Observing practices;
- Time (Local Time or GMT);
- Type of station;
- Land use/cover;
- Previous quality control and corrections;
- Periods of missing data;
- Reasons for gaps;
- Observer's comments;
- Historical/political events;
- Exact decimal rounding or values for the nearest whole degree;
- Units (°F or °C);
- Parallel measurements;
- Pictures, letters and maps;
- Automatic station (sensor type).

METEOROLOGICAL RETURN

FROM

NORMAL CLIMATOLOGICAL STATION.

(STATION OF THE SECOND ORDER OF THE INTERNATIONAL CLASSIFICATION.)

I. Observations recorded at 9 a.m.

II. " " " " p.m.

III. " " " " 9 p.m.

Station Bun Castle

Month and Year July 1909.

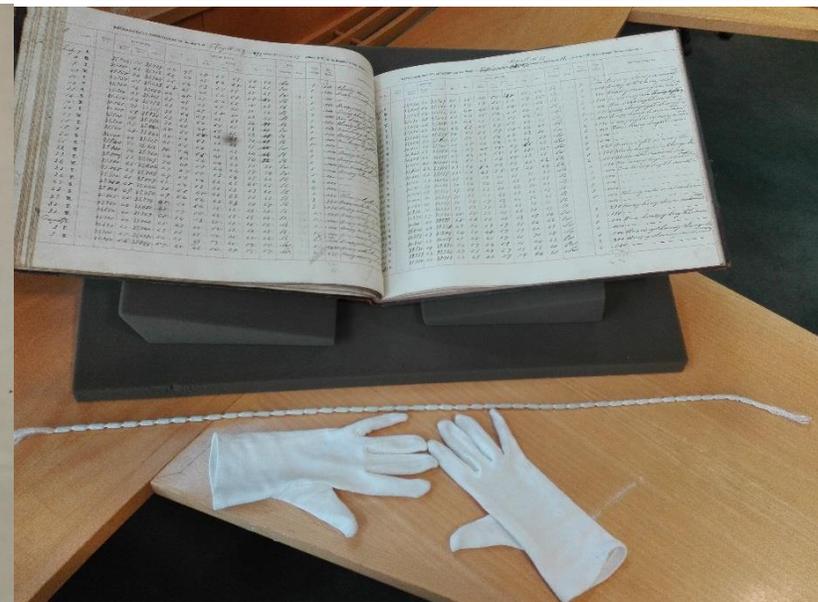
Observer John Hill © Met Éireann

NOTE. *The frost burst the 3 ft. Rain Gauge during the night of the 29th instant. A most extraordinary warm breeze has been blowing from the S.E. this afternoon, the S.W. barometer has risen AB out of order on the morning of the 10th Inst. The Index was at 9.0, which I took back by the Gale during the night, or by other means, could be ascertained. The frost burst the 3 ft. Rain gauge on the night of the 29th Inst.*

50597-16th 28 562-9th
15th 153 28 1745
30 680

Observations made by Serjeant George Brewer Royal Artillery
Computed by Geo Kelly Civil Assistant
Compared by W. B. S. Musher O. R. E. & William Conroy O. R. E.

2. 2-55.
©00—Printed by ALEX. THOM and Sons, 67, Abbey-st., Dublin. © Met Éireann



Sum	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Mean	27.671	27.671	27.671	27.671	27.671	27.671	27.671	27.671	27.671	27.671	27.671	27.671	27.671	27.671	27.671	27.671	27.671	27.671	27.671	27.671	27.671	27.671	27.671	27.671	27.671	27.671	27.671	27.671	27.671	27.671	27.671	

Barometer	Thermometer		Thermometer		Thermometer		Hygrometer		Hygrometer		Hygrometer	
	Inches.	Inches.	Temperature of Air.	Temp. of Evaporation.	Temp. of Dew-point.	Elastic Force of Vapour.	Humidity e-1.	From No. 3 Column.	From No. 4 Column.	From No. 5 Column.	From No. 6 Column.	From No. 7 Column.
Max 29.770	29.936	26.350	55.8	45.7	47.0	25.1	47.3	1.36	340	1,000	1,000	1,000
Min 29.770	29.936	26.350	55.8	45.7	47.0	25.1	47.3	1.36	340	1,000	1,000	

used from the 11th to the 10th inclusive or from the 11th to the 28th inclusive for less than returned for corrections. Service for service Dublin 10

