

Effects of sudden air pressure changes on hospital admissions for cardiovascular diseases in Prague, 1994–2009

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Abstract Sudden weather changes have long been thought to be associated with negative impacts on human health, but relatively few studies have attempted to quantify these relationships. We use large 6-h changes in atmospheric pressure as a proxy for sudden weather changes and evaluate their association with hospital admissions for cardiovascular diseases (CVD). Winter and summer seasons and positive and negative pressure changes are analysed separately, using data for the city of Prague (population 1.2 million) over a 16-year period (1994–2009). We found that sudden pressure drops in winter are associated with significant rise in hospital admissions. Increased CVD morbidity was observed neither for pressure drops in summer nor pressure increases in any season. Analysis of synoptic weather maps shows that large pressure drops in winter are associated with strong zonal flow and rapidly moving low-pressure systems with centres over northern Europe and atmospheric fronts affecting western and central Europe. Analysis of links between passages of strong atmospheric fronts and hospital admissions, however, shows that the links disappear if weather changes are characterised by frontal passages. Sudden pressure drops in winter are associated also with significant excess CVD mortality. As climate models project strengthening of zonal circulation in winter and increased frequency of windstorms, the negative effects of such weather phenomena and their possible changes in a warmer climate of the twenty-first century need to be better understood, particularly as their importance in inducing excess morbidity and mortality in winter may increase compared to cold spells.

Keywords Weather · Pressure change · Cardiovascular disease · Morbidity · Mortality · Central Europe

Introduction

It has long been believed that human health is sensitive to sudden weather changes. However, relatively few studies have attempted to quantify these relationships, which contrasts particularly with the large number of studies examining the effects of heat and cold on mortality (e.g. Gosling et al. 2009; Kyselý et al. 2009) or the joint effects of weather conditions in terms of the synoptic approach (Sheridan and Kalkstein 2004; Vaneckova et al. 2008). Previous analyses have shown that cardiovascular diseases (CVD), which constitute the leading cause of mortality worldwide (World Health Organization 2011), are closely related to weather conditions. Better understanding of the relationship between CVD and weather changes may enhance our understanding of physiological mechanisms and enable the results to be implemented in biometeorological forecasting.

In this study, atmospheric pressure changes are used as a simple proxy for sudden weather changes. Previous studies dealing with atmospheric pressure resulted in various outcomes with respect to impacts on mortality and morbidity. Buxton et al. (2001) showed a relationship between high atmospheric pressure and increased incidence of aneurysmal subarachnoid haemorrhage in the English Midlands. Töro et al. (2010) reported higher pressure on days with more cardiovascular deaths and more acute or chronic vascular death cases during rising pressure conditions in Budapest. Positive change in air pressure relative to the previous day was found to be linked to a modest increase in haemorrhagic

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strokes in Hong Kong (Goggins et al. 2012) and higher admissions rate for intracerebral haemorrhage in a part of Spain (Jimenez-Conde et al. 2008). Conversely, winter high-mortality days were identified as days with lower pressure than non-high-mortality days in Minneapolis (Allen and Sheridan 2013) and lower mean air pressure was found to be a predictor for greater occurrence of ischemic stroke in Siberia (Feigin et al. 2000). Rusticucci et al. (2002) showed significant negative correlation between pressure and emergency room visits for respiratory, cardiovascular, and chest pain at an Argentine hospital during winter. A fall in atmospheric pressure over the preceding 48 h was associated with an increased rate of haemorrhagic stroke admissions in Glasgow (Dawson et al. 2008). A V-shaped relationship between atmospheric pressure and myocardial infarction and coronary deaths was described by Danet et al. (1999) with a minimum of daily event rates at 1,016 hPa and a 12% (11%) increase with a 10-hPa decrease (increase, respectively). Allen and Sheridan (2013) also obtained an analogous V-shaped pattern at all studied locations in the US. Falling pressure and changes in other meteorological variables suggest an approaching mid-latitude cyclone and changes of air masses. Using a synoptic climatological approach based on air mass classification, significant increases in hospital admissions for myocardial infarction were identified in the days after anticyclonic continental and cyclonic air masses during winter in Florence, Italy (Morabito et al. 2006). Importantly, many studies have pointed out that, especially in winter, a lag effect is an important consideration associated with weather change-related mortality (Rusticucci et al. 2002; de Pablo et al. 2009; Goggins et al. 2012; Allen and Sheridan 2013).

However, the aforementioned studies used different analytical settings as well as different methodologies (concerning, for example, seasonal resolution and/or whether effects of influenza epidemics in the cold half-year or other confounding effects are controlled for). Therefore, their outcomes are often difficult to compare. Some of the studies are also based on relatively small data samples from a single hospital or a relatively short time period. The lack of seasonal resolution is another important issue, because weather conditions affect human health differently in winter and summer. That means the possible effects of sudden changes need to be examined for specific seasons.

