Cold spell effects on cause–related daily mortality in 6 Korean major cities using spatial synoptic classification (1991–2010)

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Abstract

This study examines the effects of cold spells on excess mortality in six major Korean cities during 1991–2010. Spatial Synoptic Classification (SSC) was utilized to sub-divide oppressive days and classify cold spell periods. Dry Polar (DP) weather effectively represented the winter climate of Korea, showing the highest frequency of weather types. Estimated standardized excess mortality was highest during colder DP subset days (DP– and DP—), characterized by lower temperatures and strong westerly winds. The daily minimum temperature on DP— days was -11.9℃, and the climatic anomaly was 6.8℃. On DP– days were associated with less cold related deaths than DP— days. Excess mortality on DP— days showed larger spikes indicating a partial contribution of weather intensity, age, lag time, and specific causes. One day after DP— the peak of all disease mortality was observed (7.1% for all ages and 11.6% for the elderly). 12.3% cardiovascular elderly mortality was observed on the 5th day with a linear increase, and the highest respiratory elderly mortality 22.3% was observed on the 3rd day. These results reveal the severity of extreme cold spells, especially for individuals with chronic circulatory disease. These results demonstrate that SSC is a suitable methodology for quantifying the effects of cold stresses on daily mortality in Korean metropolitan cities.

Key words: Cold spell, Excess mortality, Spatial Synoptic Classification, Korea

1. Introduction

Weather extremes have attracted significant Biometeorology interests because of greater socio-economic impacts as a result of their increased frequency and intensity (Kalkstein, 1991; Koppe and Jendritzky, 2005). Specifically, winter cold spells are associated with elevated mortality and morbidity compared to summer (McGregor et al., 2004). However the major risk factors for excess deaths in winter are not as well understood as those in summer, because of combination of physiological mechanism, behavioral factors and socioeconomic status disadvantage (McMichael et al., 2003).

There is a clear seasonality exhibited by maximum mortality rates in winter (McGregor *et al.*, 2004; Pell and Cobbe, 1999), and the effect of cold spells has contributed to increased elderly and respiratory mortality and morbidity (Jamason *et al.*, 1997; Keatinge *et al.*, 2000 and 2004). Most of these studies concluded that a non-linear relationship exists between temperature and mortality, with one sharp turning point similar to a U or V-shape (Diaz *et al.*, 2005), and the effect of cold weather on daily mortality is prolonged after a cold spell (Keatinge *et al.*, 2000 and 2004). In the US, health impacts of temperature extremes have been estimated, revealing that cold related mortality (770 deaths) is greater than that related to heat (384 deaths) (Kunkel *et al.*, 1999). Surprisingly, socioeconomic status is not strongly associated with winter deaths, suggesting that risk factors in winter are more widely distributed (Paul *et al*, 2004).

In Korea, cold stress is a significant factor associated with substantial excess deaths (Ha *et al.*, 2009). Recent studies have analyzed the influence of a single weather parameter on winter mortality in Korea and China (Ha *et al.*, 2009; Ma *et al.*, 2013). However, an evaluation of climate and mortality employing the synoptic procedure is still lacking in Korea. Therefore, this study examines the effects of cold spell effects on cause-specific mortality in six large Korean cities during 1991-2010.

The goal of this study is to evaluate the temporal connection between the most oppressive weather type in the Spatial Synoptic Classification (SSC) system (Kalkstein *et al.*, 1996; Sheridan, 2002), and cause-specific excess deaths in large Korean cities. Furthermore, we attempt to quantify the negative health outcomes of severe cold spells in Korean cities, and suggest an improved biometeorological basis for a cold-health warning system in Korea.

2. Data and Method

2.1. Mortality data

Figure 1 shows the geographical positions of the six study locations. The total population of South Korea, Seoul, Daejeon, Daegu, Busan, Gwangju, and Incheon in 2010 was 50,515,666, 10,312,545, 1,503,664, 2,511,676, 3,567,910, 1,454,636, and 2,758,296, respectively, according to the Korea National Statistical Office (KNSO) survey. Therefore, approximately 22 million people live in urban environments in six metropolitan cities. Daily mortality values for the period 1991 to 2010 were obtained from KNSO. The data are classified by age (all ages and over 65) and cause of death (all disease: A00–R99; cardiovascular: I00–I99; respiratory: R00–R99) according to the 10th International Classification of Disease. Before performing analyses of mortality rates associated with abnormally cold conditions, gross mortality figures were normalized to account for population structure changes and a strong seasonal cycle (Dixon *et al.*, 2005). To standardize the daily mortality according to the baseline (or expected) mortality, a direct standardization procedure was used. An annual simple linear regression was constructed for the period based on mean daily mortality data for each winter. Excess mortality for each specific cause was expressed as a deviation around the temporal baseline value.