098
153
251

Observations made by Geo Kelly Civil Assistant

© Met Éireann

Station Metadata: Sources

June July August					June July August							
1882	1	44,5	53,5	58,2	9pm			1882	1	6,9	11,9	14,6
57.2 before	2	49,2	57	55	MANUSCRIPT				2	9,6	13,9	12,8
	3	52	56,4	52,5	Minimum Thermometer corrected				3	11,1	13,6	11,4
°F	4	48	54,4	51,9	Entered as it is in the manuscript			°C	4	8,9	12,4	11,1
	5	45,8	50,1	55,7	Birr Castle				5	7,7	10,1	13,2
	6	50	50,8	57,4	Observer: George Phillips				6	10,0	10,4	14,1
	7	49,8	47,7	57,1	Confirmed				7	9,9	8,7	13,9
	8	47,3	45,3	50,8	Confirmed for different values				8	8,5	7,4	10,4
	9	45,3	48,2	47,2					9	7,4	9,0	8,4
	10	48,8	46,1	48	2nd August: Prob DWR				10	9,3	7,8	8,9
	11	41,8	52	59,1					11	5,4	11,1	15,1
	12	41	47,4	57,2	Manuscript note:				12	5,0	8,6	14,0
	13	38,2	52,8	7,3	Note on July 15h: "Minimum thermometer out of order"				13	3,4	11,6	14,1
Manuscript note:	14	50	56,2	57,2	Note on July 16th: "Minimum thermometer out of order"				14	10,0	13,4	14,0
"Addition from DWR"	15	46,8	53	50,8					15	8,2	11,7	10,4
"Addition from DWR"	16	35,2	54,7	50	50.7 before				16	1,8	12,6	10,0
	17	35	49,6	42,8					17	1,7	9,8	6,0
	18	47,8	49,6	47,7					18	8,8	9,8	8,7
	19	44,9	52,3	50,4					19	7,2	11,3	10,2
	20	50,4	48,7	51,6					20	10,2	9,3	10,9
	21	49	48,4	51,8					21	9,4	9,1	11,0
	22	44	52,2	50,2					22	6,7	11,2	10,1
	23	43,4	49,4	47					23	6,3	9,7	8,3
	24	47,1	50,3	49					24	8,4	10,2	9,4
	25	45,1	47	48,8					25	7,3	8,3	9,3
	26	49	42,1	50,1					26	9,4	5,6	10,1
	27	44,7	54,9	49,1					27	7,1	12,7	9,5
	28	52	56,4	51					28	11,1	13,6	10,6
	29	54,8	46,7	49,8					29	12,7	8,2	9,9
	30	62,7	51	46,4					30	17,1	10,6	8,0
	31		45,1	51,5					31		7,3	10,8
	MEAN	46,8	50,6	51,7	1403,6	1569,3	1602,6		MEAN	8,2	10,3	10,9

**Birr
Min Temp. July 1882**

- Metadata Sources:**
- Original manuscripts;
 - Publications;
 - Meteorological articles;
 - Meteorological Institutes;
 - Libraries and Archives;
 - Institutions.

WMO guidelines on metadata and homogenisation:

AGUILAR *et al.* (2003).

Data Rescue Procedures

- Sources:
 - Original manuscripts;
 - If the manuscripts are missing or there are gaps in the manuscripts: I used the DWR;
 - Publications:
 - When no manuscripts are available;
 - If there is an overlapping: I chose the manuscripts because it contains possible posterior corrections.
- Different sources overlapping: Sometimes are different values & corrections (e.g. manuscript & DWR).
- Rescue of paralalled readings (e.g. different screens or new station).

- Since 1920's there are 2 min/max observations per day for the majority of stations (e.g. 8am & 8pm):
 - I chose to rescue the observations: min at 8am and max at 8pm.
 - If min is lower in the evening and max higher in the morning observations: I rescued these values into a different table.

METEOROLOGICAL RETURN

FROM

STATION OF THE SECOND ORDER.

Station *Birr Castle*

Month and Year *July 1893*

Observer *William James Perry*

© Met Éireann

Digitisation Procedures

- Maximum air temperature entered to the previous day:
 - If morning observation (e.g. 7am);
 - If there is a mention in the manuscript;
 - Not entered it to the previous day if:
 - it has already been thrown back;
 - there is no observing time (confirm with metadata).
- Error control:
 - My own averages/sums and manuscripts averages/sums:
 - Matched values;
 - Erroneous values in the manuscript (e.g. erroneous decimal rounding);
 - No averages/sums in the manuscripts.
 - Digitisation in a different table: the monthly average corrections & comparison (e.g. Markree)
 - Publication or handwriting errors (outliers).
- Table for °F and °C conversion table.

	MEAN	Jan	Feb	Dec	1184	974	1046
1926	1	38	43	25	min at 7h, not thrown back		
	2	46	40	31	MANUSCRIPT		
°F	3	45	38	40	Entered as it is in the manuscript		
	4	42	32	43	Confirmed		
	5	44	42	50	Confirmed for different values		
	6	39	44	42			
	7	35	39	37			
	8	39	39	35			
	9	47	43	43			
	10	49	36	45			
	11	48	36	47			
	12	47	30	39			
	13	35	35	39			
	14	23	44	40			
	15	27	47	21			
	16	24	37	30			
	17	33	33	43			
	18	27	34	39			
	19	37	42	41			
	20	31	50	40			
	21	37	45	30			
	22	38	39	29			
	23	47	46	30			
	24	36	49	30			
	25	40	50	31			
	26	37	50	27			
	27	48	45	23			
	28	36	33	33			
	29	39		48			
	30	30		45			
	31	33		40			
	MEAN	38,0	40,75	36,6	1177	1141	1136
1927	1	42	32	33	min at 7h, not thrown back		

**Birr
Min Temp.
February 1926**

my values are correct!!!
same sum but different average
wrong decimal rounding in the manuscript???

e.g. rounding bias in the manuscript

Quality Control – Examples (Obs. Times & Corrections)

