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The historic record of cold spells in Ireland

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This paper assesses the long historical climatological record of cold spells in Ireland stretching back to the 1st millennium BC. Over this time period cold spells in Ireland can be linked to solar output variations and volcanic activity both in Iceland and elsewhere. This provides a context for an exploration of the two most recent cold spells which affected Ireland in 2009–2010 and in late 2010 and were the two worst weather disasters in recent Irish history. These latter events are examined in this context and the role of the Arctic Oscillation (AO) and declining Arctic sea-ice levels are also considered. These recent events with detailed instrumental temperature records also enable a re-evaluation of the historic records of cold spells in Ireland.

Keywords: Cold spells; Ireland; historical climatology; climate change

Introduction

There is a long history of extreme meteorological events being recorded in Ireland stretching back as far as the 2nd millennium BC, which is as a result of the survival of a number of monastic Irish annals. The recent two major cold spells in Ireland from December to May 2009–2010 and November–December 2010 have shown that these occurrences are still a part of the Irish climate record. The recent experience has also emphasised the need for a careful evaluation of both the past and the more recent cold spells that have occurred in Ireland.

Using Irish blanket peat, Blackford and Chambers (1995) have shown that wetter and/or cooler periods recorded in the peat at the western oceanic fringes of Europe can be associated with suggested variations in solar output over the last millennium. In particular they suggest that this fringing area is more sensitive to climatic change. They identify the 'Medieval Optimum' and 'Little Ice Age' in the peat record and note that colder/wetter conditions prevailed in the early 1300's (wetter), AD 1410–1540 (both) and AD 1662–1720 (both). The latter two colder/wetter periods coincided with the Spörer and Maunder Minima, but the Wolf Minimum is not obvious from the peat humidification record nor is the post-1900 period.

1740, the coldest year of Manley's Central England Temperature, falls just outside the later colder/wetter period as identified by Blackford and Chambers (1995). This exceptional year occurs just after a decade of warming and the accepted cause is a major volcanic eruption in Siberia or series of eruptions including Siberia in 1739 and early 1740 causing a dramatic downturn in global temperature and associated with blocking high pressure over the Baltic and diving very cold and dry

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air moving southeasterly over Britain and Ireland (Jones and Briffa 2006). The cold year of 1740 and 1741 had a dramatic impact on Ireland, discussed later.

This paper assesses the past record of cold spells in Ireland and puts the most recent 2009–2010 event and late 2010 event into this context. The cause of the cold spells is investigated, with a number of proposed origins of cold spells in Ireland, both historic and contemporary and both regional and global.

Data sources

Ireland is very rich in historical records of extreme weather events stretching back to the 2nd millennium BC. This is due to the survival of complete and partially complete monastic annals from a number of locations around Ireland. A typical example is the Annals of Loch Cé from Co. Roscommon, which cover Connaught, the westernmost province of Ireland, recording events in the period from AD 1014–1590. An example of a cold spell entry in these annals dating from AD 1200 state that this was 'a cold foodless year, the equal of which no man witnessed in that age' (Britton 1937, p. 77). The monastic annals record extreme events as they happened from the fifth to the early-seventeenth centuries, but also noted events dating back to the 2nd millennium BC which had clearly passed down as part of oral tradition. As a result, it is these annals which provide the earliest description of cold spells and extreme snowfalls for Ireland. Fortunately Britton (1937) carried out a detailed analysis and quality assessment of the early records up to AD 1450, resolving many issues to do with the actual dates of events and removing of dubious and duplicate events from the annals and other meteorological chronologies.

The earliest cold weather entry comes from the Annals of the Four Masters, a composite of other sources assembled between AD 1632 and 1636 in Co. Donegal. These annals covers the period from 2242 BC to AD 1616 and includes material from many other annals and fragments of annals along with other medieval manuscripts, documents and records, many of which have not survived.

The next most important source is a tabulation of weather, medical, veterinary and famine events compiled as part of the 1851 Census of Ireland (GBCO 1852) which covers weather events up to the middle of 1850. This unusual addition to the census came about as a result of the 'Great Famine' between 1845 and 1848, in which at least one million people died of hunger or hunger-related diseases and another at least one million emigrated in order to escape the terrible conditions in Ireland at that time. This source neatly overlaps with the monastic annals and is particularly good from the late 17th century onwards. It draws on a vast variety of original source material including early newspapers and journals, some of which has not survived (Hickey 2008).

The period from 1851 is amply covered in Ireland from a wide variety of sources including data from meteorological stations across Ireland and a range of documentary sources including modern newspapers. There is plenty of overlap. For example, Armagh Observatory has been making daily weather observations and instrumental weather records since 1796. Daily air and grass minimum temperatures from 14 synoptic, climatological and other stations were examined for the two most recent cold spells (Table 1). These stations cover the Republic of Ireland, including both inland and coastal locations. Additional information from Northern Ireland was also used.

Table 1. Meteorological stations mentioned in the text by type and location.

Rep. Of Ireland			Northern Ireland
Synoptic	Climatological	Other	Climatological
Ballyhaise	Clonroche	Mount Juliet	Armagh Observatory
Belmullet	Gurteen	Straide	Castlederg
Carlow Oak Park	Johnstown Castle		Omagh
Casement Aerodrome	NUI Galway		
Cork Airport	Phoenix Park		
Dublin Airport			
Knock Airport			
Malin Head			
Mullingar			
Shannon Airport			
Valentia Observatory			

Methodological issues

Cold spells in Ireland where prolonged sub-zero temperatures last for ten or more days are rare in a modern context. This is due to Ireland's maritime climate, with few extremes and a narrow annual temperature range (Rohan 1986). Snowfalls in Ireland have become relatively rare since 1980 and those that do fall rarely stay on the ground for long. However, it is noteworthy that even Boate (1652) writing in the middle of the 'Little Ice Age' commented that snowfalls were not that common in Ireland.

