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Analysis of an Occurrence of High Frosts During the Growing Season in Central-East Poland in 2001–2018

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ABSTRACT

Frosts are the most common natural phenomena during the transitional seasons. A frost occurs when the average daily air temperature is positive and the minimum temperature drops below 0°C. The problem of frost occurrence (especially spring frosts) is very important from the point of view of the threats related to crop plant cultivation, because it causes losses in crops when taking place during the plant growth. The aim of the study was to analyze the occurrence of air frosts in the years 2001–2018 in the region of central-eastern Poland on the basis of meteorological data. In the region of central-eastern Poland, the greatest number of days with mild, moderate and strong frosts in 2001–2018 was observed in Białowieża; conversely, it was the lowest in Warsaw. The distribution of the number of days with frosts in spring was similar. The distribution of autumn frosts, however, was different. The greatest number of days with autumn frosts was observed in Terespol and Białowieża, the least in Legionowo and Warsaw. The last mild spring frosts occurred in the period from the 3rd to 7th of April, and the earliest autumn frosts occurred between the 9th of September and the 27th of October. The dates of moderate frosts were similar. The last strong frosts occurred on the 2nd of May and the earliest on the 30th of September. The conducted analysis proved that in such a small area, there is a difference in the occurrence of high frosts observed both in spring and autumn.

Keywords: air frosts, intensity of frosts, central-eastern Poland

INTRODUCTION

Mild frosts are natural phenomena which are the most frequent during transitions between seasons of the year. These frosts occur when the average 24-hour air temperature is positive but the minimum temperature drops below 0°C (Szyga-Pluta 2017, Witeska 2011). There are several classification criteria of such frosts. They can be divided by season into spring and autumn frosts. The spring frosts occur from April to mid-June, and the autumn frosts are recorded at the turn of summer and autumn (Witeska 2011). According to the reason leading to the occurrence of these frosts, they can be classified as convection frosts following an arrival of cool air, radiation frosts appearing due to heat radiation from the ground to the atmosphere, and advection-radiation frosts which are a blend of both the above-mentioned types (Jerzak 2011, Doroszewski et al. 2013). In terms of height at which they occur, frosts are divided into ground and high frosts (at the level of, respectively, 5 and 200 cm from the ground). Taking their intensity into account, there are light frosts (the temperature drop ranges from –0.1 to –1.9°C), moderate frosts (from –1.9 to –3.9°C), and severe frosts (lower than –3.9°C) (Niedźwiedź 2003).

The occurrence of frosts is associated with numerous factors, including the lie of the land and its cover, hydrographic network, ground type, forested and mountainous areas and the presence of higher rises (Koźmiński and Michalska 2008). The phenomenon may occur during every growing season and, despite climate warming (warmer winters), the period when such frost is likely to occur is extending. The first autumn frost may occur very early, and the latest spring frost – very late in the season (Starkel and Kundzewicz 2008), which was confirmed by Kalbarczyk (2010) and Grabowski

(2010) who observed that, in north-east Poland, the frost-free period is shrinking. Frosts negatively influence the plant production effects, as they cause direct and indirect damage to plants, and the extent of this damage depends on how intense the frost is (Dragańska et al. 2004). Determination of the direction of long-term changes at the regional and even local scale is of paramount importance. A hypothesis was put forward that in an age when the climate is warming, there has been a shifting in time, in a long-term period, of an occurrence of the last spring frosts and the first autumn frost events, resulting in a change in the length of the frost-free period. To this end, the analysis of the frequency of high frosts was performed, the timing of the last spring frost and first autumn frost was recorded, and frost intensity was determined in central-east Poland in 2001–2018.

MATERIALS AND METHODS

The analysis of results which were daily meteorological data obtained from seven meteorological stations located in Białowieża, Legionowo, Pułtusk, Siedlce, Szepietowo, Warsaw and Terespol was performed. All types of high frosts were subjected to analysis: light, moderate and severe frosts recorded in spring and autumn. The structure and dates of an occurrence of these frosts were analysed, too. Time series regression analysis was conducted to study the trends of change in the frost-free period in the study area (Sobczyk 2007).

RESULTS AND DISCUSSION

The number of days with mild frosts, in addition to number of frosty days, cold and warm days, is an indicator describing thermal relationships in a given area. In Poland, the risk of mild frosts and damage to crop plants is an annual possibility for the whole country (Kossowska-Cezak 2003). The extent of damage due to frost depends on its intensity, frequency and timing. Spring frosts occurring at the turn of winter and spring is of greater concern because this is the crop sowing time followed by emergence of frost-tender seedlings, bud formation as well as blooming of fruit trees and shrubs, all of which are at risk of damage by the frost. In autumn, early frosts are far less harmful (Dudek et al. 2012).