	June	July	August	1866	2187	1933	1888	Jan	Feb	Dec	1888			
1922 °F	1	78	62	60	9pm		1922 °F	1	38	39	40	8am		1888
	2	64	60	61	Markree Castle			2	34	33	48	Manuscript		
	3	57	58	62	Manuscript			3	38	49	50	Entered as it is in the manuscript		
	4	62	58	66	As it is in the manuscript			4	48	47	50	Confirmed		
	5	63	59	70	Maximum Thermometer read at 9pm and			5	40	47	50	Confirmed for different values		
	6	64	59	67	Thermometer 4 feet above ground			6	41	43	50	same average as it		
	7	70	59	67	Latitude: 54° 11' N			7	48	44	50			
	8	69	53	60	Longitude: 8° 27' W			8	50	46	36			
	9	64	60	63	Observer: John R. Armstrong			9	49	46	33			
	10	58	59	61	Standard time: GMT			10	48	46	35			
	11	68	67	59	June: Maximum Thermometer No. 94861			11	44	40	47			
	12	64	59	63	Confirmed			12	45	31	39			
	13	59	60	59	Confirmed for different values			13	45	33	50			
	14	60	60	61	Same monthly average			14	41	33	50			
	15	61	60	60				15	36	36	46			
	16	56	61	61	Note in July: "From the 10th to the 16th I			16	28	36	32			
	17	56	60	60	VERY IMPORTANT!			17	31	39	34			
	18	66	59	60				18	37	43	44	38 before		
	19	59	62	70				19	40	39	45			
	20	61	62	58				20	46	38	40			
	21	58	63	62				21	48	35	41			
	22	60	62	59				22	48	36	40			
	23	57	63	59				23	44	36	43			
	24	58	65	60				24	46	34	42			
	25	55	63	59				25	48	34	37			
	26	59	65	62				26	43	32	37			
	27	57	62	65				27	41	25	37			
	28	60	65	65				28	39	33	40			
	29	58	65	60				29	31	34	36			
	30	61	62	57				30	33		30			
	31	61	60	59				31	37		34	45 before		
		61,4	61,0	61,8				MEAN	41,5	38,2	41,5			
					1842	1892	1915							

Markree, 1922
Observer's note in July:
 "From the 10th to the 16th I could not take any reading at 21h owing to the danger of being under fire. The max and min was read the following morning at 9h."

Valentia, Min temp. 1888.

- Metadata;
- Max>Min;
- Same average & sum as in the manuscript/publication;
- Rescue the corrections applied by the Met Office/Met Éireann;
- Mention the previous value before the correction;
- Reasons for corrections;
- Outliers;
- Reasons for outliers;
- Reasons for missing data;
- Jumps in the data;
- Data consistency;
- Correct nr of days per month;
- Graph the data.

Quality Control – Examples (Outliers)

	Jan	Feb	Dec		
1855	1	45	30	43	Book
	2	49	29	44	Royal Botanic Gardens, Glasnevin
°F	3	41	31	42	Thermometer MIN
	4	45	34	44	Entered as it is in the book
	5	46	37	37	January, February: 4pm
	6	49	35	38	December: 3pm
	7	46	33	30	Confirmed
	8	46	31	28	Confirmed for different values
	9	42	26	27	confirmed
	10	41	29	16	
	11	40	24	19	
	12	37	31	25	
	13	35	19	30	
	14	38	17	30	
	15	35	2	42	ERROR!
	16	31	26	37	
	17	33	24	35	
	18	28	5	41	ERROR!
	19	32	10	37	
	20	34	29	37	
	21	34	28	35	
	22	26	28	35	
	23	28	32	37	
	24	31	23	41	
	25	27	36	39	
	26	30	38	34	
	27	32	38	36	
	28	25	37	42	
	29	26		43	
	30	29		39	
	31	27		44	
		35,7	27,2	35,7	1108 762 1107

Outliers
Botanic Gardens
Min Temp.
February 1855.

	Jan	Feb	Dec		
1906	1	38,9	41,9	37,8	MANUSCRIPT
40.4 before, see dry	2	40	41	43,4	38.7 before 1906
°F	3	45,5	37,3	45,4	Entered as it is in the manuscript
	4	41,5	29,9	46	9pm Local Time
	5	35,3	27,8	38,8	Corrected Readings of Min
	6	38,9	39,4	32,2	confirmed
	7	36,2	38,5	27,8	confirmed for different values
	8	35,4	31,5	42,4	Observer: John R. Armstrong
	9	34,5	31,3	37	Latitude: 54 11' N: Longitude: 33 48 W
37.5 before	10	36,4	36,5	32,7	Manuscript Note in December: "The a
	11	33,4	31,5	38,5	
	12	33,5	30	33,5	
	13	32,9	29,3	32,5	
35.4 before, note: "see dry"	14	35	28,4	33,3	
34.2 before, note: "see dry"	15	34	30,9	33,4	
	16	31,9	33,1	47,9	
	17	32,4	30	47,9	
	18	33,1	26,2	47,5	
29.7? Before	19	28,7	32,5	45,5	
	20	27,5	29,4	41,5	
	21	33	23,5	30,6	
	22	25,7	35,5	37,3	
	23	35,7	30,1	31,5	
	24	41,3	30,5	37,5	
	25	43,1	34,5	32,5	37.5
	26	47,8	30,8	27,5	
	27	47,5	27,5	25	
	28	46,8	27,4	26,5	
	29	40,3		8	ERROR!
	30	40,7		33,4	
	31	39,4		35	
		37,0	32,1	35,4	1146,30 898,20 1098,8

Outliers
Markree Observatory
Min Temp.
December 1906.

Manuscript Note in December:

"The average depth of snow measured here from the 26th to the 29th was 15 inches. The shade min registered on 29th (8) while the grass min read 15. The later was owing to it being covered with snow".