In the population of the Czech Republic, significant increases of total and cardiovascular mortality had been detected after pressure drops in winter and on the day of large pressure drops in summer, while significant decrease in mortality was found after pressure increases in summer (Plavcová and Kyselý 2009, 2010). In the present study, we focus on whether sudden pressure changes impact also cardiovascular morbidity. We use a database of daily hospital admissions for cardiovascular diseases in the city of Prague over the 16-year period 1994–2009. Prague has a population of about 1.2 million and

comprises around one-tenth of the Czech Republic's population. We used the same methodology for calculating excess morbidity and its significance as in our previous works (Plavcová and Kyselý 2009, 2010). Pressure data were taken from a weather station situated at Prague's airport. Winter and summer seasons and positive and negative pressure changes were analysed separately.

Data and methods

Morbidity data and their standardisation

This study examines daily numbers of hospital admissions due to CVD in the city of Prague during 1994–2009. The dataset was provided by the Institute of Health Information and Statistics of the Czech Republic, and it contains 623,310 individual records over the 16-year period. Morbidity data were divided into the following five population groups: all ages, younger population (0–64 years), elderly (65+ years), males (M), and females (F).

The daily numbers of hospital admissions were standardised to account for long-term changes in morbidity (decreasing trend) as well as short-term variations due to the annual and weekly cycles (lower morbidity in late summer than in winter, and on weekends than weekdays). An indirect standardisation procedure applied widely in studies of mortality or morbidity effects was used, see e.g. Whitman et al. (1997), Guest et al. (1999), Smoyer et al. (2000) and Kyselý (2004).

A series of daily excess morbidity was established separately for the whole population and each examined population group (see above) by calculating deviations of the observed and expected (baseline) morbidity. The expected morbidity (number of hospital admissions) $M_0(y, d)$ for year y ($y = 1994, \dots, 2009$) and day d ($d = 1, \dots, 365$) was determined according to the formula

$$M_0(y, d) = M_0(d) \cdot W(y, d) \cdot Y(y)$$

where $M_0(d)$ denotes mean daily morbidity on day d in a year (computed from the mean annual cycle over 1994–2009); $W(y, d)$ is a correction factor for the observed weekly cycle of morbidity, calculated separately for individual days of the week and defined as the ratio of the mean morbidity on a given day to the overall mean morbidity; and $Y(y)$ is a correction factor for the observed year-to-year changes in morbidity, defined as the ratio of the number of hospital admissions in year y to the mean annual number of hospital admissions during the analysed period.

Periods when CVD morbidity may have been affected by influenza and/or acute respiratory infection (ARI) outbreaks (Kynčl et al. 2005) were excluded before the analysis, considering the 7-day lag after epidemics (cf. Kyselý et al. 2009).

The epidemics were defined using a dataset on morbidity from influenza/ARI taken from the national surveillance system, and the national epidemic threshold of 2000 reported ill per 100,000 population. Altogether 169 winter days during six epidemics were omitted; summer season was not affected.

The correction factors for the weekly cycle $W(y,d)$ and the year-to-year changes $Y(y)$ were calculated over the April–November period, when the effects of influenza and acute respiratory infections in the data are negligible. When calculating $W(y,d)$, all public holidays were also excluded, and they were considered as Sundays when the standardisation was applied.

For comparison, we evaluate also data on mortality (the number of deaths) due to CVD. The same standardisation procedure was applied to obtain daily excess CVD mortality for the city of Prague. We note that the sample of deaths with CVD being the primary cause is much smaller (110,708 cases over the 16 years) than the sample of hospital admissions due to CVD.

Meteorological data and definition of sudden pressure changes

Three-hourly values of atmospheric pressure from the station Prague–Ruzyně (located at the airport) were used. Large pressure increases and decreases were examined separately in winter (DJF) and summer (JJA). Sudden pressure changes were identified as events when changes in pressure on the 6-h time scale exceeded a critical threshold. The time of the change was taken as the end of the first sudden change; since the following terms are often characterised also by a large change, only the first term with a sudden pressure change within 48 h was selected to avoid multiple selection of a passage of one pressure system. The critical threshold was chosen as a quantile of the distribution of pressure changes in a given season that led to a sample of approximately 40 events for all examined sudden changes (increases and decreases; winter and summer). This corresponded to 2.5 events per season on average (given 16 years of data), which is a reasonably large sample. The thresholds used to delimit large pressure changes are summarised in Table 1. As expected, they were larger in winter than in summer. The magnitude of the change was calculated as the maximum pressure change on the 6-h time scale during the 48-h period after the sudden change was detected.

Table 1 Thresholds used to delimit large pressure changes at the Prague–Ruzyně weather station. *DJF* Winter (December, January, February), *JJA* summer (June, July, August)

	Decrease		Increase	
	DJF	JJA	DJF	JJA
Pressure change over 6 h [hPa]	−7.9	−4.6	7.6	4.9
Corresponding to quantile [%]	99.3	99.4	0.6	0.7

The definition of sudden pressure change is a modified version of the original definition proposed by Plavcová and Kyselý (2010) where spatial weather data (a set of stations covering the Czech Republic) were examined, and therefore the spatial extent of the change as well as a typical interval during which the whole area is affected by a large change in weather were taken into account. As the current study deals with the population of an individual city (Prague), pressure data were taken from a single station representing weather conditions to which the population was exposed.