From 2001 to 2018, the greatest number of days with frosts during the growing season (April-October) was recorded in Białowieża and Pułtusk (respectively, 285 and 216 days); conversely, it was the lowest in Warsaw and Legionowo (respectively, 129 and 216 days). At all the stations, the majority of frosts were light frosts with the percentages ranging from 55.4 to 64.4% in Białowieża and Szepietowo, respectively. The greatest percentages of moderate and severe frosts were recorded in Pułtusk (33.8%) and Siedlce (13.8%), respectively (Figure 1). Figures 2 and 3 demonstrate that at nearly all the stations, more frosts (regardless of their intensity) were recorded in spring rather than autumn. Terespol and Warsaw were exceptions, as their numbers of all types of frosts were higher in autumn than spring.

The greatest number of days with spring frosts, regardless of their intensity, was recorded at the station located in Białowieża and it amounted to 176 over the long-term period. Light, moderate and severe frost represented 55.0, 32.3 and slightly above 13.0% measurements, respectively, in the long-term study period. The lowest number of days with frosts (64) was recorded in Warsaw and Legionowo (91 days). The lowest number of days with light frost (39) as well as severe frosts, the frequency of which in the long-term period was approximately 6%, was found in Warsaw. The number of days with light frosts (21) represented 32.8% of all days with recorded frosts, and the percentage of such days was even higher than in Białowieża. In spring, there were 91 days with frosts, nearly 66% of which were light frosts, 27% were moderate frosts, and 6.5% severe frosts. At the remaining stations, the number of days with light frosts ranged from 60.7 to 67.5%, the range being 22.2 to 28.9% for moderate frosts and 7.2 to 11.8% for severe frosts (Figure 2). A higher share of light frosts in spring in central-east Poland has also been reported by Radzka et al. (2014) who point out that

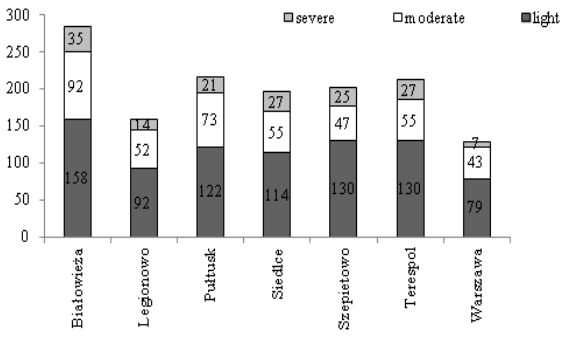

Figure 1. Number of days with individual frost types recorded at each station during the growing seasons in 2001–2018

the frequency of light frosts is much higher compared with severe frosts, the occurrence of which is much more likely in spring than autumn.

The greatest number of days with autumn frosts, regardless of their type, was recorded in Terespol (111) and Białowieża (109). The respective percentages for light, moderate and severe frosts were 59 and 57%, 27 and 32% and 14 and 11%. The greatest percentage of moderate frosts was recorded in Pułtusk and Legionowo (44 and 40%, respectively), and severe frosts in Siedlce and Szepietowo (18 and 15%, respectively). In the long term (18 years), the lowest number of days with high frost was recorded in Warsaw (65 days). At the station, the percentages reflecting an occurrence of light, moderate and severe frosts were 62, 34 and barely 5%, respectively (Figure 3).

Table 1 presents the numbers of days from the beginning of the year to the moment when the last spring frost (light type) occurred. The occurrence of the last spring high frost characterised by low intensity varied by station and year, and the dates ranged from 3rd April (Legionowo, 2018) to 23rd May (Białowieża and Pułtusk, 2004). The earliest dates of the last spring frost at the examined stations in the study period were recorded in 2002 and 2018. No light spring frosts were recorded in 2017 and 2018 in Siedlce, and in 2008, 2009 and 2017 in Warsaw. It can be noted that light frosts most frequently occurred until the end of April. Since 2012, such frosts were sporadic in May. Radziej et al. (2014) found that the last light spring frost in the Siedlce area occurred around 18th April, on average. Similarly to the study area, in other European countries a downward trend in the number of days with frosts has been observed, as suggested by the research by Loginov et al. (2007).