Quality Control - Examples (Observations In/Outside Observatory)

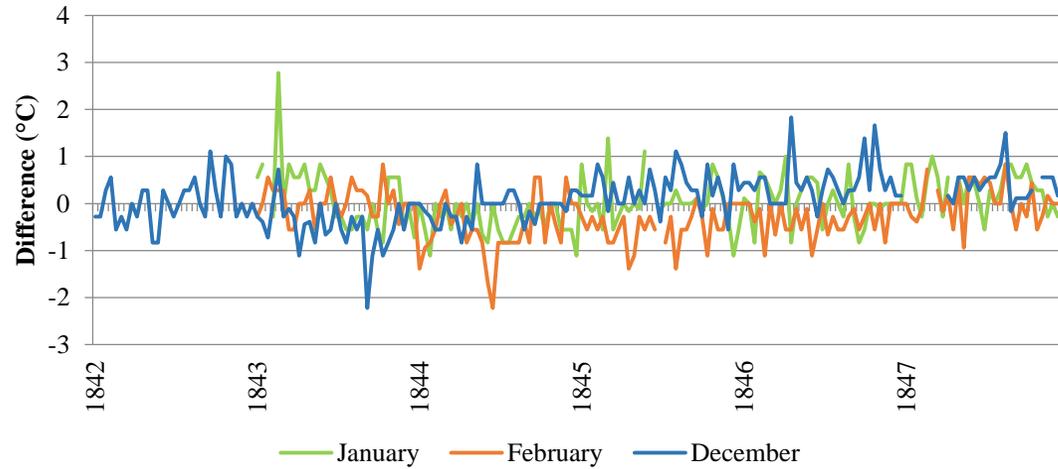


CAMERON (1856)
© Met Éireann

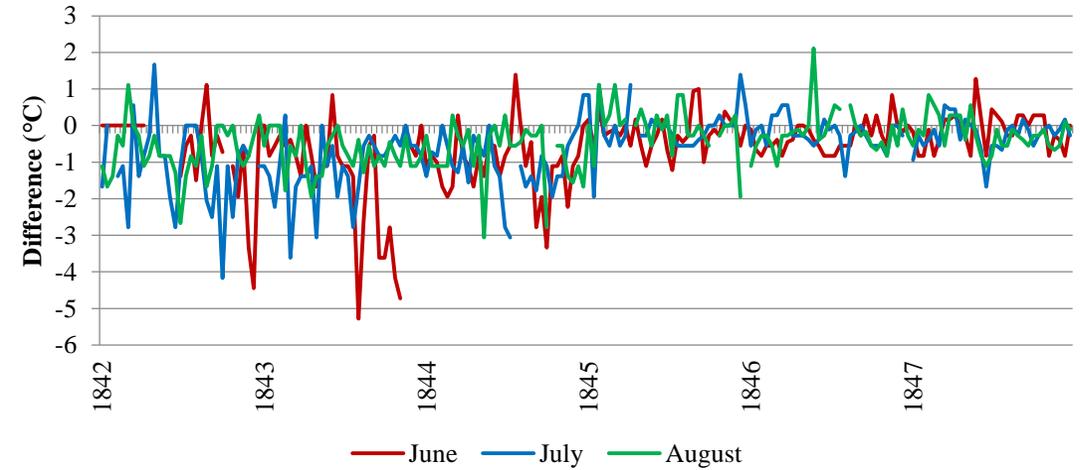
THE METEOROLOGICAL OBSERVATORY.
ORIGINALLY SURVEY OFFICE, SPENCER PARK, DUBLIN.

