INSIGHTS INTO THE HEALTH IMPACTS OF SYNOPTIC-SCALE CLIMATOLOGY IN TWO KOREAN CITIES: A RETROSPECTIVE ANALYSIS OF MORBIDITY

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1. Introduction

The Korean population is shown to be vulnerable to temperature extremes due to a highly variable climate and the irregularity of extreme heat and cold events (Choi, 2007; Kim et al., 2006; Kalkstein and Sheridan, 2011). However, few results are available regarding the effects weather on the cause morbidity (illness) in Korea (Lee et al., 2010), as there is large difficulty in obtaining high quality emergency room data sets. There is documented evidence of seasonal variations on the incidence of acute myocardial infarction (Lee et al., 2010), yet few data are available regarding the influence of individual meteorological parameters on daily hospital admissions for other outcomes of morbidity.

The most vulnerable areas for heat-related problems are found in locales where heat waves occur at irregular intervals, and summer weather is highly variable. Thus, cities such as New York, Philadelphia, Paris, Rome, Shanghai, and Seoul have demonstrated a greater number of deaths during excessive heat events, which are hypothesized to also contribute to larger numbers of morbidity outcomes.

Much work on heat health warnings systems (HHWS) has been directed at developing the most sophisticated means possible to issue heat-related warnings with respect to specific health outcomes and local climates. Further research work with HHWSs has provided assistance in the development of urban plans to lessen the impact of heat, and to check the effectiveness of heat systems in these major cities.

Recent work by Sheridan and Kalkstein (2011), and Kalkstein (2008; 2009) completed in conjunction with the Korean National Institute of Meteorological Research (NIMR) developed a HHWS for Seoul, Busan, and other major cities. Important associations between the effects of weather and climate on human health outcomes are well-known. The human body responds concomitantly on varying scales of severity to a full atmospheric situation, rather than air temperature alone. In Seoul, it was found that in July during dry tropical (DT) air mass intrusions, average daily mortality in Seoul may increase by over 30 individuals. When compared to other cities, residents of Seoul are rather sensitive to heat. Further, high mortality anomalies have been found due to air pollution in Seoul under the dry moderate (DM) and moist moderate (MM) air masses, which is evidently more important in winter in Seoul than the thermal qualities of the air mass (Kalkstein and Sheridan, 2011).

Associations of weather with mortality impacts in specific segments of the population has been described further by Choi et al. (2005), who found increased mortality in the population of Seoul (+626 deaths over the summer period in 1994), mainly among the elderly. Further, Kim et al. (2006b) reported the hot period to present enhanced mortality in Seoul, which was closely associated with the prolonged drought in the region, representative of a prolonged period of DT or DM air masses. Extreme cold air was also found to associate with excess mortality in Seoul, as well as air pollution (Sheridan and Kalkstein 2011). The city of Busan, although with a very high population of 3.62 million, is much less studied.

We build upon such past studies through application of the same synoptic climatological approach, “spatial synoptic classification” (SSC), to human health data in two large South Korean cities (Seoul: population 10.58 million; Busan: population 3.62 million).

The objectives of this evaluation are:

1. To determine the impact of weather upon anomalous warm- and cold-season morbidity (via hospital visits) for Seoul and Busan using a synoptic climatological approach.
2. To demonstrate the use of relative risk (RR) analysis in determining the risk of hospital visits due to the presence of each synoptic weather type

This is the largest synoptic evaluation of morbidity completed to date. Hospital patient visits were used as a proxy for human morbidity in both the warm and cold seasons (May–Jul; Nov–Feb, respectively).

2. Methods

2.1 Korean Climate

The country of Korea lies in a mild climate zone, with a mixture of continental and maritime influences leading to relatively cold winters and warm-hot summers.

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Maximum temperatures can reach into 35–39^{o}C range, with minimum winter temperatures dropping as low as –20^{o}C in some regions. Hence, the variability of weather on synoptic time scales is large, and hot weather conditions occur almost every summer. This results in the population being more prone to heat-related mortality. The hot, rainy summer, and cold, dry winter in Korea may partly contribute to findings of large negative human health response to weather.