A sensitivity analysis was conducted by changing several settings in the definition used. We found that identifying large pressure changes on a 3-h or 12-h time scale (instead of a 6-h time scale) led to very similar samples of large pressure changes and had a negligible influence on the results. Reducing the sample size of large pressure changes by including only a part of the largest pressure drops or increases led to results similar to those reported, except that their significance tended to be lower.

Additional climatic data (daily means of air temperature, atmospheric pressure, wind speed, cloud cover, relative humidity, and daily precipitation amounts) from the Prague–Ruzyně weather station and the ERA-Interim reanalysis (Dee et al. 2011) were used to illustrate characteristic weather patterns during the analysed sudden pressure change events.

For comparison with the sudden pressure changes, passages of strong atmospheric fronts over Prague were also analysed. Terms of the frontal passages were taken from the database of the Czech Hydrometeorological Institute. In winter, this sample includes 31 (22, 25) strong cold (warm, occluded) fronts over 1994–2009.

Methods

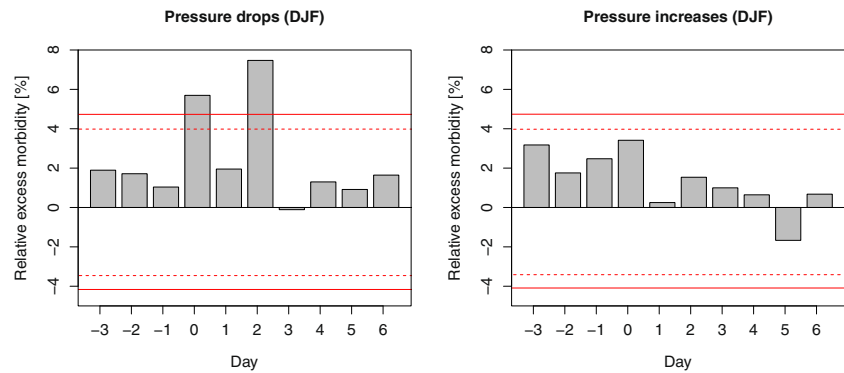
Relative deviations of morbidity on days D−3 (3 days before a pressure change) up to D+6 (6 days after) were averaged over the selected sudden change events. Their statistical significance was evaluated by the Monte Carlo method in which the same numbers of 10-day sequences (D−3 to D+6) were drawn randomly 10,000 times from the data over 1994–2009 in a given season. The 2.5%, 5%, 95% and 97.5% quantiles of the mean relative deviation of morbidity were calculated from the random samples and plotted in figures. See Plavcová and Kyselý (2010) for more detail.

Results

Relationships between sudden pressure changes and CVD morbidity

Figure 1 (left panel) shows that large pressure drops in winter are associated with increased CVD morbidity. Significant (at

Fig. 1 Mean relative excess morbidity (number of hospital admissions) due to cardiovascular disease (CVD) in Prague on days D–3 (3 days before) to D+6 (6 days after) relative to sudden pressure changes in winter. The *solid (dashed)* lines denote the 95% (90%) confidence bound around zero, calculated using the Monte Carlo method ($R=10,000$)



$P=0.05$) excess morbidity for the population as a whole was found on days D+0 and D+2, exceeding the baseline morbidity on both days by more than 5%. For large pressure increases in winter (Fig. 1 right), no significant excess morbidity on or around days with sudden pressure changes was found.

In summer, neither sudden pressure decreases nor increases were associated with excess CVD morbidity (Fig. 2). Only for pressure decreases was there relatively large excess morbidity on day D+3, but this was probably due to sampling effects as interpretation of excess morbidity with a 3-day lag would be uncertain and the excess morbidity was significant only at $P=0.10$.

The excess morbidity associated with sudden pressure drops in winter was significant at $P=0.05$ (exceeds the 97.5% quantile) not only in the population as a whole, but also in the elderly (65+ years) and males (Fig. 3). It is interesting to note that the magnitude of excess morbidity is greater in males than females, as the latter are often found to be more vulnerable to oppressive weather.

Typical weather patterns associated with sudden pressure drops in winter

Typical behaviour of basic meteorological variables in days around sudden pressure drops in winter is shown in Fig. 4. Periods around the pressure drops were characterised by

positive air temperature anomalies (with maximum on the day of change, D+0), high wind speed (daily means reach maximum of >8 m/s on D+0), and large cloud cover (maximum on day D+0 as well). Relative humidity was only slightly lower than the winter average, and days D+0 and following were characterised by above-average precipitation. A wind rose for the days of sudden pressure drops calculated from measurements taken at 14 hours local time shows that advection from the south-west was by far the most frequent during these events and far exceeded the long-term average frequency (Fig. 5). All these data suggest that sudden pressure drops in winter are characterized by disturbed weather conditions, with inflow of relatively warm and moist air masses from the Atlantic Ocean.