One of the most obvious challenges when dealing with cold spells and snowfalls is to distinguish between the two, given that snowfalls almost always form a component of cold spells. A precise definition of a cold spell has not been located. The WMO defines a heatwave as a period of five consecutive days when the air temperature was 5°C above normal, where normal is taken as being in comparison to the 1961–1990 reference period (Frich *et al*. 2002). Alternatively a certain threshold has to be reached before it can be considered a heatwave, but this must be in reference to the country or region and is usually only defined for the warmest part of the year. However, there are no equivalent definitions for a cold spell.

It is suggested here that a cold spell could be defined on this basis, consisting of a period of 10 consecutive days when the minimum air temperature was 5°C or more below normal (with reference to 1961–1990 for the coldest part of the year). This proposed definition is appropriate for when instrumental data is available. In a historical context and without instrumental data it is suggested that this definition can be extended to include situations where the descriptive evidence suggests that 10 consecutive days were significantly below usual temperatures for that location and for the coldest part of the year.

As a result of these considerations, cold spells in this survey are defined as being events of 10 or more days, whether explicitly stated or implied, of significantly below usual temperatures. In order to verify 'below normal temperatures' in the historical record where there are no instrumental measurements available, explicit statements of unusually severe cold were used. These include reports of lakes, rivers and the sea freezing over for a long duration, along with evidence of cold-related fatalities of humans, farm animals, wild animals, birds and even marine animals. These

occurrences of freeze-ups and mass mortality are all rare in an Irish climatic context dominated by mild maritime conditions. One cold spell was included although it was not clear that the 10 day threshold was reached, because of the unseasonal timing of the event indicating that something was perturbing the normal annual climate cycle very significantly. This event occurred on 23 June 1728 when ice was found on the River Liffey (GBCO 1852). This is a very late date for ice in Ireland, indicating a significant cold spell associated with this individual record, although this is not explicitly stated. This event is worthy of further research.

One of the more common problems with the historical record is when snowfall is clearly identified as having occurred over a prolonged period of time, implying a cold spell with temperatures at 0°C or below it, although the latter is not specifically stated. Six events fall into this category. These events were included as cold spells where it was obvious that a period of 10 days or more of snowfall or snow lying was being described, thereby indicating sustained very low temperatures.

The historic record

In total, some 77 cold spells were identified for Ireland covering the period from 538 BC up to the end of 2010 (Table 2). The earliest cold spell recorded for Ireland dates back to 538 BC. As the next recorded event does not occur until AD 588, this survey will consider the records from this time onwards. The next cold spell recorded was in AD 695, at which time the sea between Ireland and Scotland froze and people made visits across it. The winter of AD 763–764 was the next recorded event, described as a great snow for three months. Britton (1937) described this winter as being one of the worst in recorded history, associated with the withering of trees and vegetables and the death of many marine mammals due to the severity of the cold spell.

From the winter of AD 816–817 up to the end of the survey in 2010, records of cold spells are much more common. At a century timescale, two periods of increased recorded incidences of cold spells are apparent (Figure 1). The first is from AD 1000–1099 with eight cold spells. From 8th of December 1046 to 17th of March 1047 the winter was described as severe with heavy snows which stayed on the ground throughout the full time period. There was destruction of men, cattle and birds and also wild animals of the sea (Britton 1937). This description again indicates the duration and severity of this cold spell. This peak of cold spells in the 11th century is surprising as this occurs in the middle of the 'Medieval Warm Period' (roughly AD 800–1300) and is not an obvious artefact of the coverage of the monastic annals from which almost all of this information comes. This anomaly was also noted by Mitchell (2011). To emphasise this, there is a further slightly increase in records of cold spells in the 13th century with six events. A typical entry for this time period is the winter of 1281–1282 when great snow was recorded from the 25th December to the 1st of February (Britton 1937).

Throughout the decline into the 'Little Ice Age' from 1300–1450 and the 'Little Ice Age' from 1450 to 1699, relatively few cold spells are recorded for Ireland. The winter of 1433–1434 stands out, with cold spell that lasted for between five and seven weeks before Christmas (depending on the annals consulted) and seven weeks after. The event was described as one of great frost, so much so that much transport was carried out on the frozen rivers and lakes (Britton 1937). A similar type of event, but of somewhat shorter duration, occurred in 1517.

Table 2. Comparison of Dates of Cold Spells with Global and Icelandic Volcanic Eruptions and Low Sunspot Numbers

Cold Spell	Possible Eruption	Solar Cycles and Minima
538 BC	c.500 BC Hverfjall, Iceland	
AD 588		
695		
763–4		
816–7		
821–2		
855–6		
917	925 + / − 25 Langjökull, Iceland	
941	925 + / − 25 Langjökull, Iceland	
955	960 + / − 10 Ljósufjöll, Iceland	
963	960 + / − 10 Ljósufjöll, Iceland	
1008		
1026		
1029		
1046–7		Oort Minimum
1075–6		Oort Minimum
1078		Oort Minimum
1092–3		
1095		
1110–1		
1114–5		
1156		
1200		
1205		
1233–4		
1245	1245 Katla, Iceland	
1247		
1251		
1281–2		Wolf Minimum
1336		Wolf Minimum
1338–9		Wolf Minimum
1433–4		
1462		Spörer Minimum
1465		Spörer Minimum
1517		Spörer Minimum
1541		Spörer Minimum
1600–1		
1635		
1641		
1683		Maunder Minimum
1692		Maunder Minimum
1708–9		Maunder Minimum
1715		Maunder Minimum
1726		
1728	1727 Öræfajökull, Iceland	
1728	1727 Öræfajökull, Iceland	
1739–40	1739 Siberia, Russia.	
1744		

Table 2 (*Continued*)

Cold Spell	Possible Eruption	Solar Cycles and Minima
		1755 Mar (Solar Cycle 1)
1766		1766 Jun
1767		
1771		1775 Jun
1783–4	1783–4 Laki, Iceland	1784 Sep
1788–9		Dalton Minimum
1801–2		1798 May, Dalton Minimum
1803		Dalton Minimum
1813–4		1810 Dec, Dalton Minimum
1815	1815 Tambora, Indonesia	Dalton Minimum
1816	1815 Tambora, Indonesia	Dalton Minimum
1820		Dalton Minimum
1821		Dalton Minimum
1823		1823 May
1826		
1829		
1834		1833 Nov
1835		
1841		
1845–6		1843 Jul
		1855 Dec
1879	1879 Reykjanes, Iceland	1878 Dec
1894–5		1890 Mar
1917		1902 Feb
1947		1923 Aug
1962–3		1954 Apr
1978–9		1964 Oct
1982		1986 Sep
2009		2008 Dec
2009–10		
2010		