2.2 Data

The National Institute of Meteorological Research (NIMR) provided weather and health data for 2006–2010 for the cities of Seoul and Busan. Hospital patient visit counts for each city were used as a proxy for human morbidity in both the warm and cold seasons (May–Jul; Nov–Feb, respectively) from 2006–2012 inclusive. For the first objective—anomalous morbidity analysis—the hospitalization data were standardized to the mean patient number, as well as standardized daily based on inter-annual trends for each city within each season. This provided an anomalous morbidity to mean patient number value.

Daily SSC data were obtained online from http://sheridan.geog.kent.edu/ssc.html. Each day is classified into one of six air masses (dry moderate (DM), dry polar (DP), dry tropical (DT), moist moderate (MM), moist polar (MP), moist tropical (MT)) or a transition day. A moist tropical plus (MT+) day is also present in summertime in the two cities, classified based on the apparent temperatures being above the weather type mean diurnally (Sheridan and Kalkstein, 2004). Moderate air masses represent fair weather days, with polar and tropical presenting the coldest and hottest days, respectively, for the given city and time of year. More information on the development, use, and the history of use of the SSC can be found in Sheridan (2002) and Hondula et al. (2013).

2.3 Anomalous Morbidity Analysis

Anomalous morbidity analysis was completed using a simple procedure where a trend line was created for each month through the years. Daily values above that line represented positive anomalies, and those below were negative anomalies. Standardization was also completed using a day-of-the-week procedure. Only Sundays appeared to be statistically different; hence, Sunday data were from the anomalous mortality evaluation (Fig 1).

The morbidity data show a steady increase in patients during the period (Table 1). It was apparent that the number of patients increased very dramatically in 2011, even beyond the increases that we had found in the previous years; thus we did not use 2011 data in the anomalous morbidity analysis.

2.4 Time Series Analysis

Due to the 2011 data presenting trends with time (as apparent in Figs 1 and 2), it was clear that a complimentary second procedure to analyze the data was needed. Hence, time-series modeling through the use of a distributed-lag model (DLM) was completed. Time series models are becoming more prevalent in the literature as a means to measure the short-term health effects of weather (e.g., Anderson and Bell, 2009; Guo et al. 2011; Hpndula et al., 2013; Vanos et al. 2014). The DLM was applied using a lag of 0–3 days, based on a generalized linear model with the following time confounders, which were accounted for within the final model (Eq. 1):

- Year
- Day of week
- Julian Day (fit as a 3rd order spline)

As such time confounders could be accounted for within the model, we did not need to remove any years of data. We then developed relative risks (RR) of increased morbidity (as expressed by patient visits), with RR being equal to the risk among persons exposed to a condition divided by risk among persons unexposed to a condition. In this case, the 'unexposed' are people admitted on DM days, since this is a comfortable and benign air mass in Korea. Each of the remaining SSC types was considered to be an exposure to non-benign weather. A Poisson regression equation was developed for the hospitalization-SSC relationship, generalized as follows:

$$RR\ Mort \sim SSC\ exposure + spline(Year) + spline(TOS) + DOW \quad [1]$$

The exposure is dependent on the SSC weather type, TOS is time of season, and DOW is the day-of-week variable. The RR analysis was used to determine significant changes in hospital visits for each SSC category. For example, a three-day cumulative risk of 1.88 (95% CI 1.48–2.28) means that there is an 88% higher cumulative risk for *significantly* increased morbidity during and up to three days after the presence of a particular weather type. A RR value of 1.0 means that there is no relationship between exposure and risk, since the risks are equal. A RR >1.0 means there is increased risk due to exposure, and a RR<1.0 means there is a decreased risk. Uncertainty in the estimates is indicated by the 95% confidence intervals (CI), which also dictate statistical significance with a lower tail >1.0 RR. Significance testing was completed at the level of p<0.05.

3. Results and Discussion

3.1 Time Period Trends

In the case of Seoul, the number of patients more than doubled during the six-year period. This is much greater than the increase in population itself, which suggests that there are cultural factors at play in the registered increases. For Busan, there was a population decrease for the city through the time period; hence, the number of patients is not dictated significantly by population changes.

The average number of monthly deaths was found to be considerably greater in winter than in summer (Fig 2). January averaged over 15 patients daily in both cities, while the summer months generally averaged about 1/3 of this number. Busan's daily averages were quite close to Seoul's, despite the fact that Seoul is much larger in population. We have not been able to find an explanation for this apparent disparity. It is worth highlighting that Busan exhibited slightly higher numbers in winter, and Seoul slightly higher numbers in summer.