According to Koźmiński et al. (1990), spring frosts in central-east Poland cease taking place around 15th-20th May. Starlak and Kundzewicz (2008) claimed that the latest spring frost may occur at very late part of the season.

It can be noticed that at all the stations (excluding Terespol) there has been a decline in the number of days from the beginning of the year to the day when the first light autumn frost appeared. The years 2017 was an exception as there was an increase in the number of such days in Białowieża, Szepietowo and Terespol.

The first light autumn frosts occurred in the first half of October, as confirmed in the study by Radziej et al. (2014) who reported that, on average, the first frost of this intensity occurs around 11th October in the Siedlce area. In September, such frosts at few stations occurred in 2001–2005 and in 2012–2018. It is worth noting that in 2006–2011, the first autumn frosts were recorded as late as in October (table 2).

The last events of moderate frost were the most frequent in the first half of April. In early May, such frosts occurred in Białowieża, Pułtusk and Terespol in 2011. The year 2017 was exceptional in this respect, as the last moderate frost at five stations (Białowieża, Legionowo, Pułtusk, Siedlce and Warsaw) was recorded on 10th May, and on 21st April in Szepietowo and Terespol (Table 3).

As shown in table 4, the first moderate autumn frosts in the long-term study period occurred mainly in October or were not recorded at all (2006, 2008, 2012, 2017 and 2018), being recorded in Białowieża in September 2001 and 2013 (respectively, 26.09 and 30.09).

The last severe spring frost occurred every year in 2002–2007, mainly in the first half of April, excluding 2005 when, in Białowieża, Pułtusk, Siedlce and Terespol, they were recorded on 22nd or 24th April. From 2008 to 2012, no frost of this type was recorded. In the period 2012–2014, the last severe spring frosts were

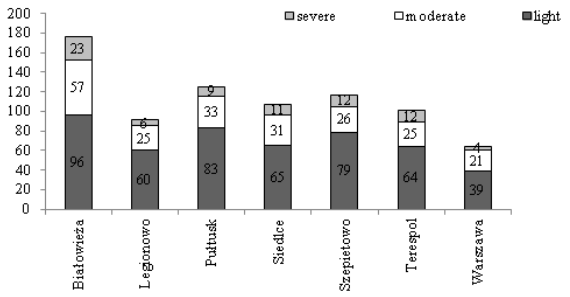

Figure 2. Numbers of days by frost type during the growing season (April-July) at the stations in the long-term period

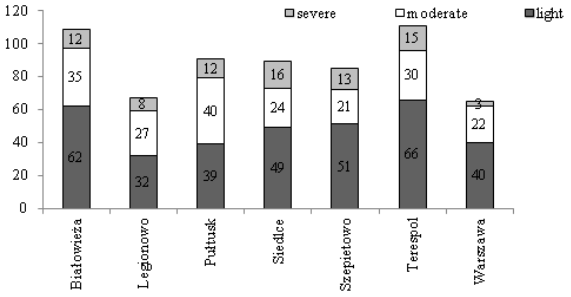

Figure 3. Numbers of days by frost type in autumn (September-October) at the stations in the long-term period

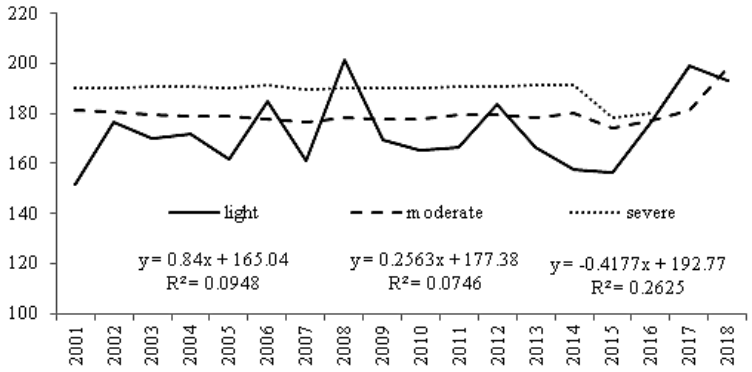

Figure 4. Trends in the number of frost-free days in the study area in 2001–2008

Table 1. Number of days, starting with the beginning of the year, with the last light spring frosts and dates of these events