Sources: Siebert and Simkin 2002, IMS 2010, NASA, 2010

It must be noted that the 1600s is particularly problematic in terms of information survival, due to the cessation of record-keeping with the dissolution of the monasteries, and the upheavals caused by the Williamite and Cromwellian Wars. Therefore the totals for the seventeenth century are unlikely to be truly reflective of what is probably the coldest century of the 'Little Ice Age' in Europe (Hickey 2010). For 1691 it is noted that there was a great frost in January and February of that year (GBCO 1852). Much work remains to be done on the seventeenth-century climate of Ireland from the scattered sources that survive.

High incidences of cold spells are found in the 1700s and 1800s. The highest number of events was recorded in the 1800s with 16 events, roughly one every 5 to 6 years. There was a fall-off in the 1900s with only five events, showing the influence of generally rising global temperatures over this time period. However, the century total for the nineteenth century is misleading, as 14 of the 16 events are recorded as part of

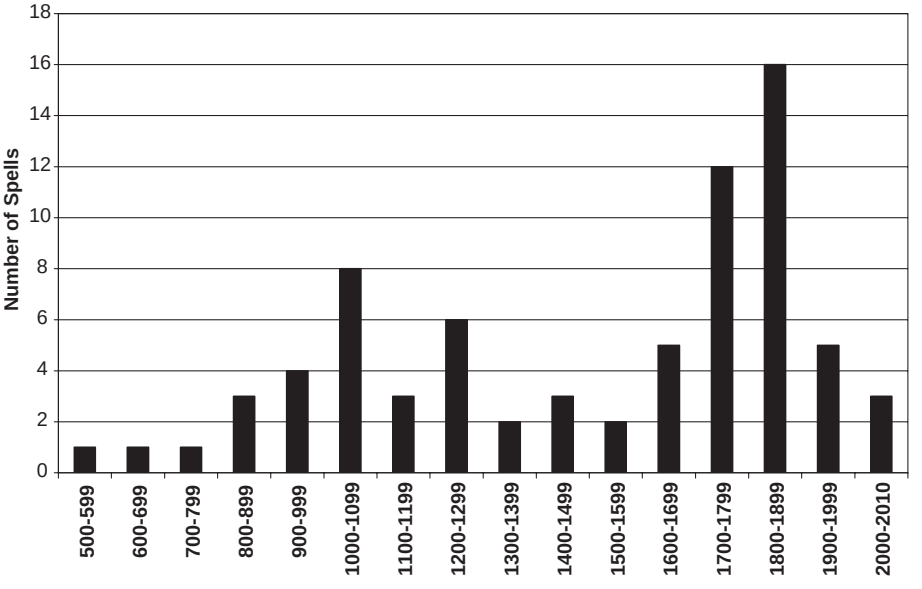


Figure 1. Cold Spells in Ireland Per Century from AD 500–2010.

the 1851 Census of Ireland (GBCO, 1852), whereas only two events are recorded for the rest of the century. It is unclear whether this high cluster coming just before the end of the record is an artefact or a true reflection of the changes in climate with the global warming period coincidentally dating back by many authors to 1850 (Danny Harvey 2000, Houghton 2009). One argument supporting the true existence of this cluster is the fact that the peak decade in the 1800s is the 1820s with five cold spells (Figure 2). Typical of the 1820's events was January 1823 when immense snowfalls fell associated with great frost caused significant disruption to road and canal transport (GBCO 1852). While instrumental data becomes available for Ireland from the late 1700s, it improves through time, particularly with the establishment of a meteorological network from the late 1860's onwards. It is very unlikely that a cluster of cold spells occurring in the latter half of the 1800s would have been missed by all the currently available records both newspaper, archival and instrumental.

In the 20th Century there were few cold spells recorded, the worst being that of January to March 1947 which was very similar to the 2009–2010 spell with sub-zero temperatures for long periods of time and regular and spectacular snowfalls. Indeed, in Ireland this event became known as 'The Big Snow'. Kearns (2011) notes that this prolonged cold spell was punctuated by five blizzards which were responsible for numerous deaths, including a number of shipwrecks with fatalities at sea. Direct fatalities due to exposure to the weather numbered in the tens and were possibly as high as 100. Most of the victims were individuals caught in shipwrecks or trying to move from one place to the next, as well as farmers trying to carrying out outdoor chores such as trying to feed and/or save their starving animals. Tens of thousands of farm animals and wild animals and huge numbers of birds also died, many of them frozen *in situ*. Indirect fatalities due to lack of fuel and food were much higher and it is likely that thousands died. This is supported by the fact that mortality rates were at

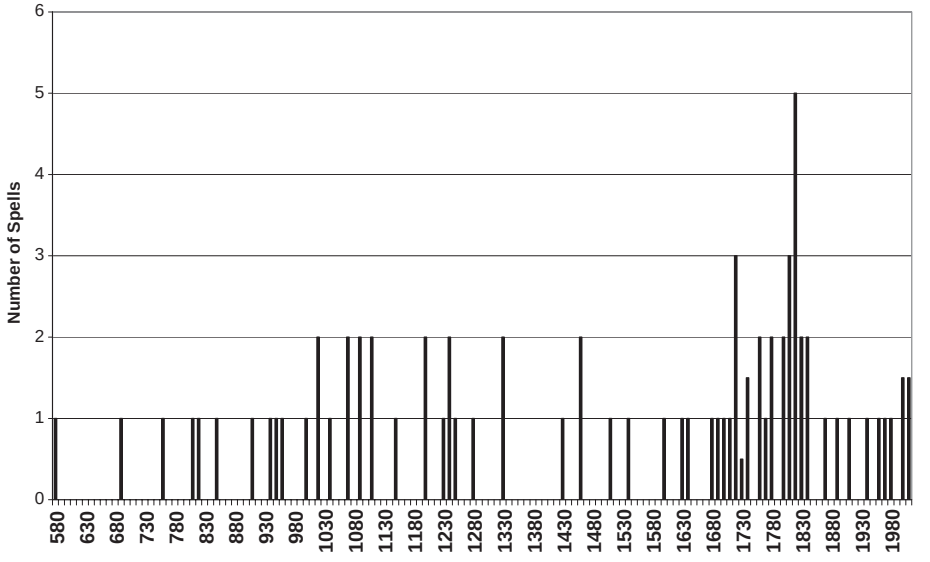


Figure 2. Cold Spells in Ireland Per Decade from AD 580–2010.

least three times normal winter levels in Dublin and elsewhere around Ireland (Kearns 2011).