Phoenix Park Dublin- Observations In/Outside Observatory

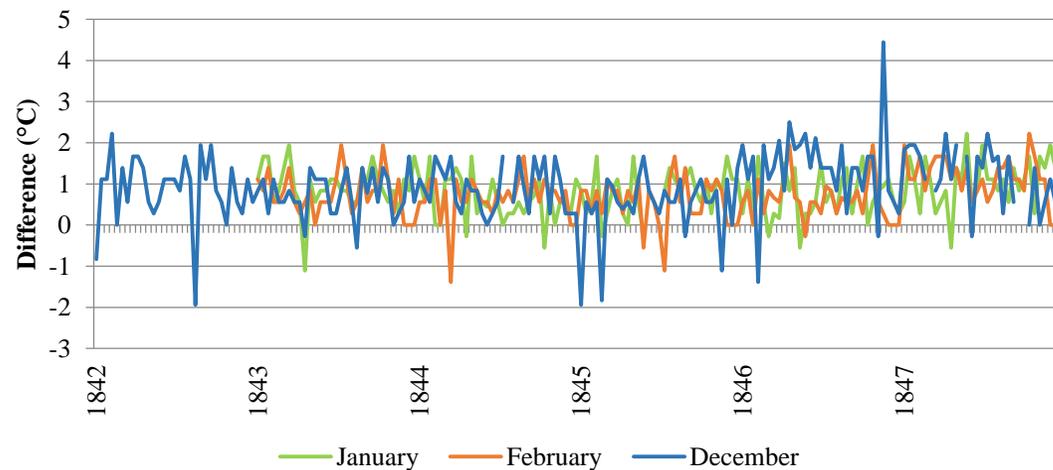
Maximum Winter



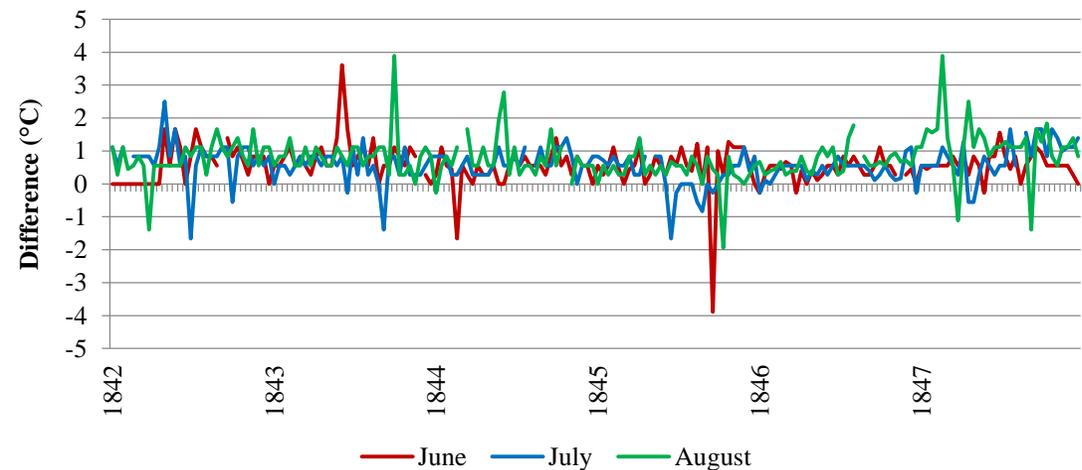
Maximum Summer



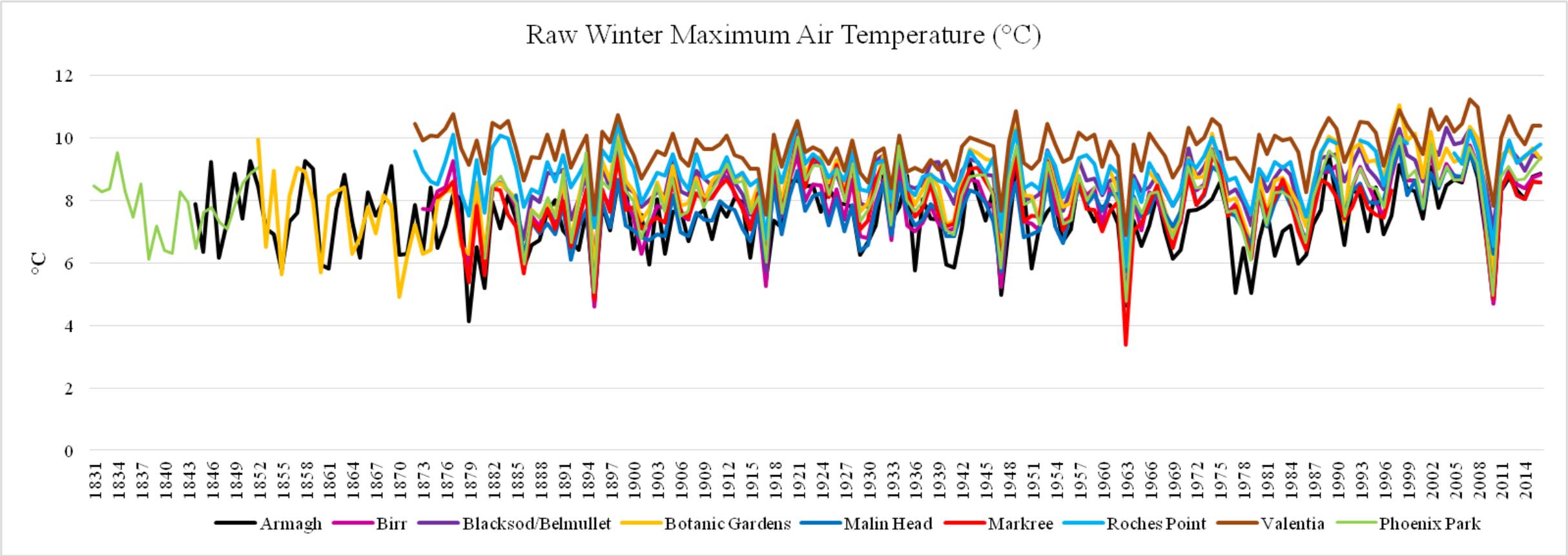