The ten largest winter pressure drops in Prague over 1994–2009 are summarized in Table 2. The largest pressure decrease (by 15.0 hPa over 6 h) occurred on 26 December 1999 and was associated with the infamous Lothar windstorm (Berz 2005). This violent cyclone swept across western and central Europe and caused major damage due to high winds and flooding (mainly in France, Germany, and Switzerland) and killed more than 100 people. The top ten list of the largest pressure drops in winter includes also the storm Kyrill on 18 January 2007, another windstorm associated with sizeable damages and death toll in Europe. All-time record-breaking wind speeds in the Czech Republic were measured during this event (60 m/s at the Sněžka Mt.).

Fig. 2 As Fig. 1, but for summer

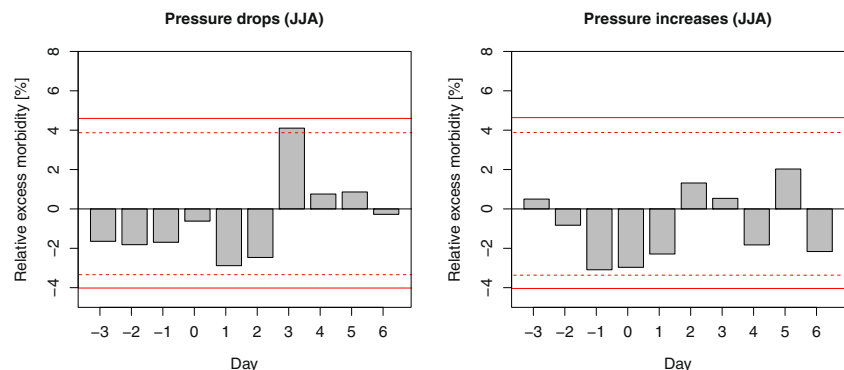
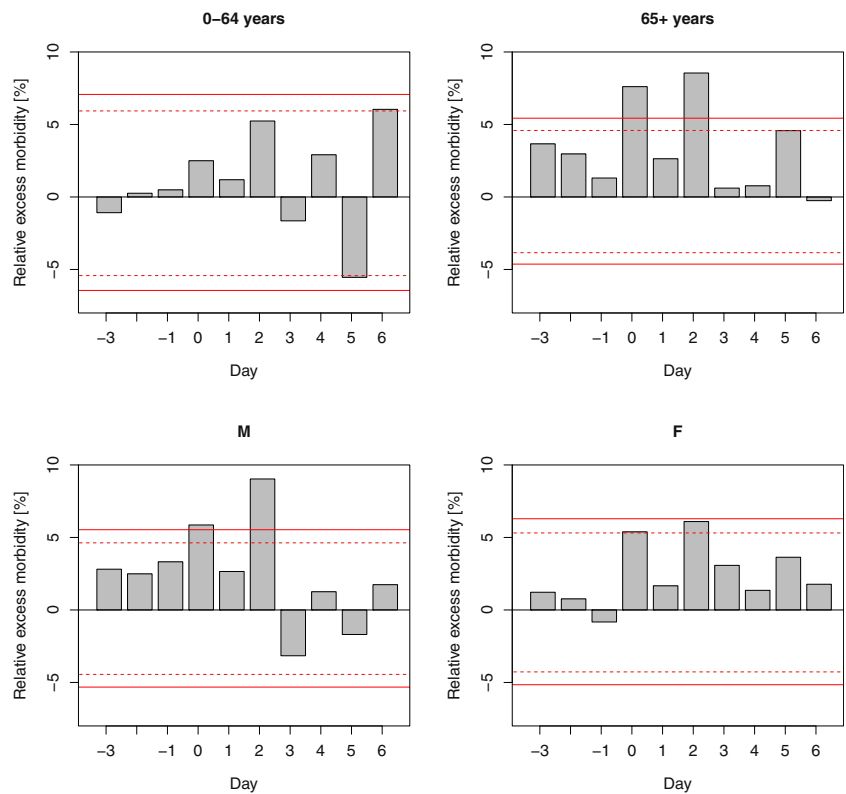


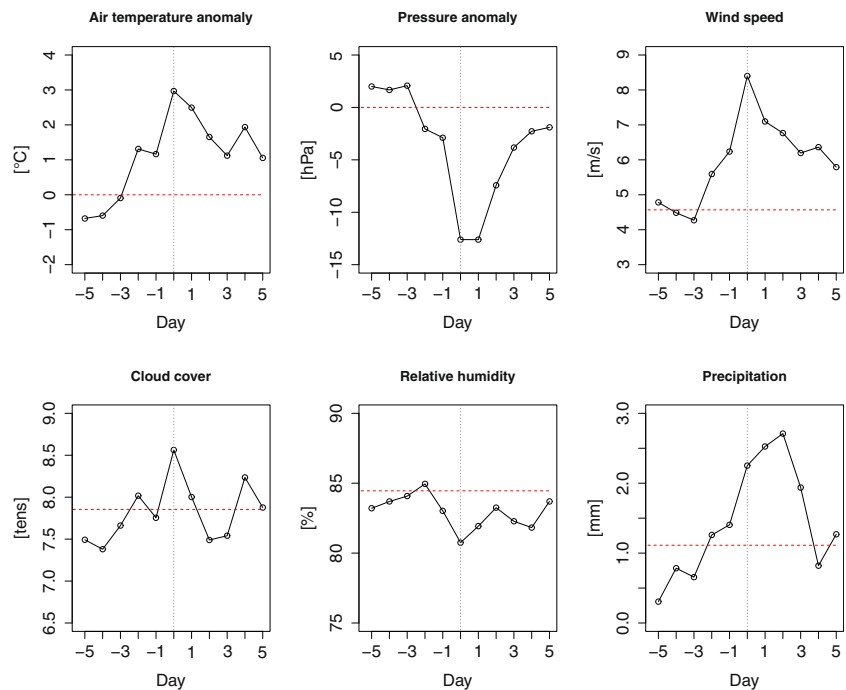
Fig. 3 Mean relative excess morbidity due to CVD in Prague around sudden pressure drops in winter in individual population groups (*M* males, *F* females). Other details as in Fig. 1