Figure 3 shows a comparison of recent cold spells in Ireland and includes the events of 1946–7, 1962–3, 1978–9, 1981–2, 2009–2010 and 2010 in Ireland. This shows that the recent cold spells contained some protracted periods of below average temperature but also pulsy temperature variations. The latter can probably be attributed to Ireland's maritime location and the position of the contact zone between northerly cold and southerly warm air masses. The recent well-instrumented cold spells give a real insight into the nature and severity of past events.

The 2009–2010 cold spell

The main, and most severe, part of the cold spell lasted from the 12th of December 2009 to the 10th of January 2010, when the main thaw set in. However, significantly below-average temperatures were recorded in Ireland right up to the first week in May. The cold spell can be broken down into two phases, the first of which is from the 12th to the 24th of December. Over this time period there was a gradual but persistent decline in temperatures, so much so that by the 24th December daytime maximum temperatures (generally day time) across Ireland were between -3°C and 5°C and minimum temperatures (generally night time) were between 0°C and -9°C (Table 3). In addition ground minimum temperatures reached -12°C across Ireland. To put these figures in an Irish context, minimum air temperatures below -5°C are rare in a normal winter (in the 2nd percentile), below -10°C ground minimum temperatures are also uncommon (in the 1st percentile) (Rohan 1986).

The second part of the main cold spell occurred between the 25th of December 2009 and the 10th of January 2010, after which there was a thaw. The 25th of December was notable for minimum temperatures of between -1°C and -10°C,

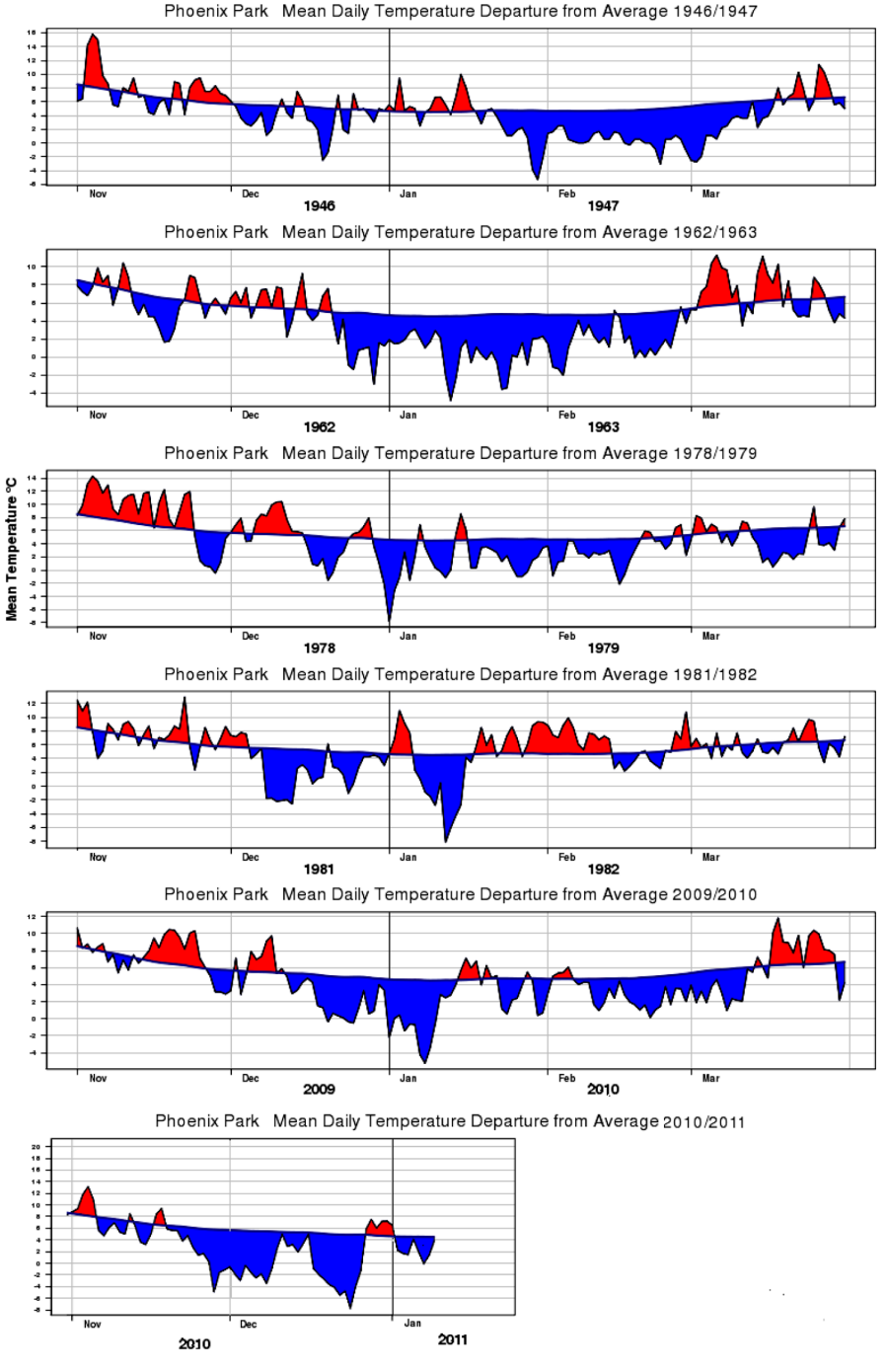


Figure 3. Comparison of Recent Cold Spells (1946–7, 1962–3, 1978–9, 1981–2, 2009–10 and 2010–11 at Phoenix Park Climatological Station, Dublin (after Met Éireann 2011).