The relationship between daily minimum temperature and all caused mortality in Seoul (observed mortality for each day per population at the end of that year × 100,000) is presented in Figure 2. The 20 year time series reveals a long–term correlation between temperature and mortality, and the recognized 'hockey stick' and 'U and V shape' of seasonality represented by the winter peak and summer trough

(McGregor *et al.*, 2004; Pell and Cobbe, 1999). The winter peak (DJF 90 days) represents 365.2 mean excess deaths, which can be expressed as four extra deaths each winter day in Seoul. Hence, this trend reflects that extreme seasonal variation can be a prior risk factor. This basic seasonality is the normal pattern in mid-latitude locations, where seasonal weather exchange and variability is significant. In this study, we focus on the effect of the coldest weather type classified by the SSC (Sheridan, 2002) in higher winter excess mortality.

2.2. Climate data

Table 1 describes six weather types and a transition (TR) category. To generate daily SSC weather types, input parameters from climate records of each city were obtained from the Korea Meteorological Administration (KMA). The input parameters are temperature (T), dew point temperature (Td), sea level pressure (SLP), wind direction and speed (U, V component), total cloud amount (TCA) for 0300, 0900, 1500, and 2100 local standard time (LST), daily maximum temperature (Tmax), and daily minimum temperature (Tmin).

2.3. Weather type classification

A series of meteorological variables were categorized into weather types using SSC, which is based on 'actual' seed day climatic properties and ranges for each location (Sheridan, 2002). SSC also considers human influenced weather conditions, such as 'umbrellas of air' (Kalkstein and Greene, 1997). As a sophisticated approach for synoptic climatology, the SSC is widely applied, and enhanced biometeorology research (Sheridan and Kalkstein, 2004; Michelozzi *et al.*, 2010; Tan *et al.*, 2004; Lee *et al.*, 2017).

The SSC characterizes the following weather types: Dry Moderate (DM), Dry Polar (DP), Dry Tropical (DT), Moist Moderate (MM), Moist Polar (MP), Moist Tropical (MT), and Transition (TR). To classify colder days of the DP subset, DP− (0300 and 1500 LST temperatures lower than the mean value of the seed day) and DP— (0300 and 1500 LST temperatures 2.5°C lower than the mean value of the seed day) were used in this study. Figure 3 presents the seasonal temperature variations for 0300 LST and 1500 LST curve values based on DP seed days, which originated from the climate data period for that weather type. Curve mean values and ranges provide the basis for synoptic weather type classification. Hence, meteorological characteristics of each weather type are associated with its own seed days based on the distinct climatology of the source region (http://sheridan.geog.kent.edu/ssc.html).

3. Results

3.1. Meteorological characteristics of weather types

Table 2 presents the mean meteorology characteristics for all winter days in Seoul. DP days were the most frequent (43.9%), and had the coldest meteorological characteristics. In this study, DP days were sub-divided into colder winter days, which represent the superimposing influences of Siberian air mass (continental and polar; cP). Table 2 also shows the mean meteorological characteristics of DP subsets DP–, and DP— defined in section 2.3. The definition of a cold spell in this study considers the time in the season that represents the julian day. During DP subset days, meteorological properties show a constant continental anticyclone influence, typified by strong westerly winds, lower temperatures, and less cloud cover, which intensifies outgoing long wave radiation, leading to nighttime surface radiative cooling on the surface.