Synoptic weather maps of the 20 largest winter pressure drops (Fig. 6) show that these events were associated with strong zonal (north-westerly to south-westerly) flow and rapidly moving low-pressure systems (usually with centres over

northern Europe) affecting the area of western and central Europe, bringing relatively warmer air masses. This may suggest that passages of atmospheric fronts may be other proxies of these events, alternative to large pressure drops.

Fig. 4 Mean course of weather variables on days D–5 to D+5 around sudden pressure drops in Prague in winter, averaged over 40 examined events. *Dashed lines* denote long-term averages in winter



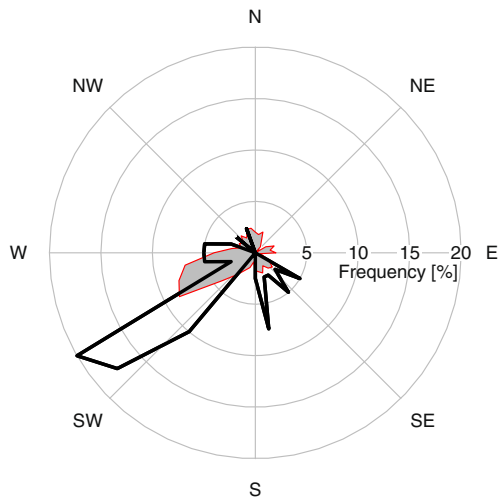


Fig. 5 Wind rose for sudden pressure drops in Prague in winter. Data on wind direction were taken from measurements at 14 hours local time and given in 10-degree bins. Long-term average in winter is depicted in grey

Relationships between passages of strong atmospheric fronts and CVD morbidity in winter

In this section, we evaluate whether excess CVD morbidity is associated with passages of strong atmospheric fronts in winter in order to compare results with those for large pressure drops. Figure 7 shows that neither cold, warm, nor occluded atmospheric fronts are associated with significant excess CVD morbidity in winter. Only occluded fronts are associated with positive morbidity anomalies on day D+0, but these are far from being statistically significant.

This negative finding for (strong) atmospheric fronts is probably related to the fact that passages of fronts involve more varied types of weather conditions than do large pressure drops. Situations of disturbed weather with inflow of moist

warm air mass from the Atlantic Ocean, which are associated with excess morbidity as reported above, represent only some of the conditions with passages of atmospheric fronts in winter. This suggests that atmospheric fronts are not useful proxies of weather changes in studies seeking links between weather and morbidity, at least in Central Europe.

Comparison of CVD mortality and morbidity associated with large pressure drops in winter

Figure 8 shows that there was also significant excess CVD mortality associated with large pressure drops in winter. This was found on day D+1, which may represent a lagged effect of large pressure drops or just the fact that unstable weather and pressure decreases are typical also on the days following large pressure drops. The mean excess mortality on day D+1 exceeds 10%. For the population of the Czech Republic as a whole, significant excess CVD mortality was detected also on days D+0 and D+2 after large pressure drops in winter (Plavcová and Kyselý 2009). This excess mortality was around 3–4% during all 3 days (D+0 to D+2), leading to the overall excess mortality associated with pressure drops in the population of the Czech Republic corresponding relatively well to that obtained for Prague on day D+1 (>10%). The multi-day effect within the population of the Czech Republic is obviously caused by the longer temporal interval during which the whole area is affected by a weather change (typically related to passage of a low pressure system; Plavcová and Kyselý 2009).