Table 3. The decline of all temperature measures (°C) between the 12th and 24th of December 2009 at all major synoptic stations in Ireland.

Date	Air Maximum	Air Minimum	Ground Minimum
12th	5 to 11	−2 to 7	lowest −6
13th	1 to 9	−4 to 3	lowest −8
14th	5 to 10	−3 to 7	lowest −8
15th	7 to 10	−1 to 7	lowest −6
16th	5 to 10	−3 to 8	lowest −7
17th	4 to 9	−2 to 5	lowest −6 and below 0 at all stations
18th	0 to 7	−6 to 2	lowest −11 and below 0 at all stations
19th	3 to 8	−4 to 1	lowest −9 and below 0 at all stations
20th	0 to 6	−3 to 1	lowest −8 and below 0 at all stations barring one
21st	1 to 6	−5 to 2	lowest −10 and below 0 at all stations barring one
22nd	1 to 7	−6 to 2	lowest −11 and below 0 at all stations barring one
23rd	−1 to 5	−7 to 0	lowest −11 and below 0 at all stations
24th	−3 to 5	−9 to 0	lowest −12 and below 0 at all stations

Source: Met Éireann 2009 December

with a ground minimum temperature of −13°C being recorded (Table 4). Between this date and the 6th of January there were persistently either zero, or more often below zero, minimum temperatures throughout Ireland. Ground minimum temperatures also remained below freezing throughout the country. The most severe temperatures of the cold spell were recorded between the 7th and 9th of January, with maximums of between −3°C and 6°C and minimums of between −1°C and −12°C and with ground minimums reaching −15°C on the 9th of January. Temperatures improved on the 10th of January and a major thaw set in on the 11th of January. The lowest temperature recorded was at Mount Juliet in Co. Kilkenny, where −16.3°C occurred on the 7th of January 2010. This was the one of lowest temperatures ever recorded for Ireland and was just over 3°C higher than the record low of −19.4°C, recorded at Omagh, Co. Tyrone on the 23rd of January 1881.

To put these figures in context, December 2009 was the coldest December on record since 1981 and was the coldest month on record since February 1986. January 2010 was the coldest January on record since 1985 and the coldest in the Dublin area since 1963. January 2010 was 6°C below normal and this emphasises the severity of the cold spell. Snowfall was common throughout the cold spell but there was little accumulation of snow because of day time temperatures, except at altitude where substantial snow amounts built up.

This event had a significant impact on Ireland. No direct fatalities were recorded, but thousands of people suffered serious injuries from falls and car accidents due to frozen footpaths and roads. In addition, when the thaw came there was widespread water damage to houses and other buildings due to burst pipes. Insurance claims amounted to 297 million euro, with estimates of between 200 and 300 million euro being lost due to reduced economic activity. Allowing an additional several hundred million for non-insured damage, this event was the most costly weather disaster in recent Irish history (Hickey 2010).

However, this was only the end of the main cold spell. Periods of well below average minimum air temperatures persisted right up to the first week in May 2010.

Table 4. The temperature (°C) of the main cold spell between the 25th of December 2009 and the 10th of January 2010 at all major synoptic stations in Ireland.

Date	Air Maximum	Air Minimum	Ground Minimum
December			
25th	1 to 9	−10 to −1	lowest −13 and below 0 at all stations
26th	2 to 9	−3 to 5	lowest −7 and below 0 at all stations barring one
27th	3 to 9	−4 to 2	lowest −8 and below 0 at all stations
28th	1 to 8	−6 to 5	lowest −11 and below 0 at all stations barring one
29th	2 to 6	0 to 4	lowest −1
30th	2 to 9	0 to 4	lowest −1
31st	2 to 7	−4 to 1	lowest −8 and below 0 at all stations
January			
1st	−2 to 6	−6 to 1	lowest −11 and below 0 at all stations barring one
2nd	2 to 7	−7 to 3	lowest −12 and below 0 at all stations barring one
3rd	1 to 6	−6 to 2	lowest −12 and below 0 at all stations
4th	0 to 5	−7 to 1	lowest −12 and below 0 at all stations
5th	0 to 6	−5 to 2	lowest −9 and below 0 at all stations barring one
6th	0 to 5	−9 to 2	lowest −13 and below 0 at all stations
7th	−3 to 6	−12 to −1	lowest −12 and below 0 at all stations
8th	−4 to 6	−12 to −1	lowest −13 and below 0 at all stations
9th	−3 to 6	−12 to −3	lowest −15 and below 0 at all stations
10th	0 to 6	−7 to 2	lowest −7

Source: Met Éireann 2009 December, 2010a January

Most major meteorological stations recorded their coldest temperatures in February between the 8th and the 10th ranging from −2.4°C to −6.6°C. Temperatures got even colder again in March, with notable cold conditions prevailing on the 11th of March and between the 20th and 22nd of March. In the former case lowest temperatures were recorded at some major meteorological stations for the month and ranged from −4.6°C to −7.5°C (the lowest figure recorded for the month). Temperatures were not quite so low for the latter period but still ranged from −1.4°C to −7.3°C.

One of the causes of this particularly severe cold spell in Ireland was the behaviour of the Arctic Oscillation (AO) which came to dominate airflows over Ireland. Northerly and northwesterly airflows were dominant throughout much of the period from late December to early May. This had the effect of blocking the more common westerly and southwesterly airflows which generally lead to mild and wet conditions throughout the winter, interspersed with the occasional colder period dominated by more easterly airflows. Significantly low values for the Arctic Oscillation were recorded for this cold spell. February 2010 had the lowest ever recorded value of any month (−4.266) since systematic records began in 1950 (Table 5). The months of December and January had very low values. When the mean daily values for the actual cold phases in Ireland are computed, they are substantially lower than the monthly values. Within these cold phases individual days had even lower values, with the 21st of December 2010 having an AO of −5.821.