Figure 4 shows the daily variations in the mean daily minimum temperature and climatic anomaly after DP– and DP— days. In Seoul, the average daily minimum temperature on a DP— day was -11.9℃ (anomaly -6.8℃). The lowest anomaly compared to the normal year level was recorded on the 4th day. Therefore, the observed recovery time to normal levels follows historical Korean winter climate patterns, whereby three cold days due to the backward position of an eastern anticyclone in the north east of China and the Korean peninsula were followed by four warm days as a result of the subsequent system. Hence, this study considers a time lag period of seven days for health effects. Also, this historical winter oscillation pattern was observed during winter DP generated by the SSC. The following section presents the health effects according to cause-specific mortality for the DP– and DP— days.

3.2. Winter mortality according to weather type

Figure 5 presents the 7-day lagged effects on mortality according to four major causes in the six studied

Korean cities. During 0 and 7 days after DP–– and — days, negative health effects occurred, and the coldest DP— day had clear effects on all diseases (Figure 5c and 5d) and cardiovascular deaths (Figure 5g and 5h). All disease deaths indicate that, of the population with chronic disease, 11.6% more elderly people died on the on 2nd day, and over 8% more people of all ages died during the 2nd to 4th day. For cardiovascular mortality, a 4% increase on the 3rd day and a 12.3% increase on the 5th day were observed for all ages and the elderly, respectively. For respiratory mortality, the highest excess mortality (22.3%) was observed on the 3rd day after the coldest day.

These results confirm that increased elderly mortality related to all diseases is much more likely and persistent after DP— days. Moreover, excess mortality after DP— days showed a partial contribution from cold weather intensity, older age, time lag, and sensitivity to causes. This suggests the importance of age when considering vulnerability to extreme cold spells, especially for individuals with chronic circulatory disease. This study considered not only the intensity of DP subsets, but also the TOS (time of season) based on seed day seasonal variations using the SSC. A decrease in the cold spell effect throughout the winter season was not observed in this study, which suggests that acclimatization did not occur due to the enhanced pathologies produced in previous spells (Diaz *et al.*, 2005). Nevertheless, significant cold-health effects in winter were shown for every cause of mortality.

In recent years, severe weather warnings have become common, such as national cold advisories based on temperature intensity and anomalies using climate data for a specific location. Nevertheless, the synoptic climatological approach can successfully analyze cold weather extremes, and reveal negative health outcomes. Regarding public health, national preparedness (e.g. a warning system based on health effects) and individual recognition will play a major role improving health, under increasing population vulnerability and cold weather severity.

4. Summary and discussion

This study revealed the major short–term health effects of cold spells in six large Korean cities during 1991–2010. There is greater seasonality in winter mortality than summer mortality, with an inverse correlation between temperature and mortality. The fraction of elderly morality has increased significantly, which suggests increasing vulnerability of the population. Findings from this study can be summarized as follows:

1) The Dry Polar (DP) weather type effectively explains the typical winter climate of Korea, and occurs the most frequently, whereby cold and dry weather types are superimposed during the winter period.

2) According to the mean meteorological characteristics of DP– and DP–– days, climatic anomalies were 4℃ (Tmin is -8.8℃), and 6.8℃ (Tmin is -11.9℃). The time to recovering to normal year levels was 4 days and 5 days, respectively.

3) After DP–– days, all disease deaths recorded an 11.6% increase on the 1st day for elderly people, and more than an 8% increase that lasted from the 2nd to 4th day. For cardiovascular elderly mortality, a 12.3% occurred on the 5th day, and the highest respiratory elderly mortality (22.3%) was observed on the 3rd day.

Susceptibility of the elderly population indicates that long-lasting, severe health effects could occur after extremely cold weather. Mortality related to all ages and all causes suggests the importance of personal recognition. National advisory policies will be important for anyone with chronic cardiovascular disease, regardless of age. Hence, a pre-cautionary Cold Health Warning System (CHWS) will be an important future adaptation measure for public health.

In this study, no short-term mortality displacement (harvesting effect) or acclimatization effects according to time of season (TOS) were found. Nevertheless, these topics should be analyzed further, in appropriate detail, as well as other confounding variables, e.g. air quality is known to be linked to cold-related mortality (Dear *et al.*, 2005), and regional acclimatization. Hence, future research should characterize the relationship between synoptic climatology and air quality, and compare their regional health effects (Analitis *et al.*, 2008). Synoptic climatology efficiently represent cause-specific excess mortality, and is thus expected to be a more reliable indicator of human biometeorology.

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