Discussion

Seasonal differences

Our findings point out the necessity of a seasonal approach to the analysis of weather-related morbidity/mortality. While pressure drops are associated with excess morbidity in winter, morbidity is below the baseline after pressure drops in summer (cf. Figs. 1, 2). The different response may be related to several factors. First, the magnitude of sudden pressure changes is generally larger in winter than in summer (see Table 1) due to larger pressure gradients typical for the cold season in mid-latitudes. Second, large pressure drops represent different changes in weather conditions in the two seasons. While pressure decreases are characterised by increasing air temperature and positive temperature anomalies in winter (Fig. 4), there is a substantial cooling in the days after pressure drops in summer (the average decrease of mean daily temperature between days D+0 and D+1 is 3°C). This illustrates that the overall weather patterns associated with pressure changes are entirely different depending on season. If a single critical threshold was used over the whole year, it would strongly

Table 2 Ten largest pressure drops at the Prague–Ruzyně weather station in winter over 1994–2009

Rank (name of associated storm)	Year	Month	Day	Time (local time)	Size (hPa)
1 (Lothar)	1999	12	26	10 hours	−15.0
2	1995	1	10	1 hour	−14.0
3	2005	12	16	7 hours	−13.4
4 (Klaus)	2009	1	23	1 hour	−13.4
5	1994	1	28	1 hour	−12.9
6	2005	2	12	10 hours	−12.7
7	2002	2	20	7 hours	−11.6
8	1994	1	25	16 hours	−10.6
9 (Anatol)	1999	12	3	16 hours	−10.3
10 (Kyrill)	2007	1	18	13 hours	−10.3

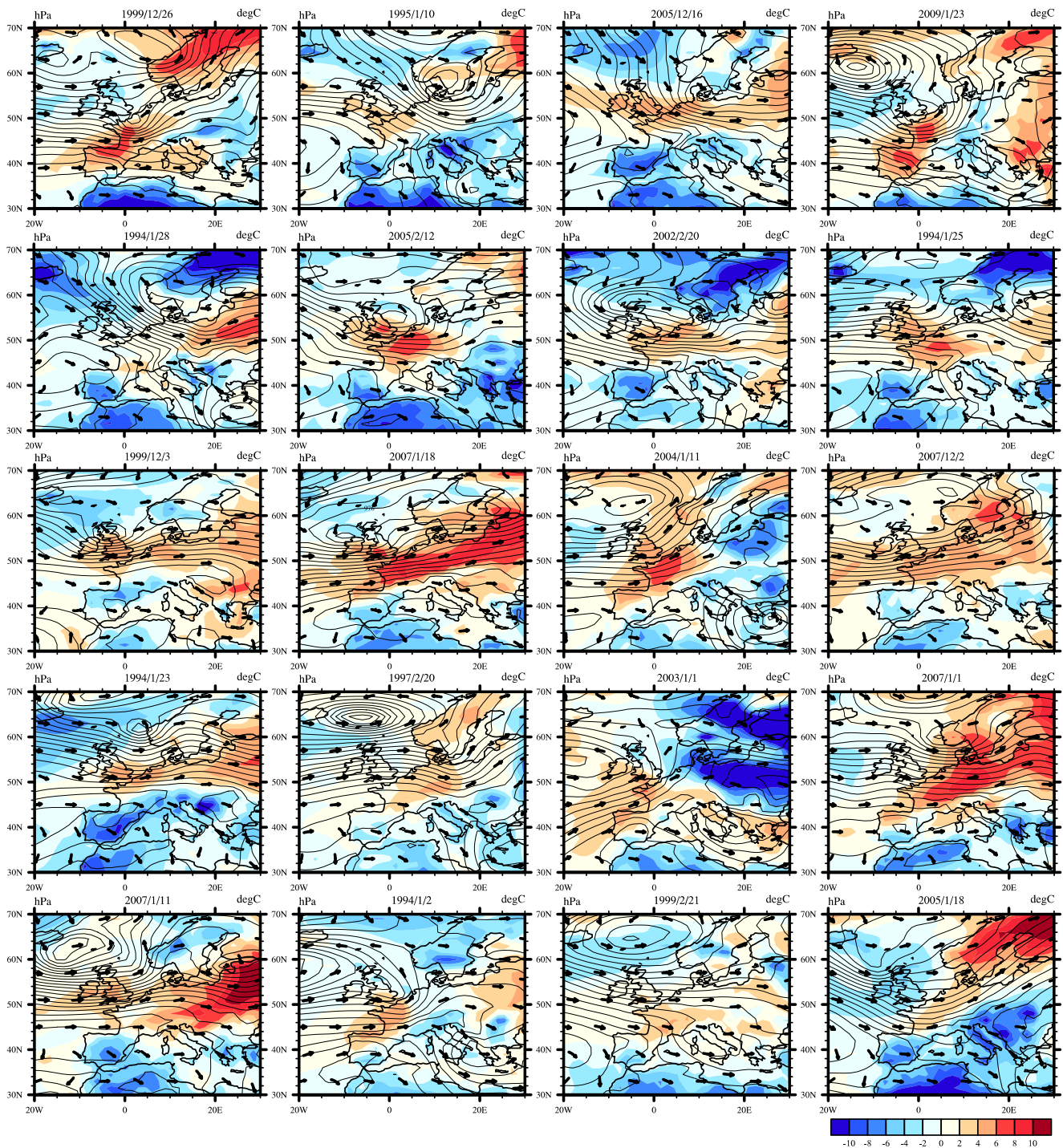


Fig. 6 Synoptic maps for days D+0 of the 20 largest pressure drops in winter in Prague. Days are sorted according to the magnitude of the pressure drop in descending order. Data are taken from ERA-Interim at

6 UT. Contours stand for sea level pressure (steps of 4 hPa), temperature anomalies from the seasonal mean are shown by colours, and arrows indicate the direction of the 10 m wind

influence the sample of events in favour of winter and the sample would mix different weather patterns associated with pressure drops. Differences in the impacts of pressure changes between winter and summer seasons have been shown for CVD mortality as well (Plavcová and Kyselý 2009).