Table 5. Values of the Arctic Oscillation during the two most recent cold spells.

Month	Value	Phase	Mean Daily Value	Date of Highest Value	Value
2009					
December	−3.412	12–24 Dec	−4.543	21 Dec	−5.821
2010					
January	−2.587	25 Dec–10 Jan	−4.435	3 Jan	−5.533
February	−4.266			6 Feb	−5.205
November	−0.376	27 Nov–9 Dec	−1.578	26 Nov	−4.085
December	−2.931	17–26 Dec	−4.111	18 Dec	−5.265

Source: NOAA, 2011

One of the by-products of this dominant northerly and northwesterly airflow was the ash crisis across Europe caused by the eruption of the Eyjafjallajökull volcano in Iceland. Ireland was particularly badly affected because of the prevalence of the volcanic plume over or near Ireland as a result of this dominant airflow (Met Éireann 2010a).

The November–December 2010 cold spell

The year 2010 featured an almost unprecedented second severe cold spell which lasted from the 27th of November to the 26th of December, setting new all-time record low air temperatures for Ireland for both November and December. However, in the interval between the 10th and 17th of December, temperatures recovered towards normal. As a result, this cold spell can also be broken down into two phases. The first phase was from November 27 to December 9, with lowest temperatures being recorded at most Irish meteorological stations on either the 29th or 30th of November (Table 6). The new record low air temperature was set on the 29th of November at Clonroche, Knoxtown, Co. Wexford, when a value of −11.5°C was recorded. A new record low grass minimum temperature of −17.1°C was set for the same location and date. The month of November was the coldest on record in Ireland since 1985 with mean monthly temperatures from −0.5°C to −2.5°C below normal. This was despite an exceptionally warm start to the month with temperatures reaching 19°C in places.

The second phase of the cold spell, although shorter, was the severest. It lasted from December 17th to 26th. Most meteorological stations recorded their coldest temperatures on the 25th or 26th of December (Table 6). Straide in Co. Mayo had the new record low for December for the Republic of Ireland on the 25th of the month with −17.5°C. However an even lower temperature of −18.7°C was recorded in Northern Ireland on the 23rd of December at Castlederg, Co. Tyrone. This latter figure is very close to the all-time record low temperature ever recorded for Ireland. Unsurprisingly, the month of December 2010 was the coldest December on record for much of Ireland, with mean monthly temperatures varying between −2°C and −7°C below normal. Casement Aerodrome, Co. Dublin recorded its lowest ever temperature on the 25th at −15.7°C (Table 6). Snowfall was widespread, persistent and slow to melt, with maximum ground totals reaching 0.27m at Casement Aerodrome, Co. Dublin.

Table 6. Lowest air temperature values for selected synoptic and climatological stations (°C) from November to December 2010

	Nov		Dec	
Station	Temp	Date	Temp	Date
Ballyhaise	−6.5	28	−15.2	25
Belmullet	−4.5	29	−7.6	22 & 24
Carlow Oak Park	−6.4	30	−12.9	3
Casement Aerodrome	−9.1	28	−15.7	26
Cork Airport	−3.3	29 & 30	−7.2	21 & 23
Dublin Airport	−8.4	29	−12.2	26
Gurteen	−6.5	29	−13.4	25
Johnstown Castle	−4.6	29	−4.5	5
Knock Airport	−4.5	29	−7.4	22
Malin Head	1.1	14	−3.5	22
Mullingar	−5.3	29	−14.1	25
NUI Galway	−7.8	29	−15	25
Shannon Airport	−6.6	29	−11.4	25
Valentia Observatory	−3.1	29	−7.7	22

Source: Met Éireann 2010a November–December

Between 5 and 10 people died as a direct result of the second cold spell and once again thousands suffered serious injuries due to falls and car accidents. Again the thaw generated significant water damage and was the major component in the 224 million euro in insurance claims. Lost economic output was lower than in the previous cold spell, but was at least 100 million euro. Allowing for non-insured losses, this event was the second worst weather disaster in recent Irish history with a greater impact than either the 2009 flooding in Galway, Cork, the West of Ireland and the Shannon Basin or the 2011 flooding in Dublin and Wicklow.

The causes of the first cold spell were mirrored for the second cold spell, in particular the behaviour of the AO which came to dominate airflows over Ireland. Northerly and northwesterly airflows once again blocked the more usual milder westerly and southwesterly airflows (Met Éireann 2011). Again, low values for the AO were recorded for this cold spell, although they were not quite as extreme as in the previous case (Table 5). November had a value of only −0.376, but this is a product of very positive values of AO at the start of the month and very negative values at the end of the month. If the cold spell is just examined, the AO drops to −1.578. Within this period a value of −4.085 was recorded on the 26th of November. The value for December was much more negative at −2.911, with −4.11 for the cold phase and the lowest AO value of −5.265 on the 18th of December.

Duration of cold spells

One of the features of the cold spells considered here is their duration. Many consist of weeks and even months of continuous low temperature and high pressure. The long duration of the events clearly indicates stable atmospheric conditions over Ireland. Only events with specific dates are included in this brief analysis of duration.

Unfortunately many events are rather vague about actual start and finish dates. For example, the winter of 1517 was described as having great frosts, so much so that some rivers were frozen for weeks at a time (Smith 1839, GBCO 1852). For some of the earlier events, there is no indication as to what part of the year was affected. As a result, of the 77 identified cold spells discussed in this paper, only 24 have specific start and end dates.

Most events with specific dates fall within the two categories of 25–49 days duration or 50–74 days durations (Figure 4). Two events of 100 days duration or more have been identified. The first of these occurred from the 8th December 1046 to the 17th March 1047, a duration of 100 days. The second and longer event occurred in 1771 from the 3rd of January to the 18th of April. This 106-day period was described as one of almost continuous frost and snow and an easterly breeze, indicating a continental origin for this cold spell (GBCO 1852). It is likely that other longer-duration cold spells occurred amongst the 77 events, but the dating is not specific enough to enable them to be firmly identified.