Minimum Winter



Minimum Summer

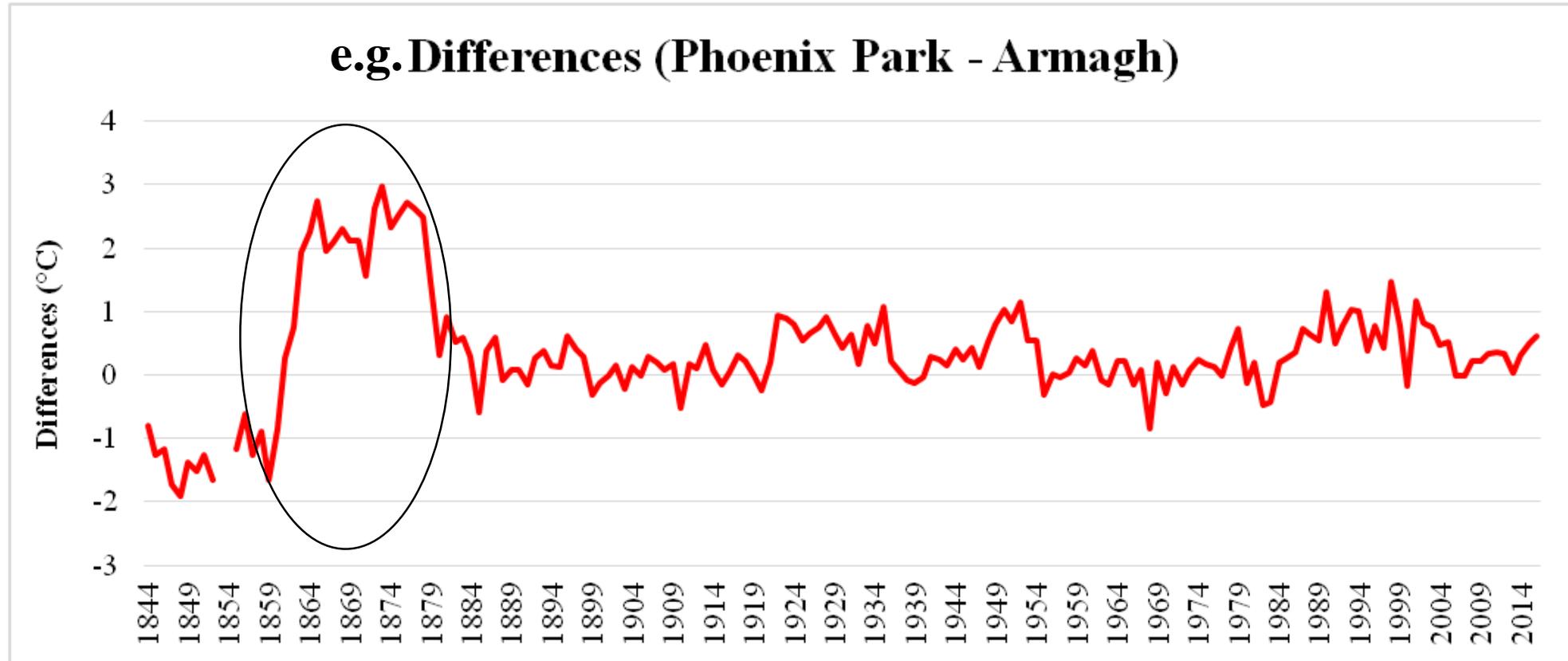


Quality Control - Raw Winter Maximum Air Temperature



Note: Still doing quality control in Phoenix Park Dublin (1853 – 1880).