Region and population under study

An advantage of our study is the relatively long period (16 years) of detailed data on all hospital admissions due to CVD, including information on the age and gender of patients.

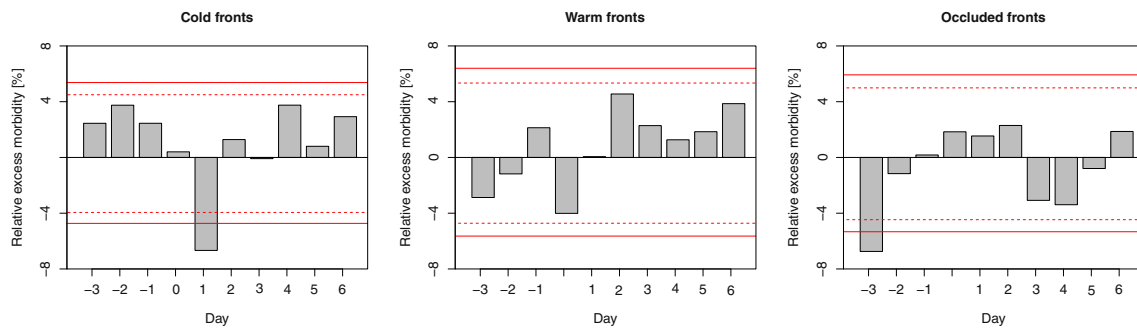


Fig. 7 Mean relative excess morbidity due to CVD in Prague around passages of strong atmospheric fronts in winter. Other details as in Fig. 1

While some previous studies on the effects of air pressure changes were based on data from a single hospital, our data cover an entire city of ~1.2 million inhabitants (623,310 records of individual hospital admissions due to CVD over 16 years). Moreover, as the population lives in a relatively small area (~22 x 22 km), it may be assumed that data from a single station represent reasonably well the weather conditions to which the population under study was exposed.

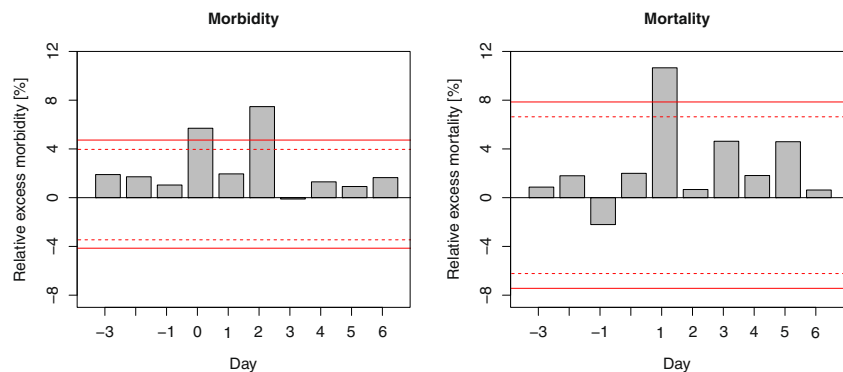
Since our study focusses only on an urban population, impacts in rural areas could differ due to variances in lifestyle and the level of exposure to oppressive weather conditions (due to, for example, different proportions of outdoor occupations). The association between sudden pressure changes and human health is also thought to depend on the adaptability to specific climate and climate variability in the region where a population lives. Allen and Sheridan (2013) showed that the winter relationship between atmospheric pressure and mortality was more obvious for northern US cities than southern cities, where high-peak mortality was linked more strongly to temperature changes.

Confounding effects

Several confounding factors bring difficulties to studying weather-related morbidity and mortality. Prevalence of diseases (primarily outbreaks of acute respiratory infection) strongly affects mortality levels in winter (Kynčl et al. 2005).

To eliminate this effect, periods when CVD morbidity may have been affected by epidemics of influenza and/or acute respiratory infections were excluded (see [Materials and methods](#)). We note that, in this step, our analysis differs from most other biometeorological studies, as those typically do not address possible confounding from elevated morbidity/mortality due to epidemics. Another factor making the relationships between pressure changes and morbidity/mortality difficult to discern, especially in winter, is the lag effect. This is in contrast to heat-related mortality in summer, for which the physiological response of human health is often acute (Gosling et al. 2009). Our results show that the number of CVD hospital admissions is significantly elevated not only on day D+0 but also on day D+2 after the sudden pressure drop (Figs. 1, 3). The lagged effects of weather on human health in winter have not been interpreted clearly, and this holds true even more for morbidity than mortality. However, significant effects for even longer lags have been reported in several related studies on the effects of air pressure changes. Goggins et al. (2012) described effects between higher haemorrhagic risk and pressure change over the previous 0–4 days, and a lag of up to 7 days in increased hospital admissions was found by de Pablo et al. (2009) after some circulation weather types in Spain. Such long lags need to be evaluated critically and should be confirmed for other populations and datasets, since significant results without causal links may appear due to multiple testing and random variability.