Given the small sample size, it is impossible to indicate any temporal variability in the duration of cold spells with any certainty. With the exception of one event, all of the cold spells are associated with the winter half of the year, with a little overspill into the summer half of the year, most commonly at the end of cold spells.

Causes of cold spells in Ireland

The predominant cause of recent cold spells in Ireland is the extension either of cold continental air westwards or cold polar air southwards. The latter is associated with the behaviour of the Arctic Oscillation (AO), which played a key role in the cold spells of both 2009–2010 and late 2010, with exceptionally low values as discussed above (Table 5). The role of the AO in generating cold spells in north-western Europe is down to the presence of a persistent zone of high pressure near Greenland and over

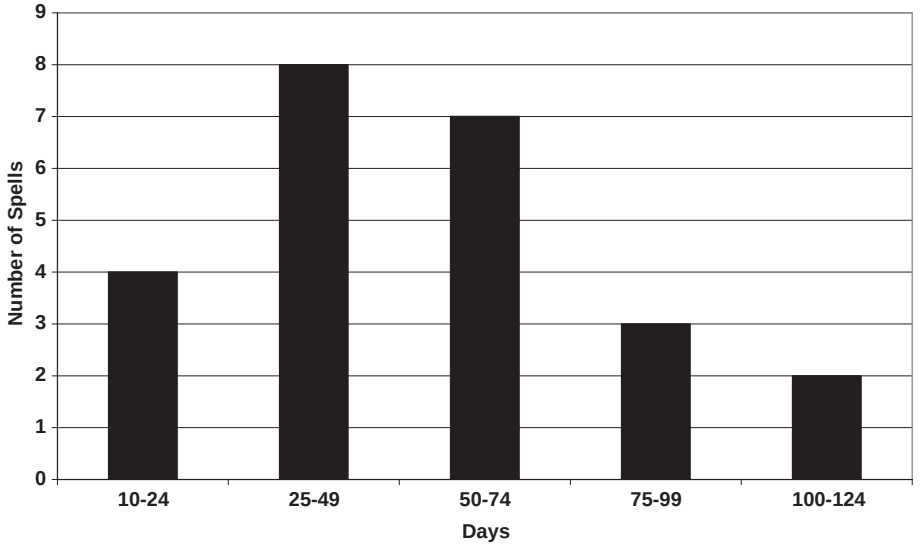


Figure 4. Duration of Specifically Dated Cold Spells in Ireland

the Arctic in general, which in turn facilitates the movement of cold Arctic air southeastwards into Europe, aided by weak zonal winds. This was reflected in an almost north-south movement of the jetstream from west of Greenland and Iceland to south of Ireland and Britain before turning eastwards across Northern France. This generated a significant low pressure over Ireland, Britain and parts of Europe.

It is apparent from the descriptions of historic cold spells that there is also an important volcanic component to the record. For the year 1023 BC the Annals of the Four Masters state that 'there was this year a huge snow with a vinious taste from which *Oill-finsneachta* was so called' (Britton 1937, p. 7). *Oill-finsneachta* has been translated as wine snow. It is likely that this unusual snow was associated with volcanic fall-out from Iceland, hence the unusual description. Similar descriptions of unusual snow are recorded for 665 BC and 538 BC. It is possible that this is just one event, but equally it could refer to two or three separate events, particularly given the fact that the information was written down long after these events took place. The volcanic record from Iceland shows that there were eruptions in all three of these time periods, further supporting the suggestion that these eruptions are the most likely origin of these unusual snows (Hickey 2010).

Two of the historic cold spells took place as a result of major global volcanic eruptions, and it is very likely that some of the other cold spells prior to AD 1500 may also be as a result of such events. However, the record of volcanic eruptions prior to AD 1500 is very incomplete, deteriorating further as one moves back in time. The role of large scale explosive volcanic eruptions in reducing global temperature, among other effects, is well established (Eddy 1980, Dawson *et al*.1997, Robock 2000). Their role in previous cold periods is still under investigation (Wohletz 2000).

In terms of human impact, the 1739–1741 cold spell was the worst recorded for Ireland. This was most likely due to a major volcanic eruption in Siberia. This eruption caused a climatically induced famine in Ireland which, in combination with the extreme cold weather, resulted in the estimated deaths of between 310,000 and 480,000 people (Dickson 1997). 1740 is the coldest year on record in Manley's Central England Temperature Record, emphasising the uniqueness of this event (Manley 1974 and updates). Only one outdoor instrumental temperature value survives from this time for Ireland. This was -33°C, which is nearly 14°C lower than the modern record for Ireland. Even allowing for inaccuracy in the reading from a non-standard instrument, this is indicative of just how extreme was the cold (Dickson 1997). The 1815 Tambora eruption in Indonesia also produced a cold spell, mostly associated with collapsed summer time temperatures across Ireland, so much so that 1816 became known universally as 'The Year with no Summer' (Harrington 1992).

The second volcanic component comes from Iceland, which appears to be directly involved with some cold spells in Ireland, representing a more regional effect across north-western Europe and possibly beyond (Table 2). The possible role of volcanism in the cold spell of 538 BC has already been mentioned above. None, one or some of the four events of AD 917, 941, 955 and 963 may be attributed to the eruptions of Langjökull $925 +/- 25$ and Ljósufjöll $960 +/- 10$, although there is nothing in the brief descriptions of these cold spells to clearly identify a volcanic role. The cold spell of AD 1245 is clearly linked with an eruption at Katla. The description of the event in the Annals of Loch Cé notes that on December 5 'Poisonous snow fell on the night of the festival of St. Nicholas which took off the heels and toes of those who walked

in it [presumably barefoot]: this snow did not disappear until Christmas arrived' (Britton 1937, p. 96).

The two events that occurred in 1728 are likely to be at least partly a product of the eruption of Öræfajökull in 1727. This is particularly the case for the earlier of the two events when, on the 3rd of June, ice was found on the River Liffey (GBCO 1852). In the second event, December was described as having frost and snow that was more severe and of longer duration than for many years past (GBCO 1852).