Year	Specification	Białowieża	Legionowo	Pułtusk	Siedlce	Szepietowo	Warsaw	Terespol
2001	Number of days	108	106	142	143	103	108	143
	date	18–04	16–04	22–05	23–05	13–04	18–04	23–05
2002	Number of days	98	99	97	99	98	98	99
	date	8–04	9–04	7–04	9–04	8–04	8–04	9–04
2003	Number of days	111	104	116	116	111	94	116
	date	21–04	14–04	26–04	26–04	21–04	4–04	26–04
2004	Number of days	144	106	144	119	119	106	107
	date	23–05	15–04	23–05	28–04	28–04	15–04	16–04
2005	Number of days	131	115	115	128	128	94	115
	date	11–05	25–04	25–04	8–05	8–05	4–04	25–04
2006	Number of days	104	106	106	106	106	106	106
	date	14–04	16–04	16–04	16–04	16–04	16–04	16–04
2007	Number of days	125	124	120	120	124	122	124
	date	5–05	4–05	30–04	30–04	4–05	2–05	4–05
2008	Number of days	135	105	116	116	100		116
	date	14–05	14–04	25–04	25–04	9–04		25–04
2009	Number of days	123	112	135	115	113	110	112
	date	3–05	22–04	15–05	25–04	23–04	20–04	22–04
2010	Number of days	113	116	115	114	115	114	114
	date	23–04	26–04	25–04	24–04	25–04	24–04	24–04
2011	Number of days	126	126	126	126	124	126	126
	date	6–05	6–05	6–05	6–05	4–05	6–05	6–05
2012	Number of days	135	94	105	94	102	109	109
	date	14–05	3–04	14–04	3–04	11–04	18–04	18–04
2013	Number of days	119	112	111	112	106	99	97
	date	29–04	22–04	21–04	22–04	16–04	9–04	7–04
2014	Number of days	126	125	125	125	126	124	107
	date	6–05	5–05	5–05	5–05	6–05	4–05	17–04
2015	Number of days	123	136	136	120	120	93	123
	date	3–05	16–05	16–05	30–04	30–04	3–04	3–05
2016	Number of days	95	117	114	112	119	93	94
	date	4–04	26–04	23–04	21–04	28–04	2–04	3–04
2017	Number of days	121	111	113	82	129	84	130
	date	1–05	21–04	23–04	23–03	9–05		10–05
2018	Number of days	94	93	97		97	97	97
	date	4–04	3–04	7–04		7–04	7–04	7–04

Table 2. Number of days, starting with the beginning of the year, with the first light autumn frosts and dates of these events

Year	Specification	Białowieża	Legionowo	Pułtusk	Siedlce	Szepietowo	Warsaw	Terespol
2001	Number of days	296	269	269	269	269	269	272
	date	23–10	26–09	26–09	26–09	26–09	26–09	29–09
2002	Number of days	256	294		256	268	256	285
	date	13–09	21–10		13–09	25–09	13–09	12–10
2003	Number of days	254	288	262	288	290	288	288
	date	11–09	15–10	19–09	15–10	17–10	15–10	15–10
2004	Number of days	285	293	292	298	293	293	293
	date	11–10	19–10	18–10	24–10	19–10	19–10	19–10
2005	Number of days	262	293	292	262	293	262	293
	date	19–09	20–10	19–10	19–09	20–10	19–09	20–10
2006	Number of days	291	291	289	291	291	291	291
	date	18–10	18–10	16–10	18–10	18–10	18–10	18–10
2007	Number of days	284	283	288	284	283	284	283
	date	11–10	10–10	15–10	11–10	10–10	11–10	10–10
2008	Number of days	280						
	date	6–10						
2009	Number of days	283	289	283	290	287	283	293
	date	10–10	16–10	10–10	17–10	14–10	10–10	20–10
2010	Number of days	275	282	280	280	280	280	281
	date	2–10	9–10	7–10	7–10	7–10	7–10	8–10
2011	Number of days	288	301	291	288	300	288	290
	date	15–10	28–10	18–10	15–10	27–10	15–10	17–10
2012	Number of days	287	302	287	286		266	
	date	13–10	28–10	13–10	12–10		22–09	
2013	Number of days	274	273	278	273	273	273	277
	date	1–10	30–09	5–10	30–09	30–09	30–09	4–10
2014	Number of days	278	278	277	276	277	276	300
	date	5–10	5–10	4–10	3–10	4–10	3–10	27–10
2015	Number of days	274	281	274	281	280	274	282
	date	1–10	8–10	1–10	8–10	7–10	1–10	9–10
2016	Number of days	281	288	281	281	281	281	288
	date	7–10	14–10	7–10	7–10	7–10	7–10	14–10
2017	Number of days	273				275		293
	date	30–09				2–10		21–10
2018	Number of days	282	324	269	273	284	273	293
	date	9–10		26–09	30–09	31–10	30–09	21–10

recorded at almost each station in early April. During the last four years, severe spring frost events occurred only in 2017 in the greater part of the study area (excluding Warsaw) and the time of this occurrence was the latest (table 5). In their work, Starlak and Kundzewicz (2008) reported that despite warmer winters, the period when frosts may occur is extending.