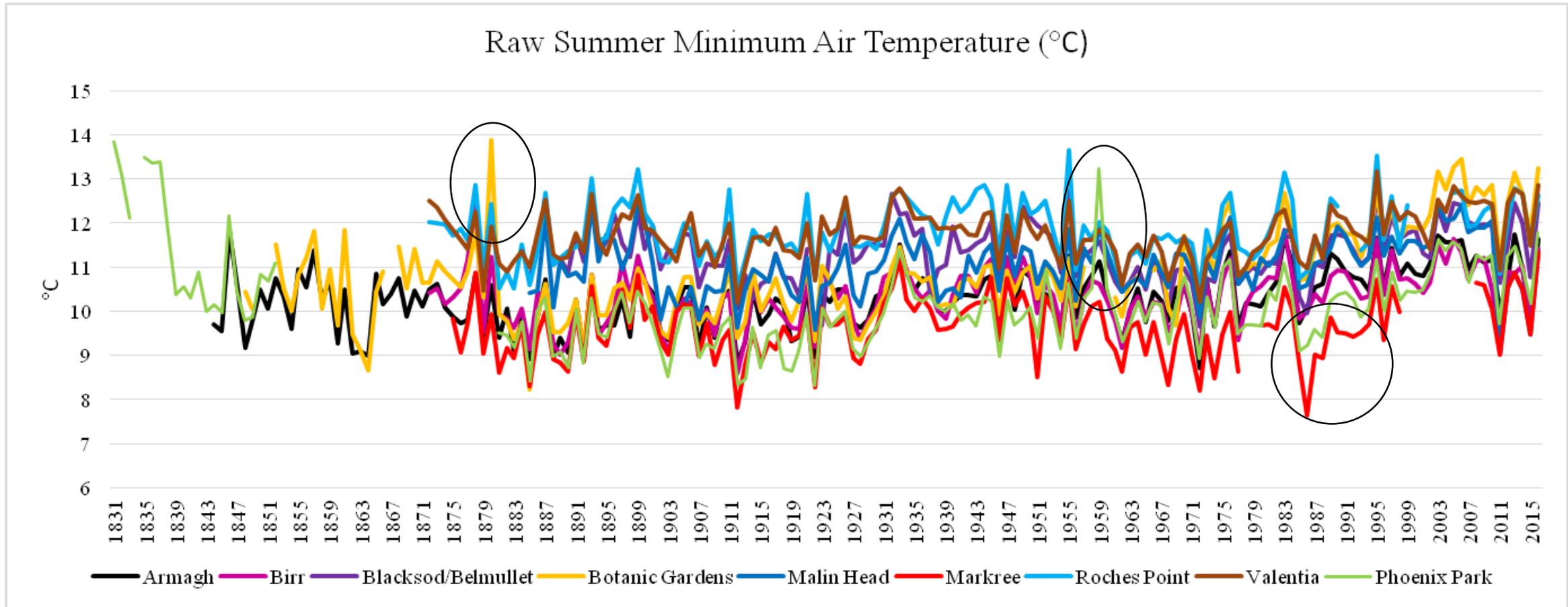
Quality Control - Difference Series



1855 – 1879: Dry Bulb Max. in air (Instrument change)
Phoenix Park

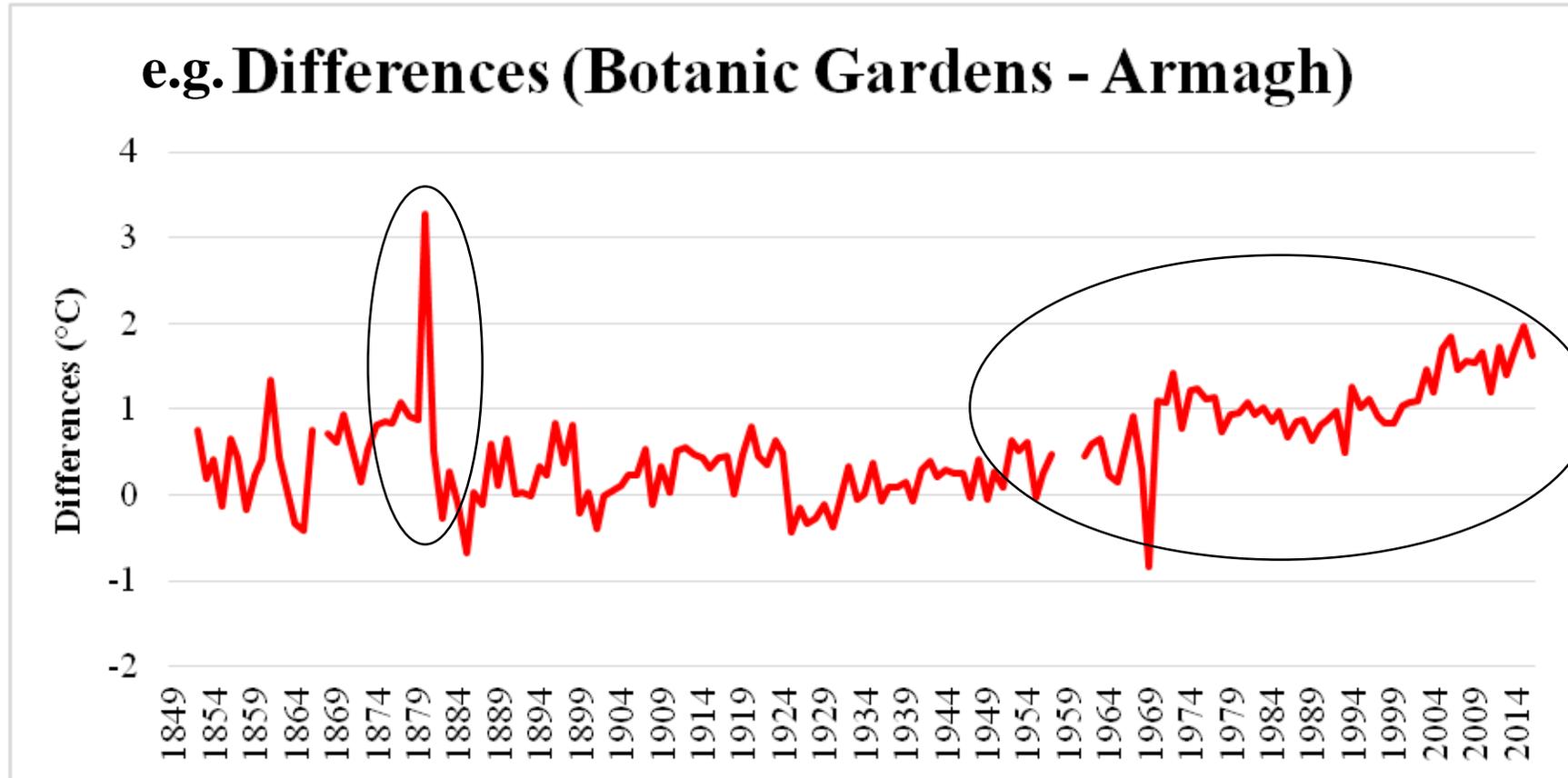
**It is necessary to compare to other
climate stations!**

Quality Control - Raw Summer Minimum Air Temperature



Note: Still doing quality control in Phoenix Park Dublin (1853 – 1880).