The 1739–1741 event has already been discussed above, while the Laki eruption of 1783–4 and 1816 Tambora are well known. In the case of Laki, yellow snow was recorded as falling in Scotland (Dawson 2009). The last event prior to 2010 which coincides with an Icelandic eruption is that of Reykjanes in 1879. Siebert and Simkin (2002) consider that this event had a very significant impact on Ireland. In particular the intense and prolonged winter caused an excess mortality nationally of 12%, with an excess mortality of 20% in Dublin (mostly in the age categories of below 5 years and above 50 years). These figures suggest that thousands more people than usual died of cold and cold-related illnesses as a result of this severe cold spell (Siebert and Simkin 2002).

It is possible that additional volcanic eruptions were associated with other Irish cold spells. This can be theorised due to roughly matching dates, with the eruption obviously occurring before the cold spell. This idea became clear as a result of the 2010 ash crises across Ireland and Europe with the drifting of ash across the region on a number of occasions, although not enough ash and aerosols were produced to have any noticeable climatic effect (Hickey 2010). However, there is one further complication that must be clearly expressed, as exemplified in the 2010 eruption. In this case the volcanic influence was a result of the behaviour of the AO which pushed cold air, and with it the volcanic plume, southeastwards towards Ireland and Europe. In this case the volcanic influence was a consequence and not a cause.

Finally, two other factors should also be considered in assessing the causal factors of cold spells in Ireland and NW Europe. The first of these is the role of decreased solar output as evidenced by reduced sunspot numbers. Lockwood *et al.* (2010) suggest that during times of reduced sunspot numbers and where they stay low, that the northern part of the Northern Hemisphere (in particular Northern Europe) can be affected by reduced winter temperatures leading to an increased likelihood of cold spells. Blackford and Chambers (1995) were able to demonstrate this relationship using peat humidification records from Ireland, but noted no evidence of the Wolf Minimum or post-1900 relationship with solar variability. In the former case it is suggested that the North Atlantic climate, as evidenced by major reduction in the NAO prior to AD 1420, may have been operating very differently (Dawson *et al.* 2007). Given the relationship between the NAO and AO it is likely the AO would also operate very differently in this time period.

During the post-1900 period, anthropogenic warming becomes more important and swamps solar variations. The recent non return/ low numbers of sunspots at the start of solar cycle 26 and cold spells in Europe occurring in the winters of 2008–2009, 2009–2010 and 2010–2011 (the first after a long run of mild winters throughout the 1990s and 2000s in Ireland) suggest that solar output is still important. This regional effect can occur irrespective of the overall global warming pattern that is occurring. It is noteworthy, for example, that 2010 was the joint warmest year on record globally. It has also been suggested that because of the

influence of human-induced global warming, the effect of decline in sunspot numbers similar to the Maunder Minimum would only lead to a drop in global temperatures of 0.3°C, so that the severe cold experienced during the Maunder Minimum would not be repeated (Feulner and Rahnstorf 2010). This may be behind the unusual behaviour of the Arctic Oscillation in causing the cold spells of 2009–2010 and late 2010 and is likely to have been a factor in a number of other cold spells that have affected Ireland.

The past record of solar cycle lows and minima shows a strong coincidence with many cold spells in Ireland (Table 2). Of the 77 events, 30 events can be associated with either periods such as the Oort and Wolf Minima with three cold spells each, the Spörer and Maunder Minima with four events each and the Dalton Minimum with nine events. As previously stated, the record of Irish cold spells during the 17th century is poor because of the absence of monastic annals and other disruptive events, so the total here should be higher or the lowest point of each solar cycle since 1755. However, with the exception of the 2008 December low, no cold spells coincides with solar cycles lows going as far back as 1879. The latter point emphasises the way that anthropogenic-induced warming has dominated the recent solar signal.

Remarkably some events seem to be associated with both reduced solar output and volcanic activity. These conditions would obviously increase the likelihood of a significant cold spell occurring in Ireland (Table 2). Three cold spells can be identified that fall into this category: the 1783–4 Laki eruption and Solar Cycle 4, 1816 Tambora and the Dalton Minimum in 1816, and the 1879 Reykjanes eruption and Solar Cycle 12 which started in December 1878.

The decline in all forms of ice around the North Pole has caused increasing concern and may yet become a factor in aiding the generation of cold spells across Ireland and Northern Europe (HSBC 2010). In particular, attention has been focussed around the North Pole notably the Barents-Kara sea-ice in summer. There is now some evidence to suggest that this change may be altering the polar climate and in so doing altering north-western Europe's climate to colder winters. Of particular note in this respect was the 2005–2006 cold winter in Europe and parts of Asia (Petoukhov and Semenov 2010). Ireland was not affected by this cold winter to any noticeable extent.

Conclusions

The 77 cold spells identified for Ireland clearly show that these events occur irrespective of the climatic period in which they are found and that there is a remarkable record stretching back to the 1st millennium BC which can be used to analyse such spells. In addition, the causes of these cold spells may not be clear cut; the role of different cold air masses and their position over Ireland, although still a major cause of cold spells, is not the only cause by any means. The role of the AO in recent events needs to be considered for previous historical events, including the triggers that cause the AO to behave in an unusual fashion in the modern context at least.

Other triggers may be at work. These include large-scale volcanic eruptions, which have caused significant cold spells in Ireland on a number of occasions. In addition, the role of Icelandic volcanic eruptions in a regional context should not be

underestimated. Reduced solar output, even in the recent context of a human-induced warming world, may also play a role in causing cold spells in an Irish and Northern European context, either directly, or by affecting the Arctic Oscillation. The loss of summer sea-ice around the North Pole may also be a factor in influencing recent cold spells in Ireland and Northern Europe. Remarkably, some Irish cold spells may even be the product of both reduced solar output and Icelandic volcanic activity. This suggests that cold spells in Ireland are not a simple outcome of meteorological variability but can result from complex forces (i.e. solar, volcanic, loss of North Pole sea ice) interacting on the weather patterns that affect Ireland.

Acknowledgements

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