Fig. 8 Comparison of mean relative excess morbidity and mortality due to CVD in Prague around sudden pressure drops in winter



We do not take into account air pollution levels as another possible effect modifier. Weather conditions characteristic for large pressure drops in winter (strong zonal flow, windy conditions) do not favour high surface-level concentrations of air pollutants, so this effect is unlikely to play an important role in inducing excess morbidity.

Differences among population groups

Elderly people, particularly those in nursing and care homes, have been found most vulnerable to heat- and cold-related mortality (Hajat et al. 2007). Elderly patients are particularly susceptible because of pre-existing chronic diseases (Kenney and Munce 2003). Danet et al. (1999) describe stronger effects of air pressure and daily rates of myocardial infarction and coronary deaths also for elderly people. With respect to sudden pressure changes and overall CVD morbidity, Fig. 3 shows that the elderly population (65+ years) is more vulnerable than the younger population. This is consistent with Goggins et al. (2012), who found similar results for association between change in air pressure and hospitalisation for haemorrhagic stroke. On the contrary, while Goggins et al. (2012) found that gender does not appear to be an effect modifier of the association, we find males slightly more vulnerable than females to sudden pressure drops in winter (Fig. 3). This is in contrast to heat-related mortality, which is more pronounced in females than males (e.g. Pirard et al. 2005) due to the social and demographic structure of European populations, with larger percentages of women in the older age groups and among those living alone (cf. discussion in Kyselý and Kříž 2008). Nevertheless, some studies on cold-related cardiovascular mortality have reported larger effects in males than females (e.g. Gorjanc et al. 1999; Kyselý et al. 2009), so it is probable that the patterns are different for oppressive weather conditions in winter.

Although the exact physiological mechanisms by which exposure to pressure changes can increase the risk of cardiovascular morbidity remain unclear (Dawson et al. 2008), better understanding of which population groups and which chronic diseases are at higher risk may help in issuing better focussed and more specific biometeorological forecasts and alerts.

Combined effects of multiple variables, comparison with effects of atmospheric fronts

It is evident that human health is not affected by a pressure change per se, as the human body is often exposed to much larger pressure variations (e.g. due to changes in altitude). However, our study contributes to the growing evidence that events of large sudden pressure changes are useful proxies for overall weather conditions associated with negative effects on cardiovascular

health. A whole complex of meteorological factors is involved; large pressure changes represent a combination of typical changes in ambient weather conditions relative to the preceding days (see Fig. 4).

Our results show that the effects on CVD morbidity are much better expressed for weather changes as represented by large pressure changes than for those represented by passages of strong atmospheric fronts. The weak and insignificant results for atmospheric fronts may be related to the fact that the intensity and time of passage are determined subjectively; furthermore, the range of weather patterns associated with passages of strong atmospheric fronts is more diverse than in the case for rather sharply defined pressure changes. The events of large pressure drops in winter are almost always associated with strong zonal flow (from the westerly quadrant) and rapidly moving low-pressure systems over Central Europe (see Fig. 6), while atmospheric fronts may be linked to entirely different cyclone paths (e.g. Atlantic vs Mediterranean influences) and thus different weather patterns. This also suggests that studies on human health effects that examine atmospheric fronts as proxies for weather changes need to be interpreted with caution, as the fronts are determined subjectively and may represent a mixture of weather conditions. While some previous studies have reported links between atmospheric fronts and human health (Květoň 1991; Gluszak et al. 2008), they were based on small samples and therefore their results cannot be considered robust or representative for a larger population.

Conclusions

This study has shown that:

- sudden pressure drops in winter are associated with significant increases in cardiovascular (CVD) hospital admissions in the population of Prague;
- increases in CVD morbidity are observed neither for sudden pressure drops in summer nor for pressure increases in any season;
- the links to CVD morbidity disappear if weather changes are represented by passages of strong atmospheric fronts;
- the sudden pressure drops in winter are associated also with significant excess CVD mortality;
- typical weather patterns related to the sudden pressure drops in winter are strong zonal flow and rapidly moving low-pressure systems over Central Europe, leading to disturbed weather characterised by positive temperature anomalies, windy and cloudy conditions, and above-average precipitation.

Some of the largest pressure drops were related to severe windstorms that brought major damages over western and central Europe, such as Lothar in December 1999 and Kyrill in January 2007. As climate models project strengthening of the zonal

circulation in winter (Leckebusch et al. 2008; Demuzere et al. 2009; Plavcová and Kyselý 2013) and increased frequency of windstorms (Fink et al. 2009; Donat et al. 2010), the negative effects of such weather phenomena and their possible changes in the warmer climate of the twenty-first century need to be better understood, particularly as their importance in inducing excess morbidity and mortality in winter may increase compared to that of cold spells.

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