Quality Control - Difference Series

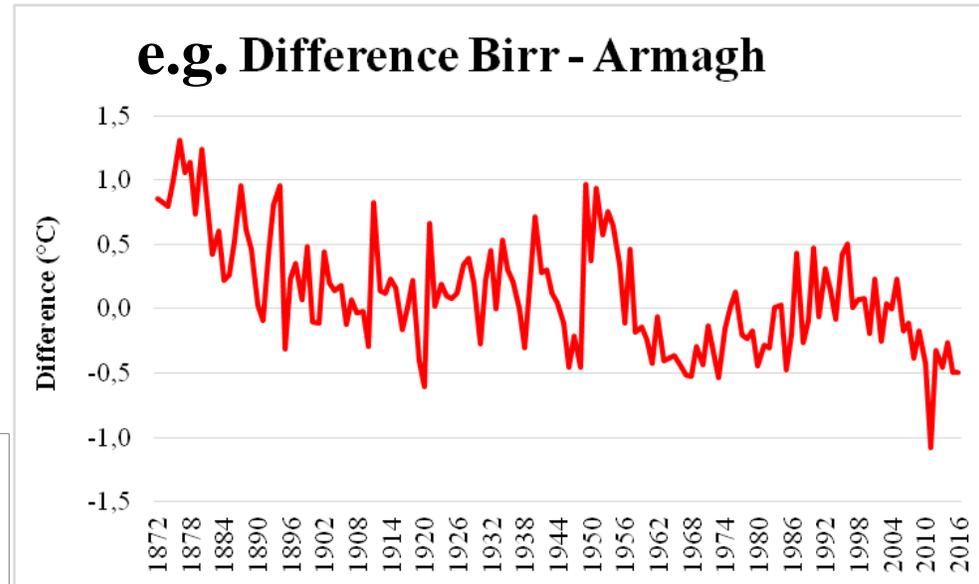
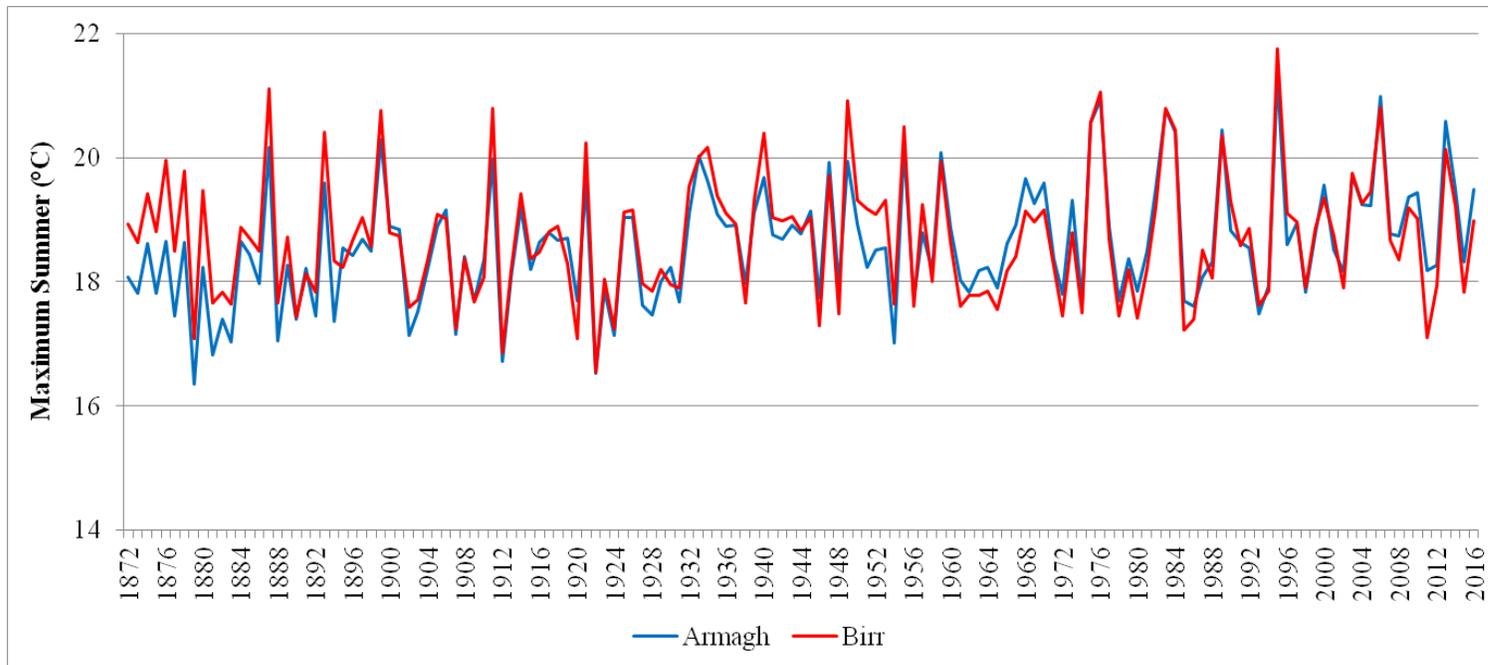


Higher Min Summer values in Botanic Gardens: 1868 – 1881; 1961 – 2016.

It is necessary to compare to other climate stations!

Principal Non-climate Inhomogeneities In These Series

- Relocation of stations (e.g. from a coastal location to a more inland site);
- Instrument changes (also its location and exposure);
- Screens (e.g. Bilman & Stevenson screens);
- Observing practices (e.g. observations in/outside observatory);
- Changes in surroundings and station enclosure .



Max Summer

It is necessary to compare to other climate stations!

IMPORTANCE OF METADATA!

Preliminary Raw Data Analysis – Spatial Comparison of Series

- Pearson correlation among climate series (daily, monthly, seasonal);
- First difference correlation coefficient for reference and candidate climate series nearby (PETERSON and EASTERLING, 1994) (daily, monthly, seasonal);
- Pearson correlation and first difference correlation coefficient for parallel measurements (e.g. manual and automatic stations; observations in/outside observatory; different screens; station relocation) (daily).

DISCUSSION ON PARTICULAR CASES:

- No overlapping between manual and automatic stations (e.g. Markree);
- Available values: °F nearest whole degree instead of the exact decimal degree. What corrections apply in this case?
- Thermometer on stand;
- Thermometer on roof (e.g. different level);
- Observations hours (correction of early series for 09UTC readings).
- Correction of errors.

Next Steps

- Conclusion of the quality control process (Manual & Automatic);
- Application of Software: MASH 3.v.03:
 - Parallel measurements (e.g. overlapping of data from: manual and automatic stations, different screens, in/outside observatory):
 - Composing reference series;
 - Homogeneity tests;
 - Break-points detection and non-climate increase/decrease trend bias in the climate series;
 - Adjustment of non-climatic inhomogeneities through statistical techniques.
 - Quantification of statistically significant break-points, its amplitude and identification of its reason through comparison with metadata for each station;
 - Ascertain the range of breaks for maximum and minimum air temperatures for summer and winter;
 - Validation.
- Homogenisation of monthly and seasonal data;
- Dissemination of the homogenisation results;
- Statistical Analysis and Climate Modelling of:
 - Air temperature extreme indices; extreme air temperature events, cold and heat waves; climate variability and trends based on homogenised data;
 - Gridded air temperature datasets;
 - Dissemination of results.

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Botanic Gardens Library: Botanic Gardens manuscripts.

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Royal Dublin Society Proceedings: Botanic Gardens data.

Raster: NASA SRTM 90m and the EUDEM 30m topography raster image.

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Thank you for your attention & feedback!

For feedback:

C.PEDROSOMATEUS2@nuigalway.ie