Severe autumn frost events were absent during the final three study years, whereas in the preceding years, they were recorded mainly in mid- or late October. The earliest occurrence of the first severe autumn frost (the end of September or early October) was observed in 2013 and 2010 (Table 6).

CONCLUSIONS

In 2001–2018, the greatest number of days with frosts during the growing season (April-October) was recorded in Białowieża and Pułtusk (285 and 216 days, respectively); conversely, it was the lowest in Warsaw and Legionowo (129 and 216 days, respectively). At all the stations, the majority were light frosts

Table 3. Number of days, starting with the beginning of the year, with the last moderate spring frosts and dates of these events

Year	Specification	Białowieża	Legionowo	Pułtusk	Siedlce	Szepietowo	Warsaw	Terespol
2001	Number of days	106	105	105	88	106	105	104
	date	16–04	15–04	15–04	29–03	16–04	15–04	14–04
2002	Number of days	97	94	94	93	93	82	93
	date	7–04	4–04	4–04	3–04	3–04	23–03	3–04
2003	Number of days	110	103	103	103	116	103	92
	date	20–04	13–04	13–04	13–04	26–04	13–04	2–04
2004	Number of days	119	94	94	106	118	0	94
	date	28–04	3–04	3–04	15–04	27–04	31–12	3–04
2005	Number of days	115	114	113	112	112	114	114
	date	25–04	24–04	23–04	22–04	22–04	24–04	24–04
2006	Number of days	106	102	102	98			98
	date	16–04	12–04	12–04	8–04			8–04
2007	Number of days	124	122	124	124	122	121	113
	date	4–05	2–05	4–05	4–05	2–05	1–05	23–04
2008	Number of days	115					100	
	date	24–04					9–04	
2009	Number of days	115	110	112	110	112		
	date	25–04	20–04	22–04	20–04	22–04		
2010	Number of days	116			115			115
	date	26–04			25–04			25–04
2011	Number of days	125		124				125
	date	5–05		4–05				5–05
2012	Number of days	109	109	109	109	109	101	100
	date	18–04	18–04	18–04	18–04	18–04	10–04	9–04
2013	Number of days	112	99	99	98	99	0	98
	date	22–04	9–04	9–04	8–04	9–04	31–12	8–04
2014	Number of days	107		92		96	92	93
	date	17–04		2–04		6–04	2–04	3–04
2015	Number of days	120				112		
	date	30–04				22–04		
2016	Number of days	114			114	114		114
	date	23–04			23–04	23–04		23–04
2017	Number of days	130	130	130	130	111	130	111
	date	10–05	10–05	10–05	10–05	21–04	10–05	21–04
2018	Number of days	97	97	93	97		93	
	date	7–04	7–04	3–04	7–04		3–04	

and their percentages ranged from 55.4% in Białowieża to 64.4% in Szepietowo.

At almost all stations, more frosts (regardless of their intensity) occurred in spring than autumn. The Terespol and Warsaw stations were exceptions, as their numbers of autumn light and severe frost events were higher compared with the spring.Regardless of frost intensity, the greatest number of days with spring frost events was recorded in Białowieża. Light frosts accounted for 55.0%, moderate frosts 32.3% and severe frosts slightly more than 13.0% of events in the long-term period. In The lowest number of days with light frosts was recorded in Warsaw.

The last light spring frosts occurred from 3rd to 7th April, and the earliest autumn frosts from 9th September to 27th October. The dates of moderate frost events were similar. The latest date of the last severe spring frost was 2nd May and the earliest autumn frost events took place on 30th September.

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Table 4. Number of days, starting with the beginning of the year, with the first moderate autumn frosts and dates of these events

Year	Specification	Białowieża	Legionowo	Pułtusk	Siedlce	Szepietowo	Warsaw	Terespol
2001	Number of days	269		298	298		297	
	date	26–09		25–10	25–10		24–10	
2002	Number of days	283	284	283			284	283
	date	10–10	11–10	10–10			11–10	10–10
2003	Number of days	292	290	290	290	292	290	292
	date	19–10	17–10	17–10	17–10	19–10	17–10	19–10
2004	Number of days	288	286	288		287		286
	date	14–10	12–10	14–10		13–10		12–10
2005	Number of days	298	302	293	301	301	302	298
	date	25–10	29–10	20–10	28–10	28–10	29–10	25–10
2007	Number of days	283	294	283	283			283
	date	10–10	21–10	10–10	10–10			10–10
2009	Number of days	290	293	291	283	290	292	0
	date	17–10	20–10	18–10	10–10	17–10	19–10	31–12
2010	Number of days	280	281	281	282	281	285	285
	date	7–10	8–10	8–10	9–10	8–10	12–10	12–10
2011	Number of days	295	290	289	295	291	289	291
	date	22–10	17–10	16–10	22–10	18–10	16–10	18–10
2013	Number of days	273	278	273	277	278		277
	date	30–09	5–10	30–09	4–10	5–10		4–10
2014	Number of days	277	299	299	299	299	297	277
	date	4–10	26–10	26–10	26–10	26–10	24–10	4–10
2015	Number of days	285	282	281	301	285	284	282
	date	12–10	9–10	8–10	28–10	12–10	11–10	9–10
2016	Number of days	291		288	288	288		
	date	17–10		14–10	14–10	14–10		

Table 5. Number of days, starting with the beginning of the year, with the last severe spring frosts and dates of these events

Year	Specification	Białowieża	Legionowo	Pułtusk	Siedlce	Szepietowo	Warsaw	Terespol
2002	Number of days	99			94	97		94
	date	9–04			4–04	7–04		4–04
2003	Number of days	100				100	100	100
	date	10–04				10–04	10–04	10–04
2004	Number of days	95		93	93	93		94
	date	4–04		2–04	2–04	2–04		3–04
2005	Number of days	112	92	114	114			112
	date	22–04	2–04	24–04	24–04			22–04
2006	Number of days	98	97	97	97		97	
	date	8–04	7–04	7–04	7–04		7–04	
2007	Number of days	113		122		97		95
	date	23–04		2–05		7–04		5–04
2012	Number of days	101	100	100	101	101	100	101
	date	10–04	9–04	9–04	10–04	10–04	9–04	10–04
2013	Number of days	99		98	99	98		98
	date	9–04		8–04	9–04	8–04		8–04
2014	Number of days	95	92		92	92		92
	date	5–04	2–04		2–04	2–04		2–04
2017	Number of days	111	107		107	107		107
	date	21–04	17–04		17–04	17–04		17–04

Table 6. Number of days, starting with the beginning of the year, with the first severe autumn frosts and dates of these events

Year	Specification	Białowieża	Legionowo	Pułtusk	Siedlce	Szepietowo	Warsaw	Terespol
2001	Number of days	269		298	298		297	
	date	26–09		25–10	25–10		24–10	
2002	Number of days	283	284	283			284	283
	date	10–10	11–10	10–10			11–10	10–10
2003	Number of days	292	290	290	290	292	290	292
	date	19–10	17–10	17–10	17–10	19–10	17–10	19–10
2004	Number of days	288	286	288		287		286
	date	14–10	12–10	14–10		13–10		12–10
2005	Number of days	298	302	293	301	301	302	298
	date	25–10	29–10	20–10	28–10	28–10	29–10	25–10
2007	Number of days	283	294	283	283			283
	date	10–10	21–10	10–10	10–10			10–10
2009	Number of days	290	293	291	283	290	292	
	date	17–10	20–10	18–10	10–10	17–10	19–10	
2010	Number of days	280	281	281	282	281	285	285
	date	7–10	8–10	8–10	9–10	8–10	12–10	12–10
2011	Number of days	295	290	289	295	291	289	291
	date	22–10	17–10	16–10	22–10	18–10	16–10	18–10
2013	Number of days	273	278	273	277	278		277
	date	30–09	5–10	30–09	4–10	5–10		4–10
2014	Number of days	277	299	299	299	299	297	277
	date	4–10	26–10	26–10	26–10	26–10	24–10	4–10
2015	Number of days	285	282	281	301	285		282
	date	12–10	9–10	8–10	28–10	12–10		9–10
2016	Number of days	291		288	288	288		
	date	17–10		14–10	14–10	14–10		

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