Both cities react similarly regarding DOW patient variation; there was a great depression on Sunday (which had approximately 80 percent less patients overall), with slightly elevated patient numbers on Monday, and a small depression during the middle of the week. The evaluation of the DOW time confounder demonstrates Sunday to be significantly different from the remaining days. This supports the removal of Sundays from anomalous morbidity analysis, yet since we account for this within the DLM to produce RRs, Sundays were left in. The small weekly DOW variations were not significant and all data could be used. A Monday peak and Sunday trough is common in the literature for mortality as well (Lee et al., 2010; Ku et al., 1998) which is closely related to the occurrence of heart attack in the working population (Gruska et al., 2005; Ku et al., 1998). This is related to stress on the vascular and nervous system issues that are likely to be triggered by psychological and physical factors on the first work-day of the week (Lee et al., 2010).

3.2 Anomalous Morbidity Analysis

Evaluations for the period through 2010 showed strong and intuitive relationships between anomalous patient numbers and air mass type (Tables 1 and 2). During the winter, there were demonstrably more patients in both Seoul and Busan on DP air mass days. The sample sizes were quite large so this is a robust result. For a number of winter months in both cities, the mean number of patients was over 10 percent higher than the expected baseline number, with greatest deviations in both cities noted in February. Moist polar air mass days also demonstrated generally higher than expected patient numbers, although sample size was an issue, with only a few MP days occurring in Busan. DM and MM air mass days showed patient numbers to be generally below the mean, also an intuitive result.

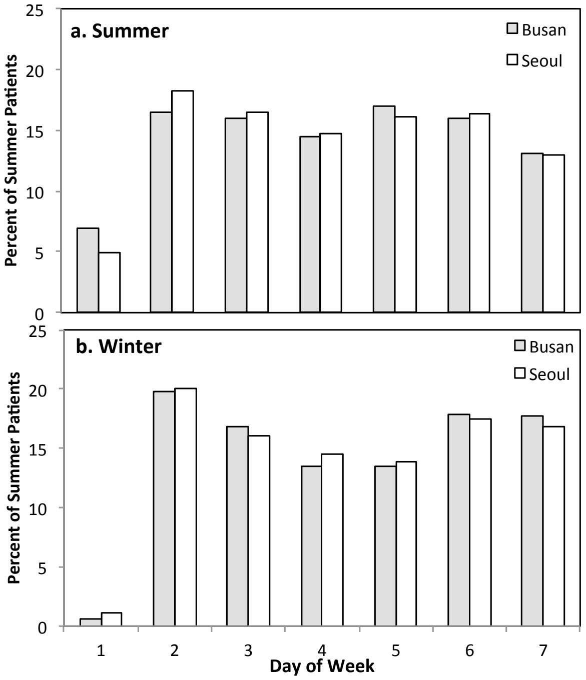

Figure 1: Day of the week (DOW) variation in patients for Busan and Seoul (a. summer; b. winter). Sunday is day 1, Saturday is day 7.

For summer in Seoul, results greatly differ from that of winter, with the MT, MT+ (when present late in the season), and DT (mostly early in the season) showing highly positive patient numbers. The summer patient

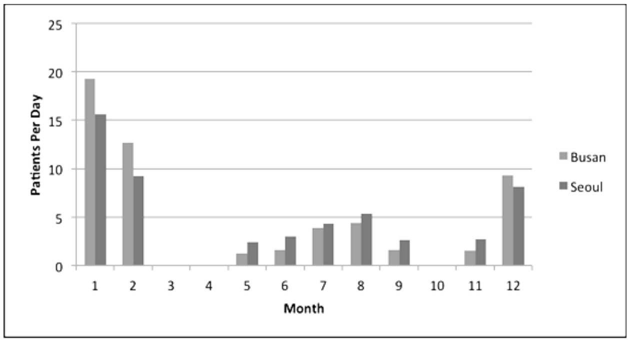

Figure 2: Seasonal dynamics of morbidity. Only May–Sept where used for warm season, and Nov–Feb for cold season.

Table 1: Relationship between air mass type and mean daily standardized morbidity values for each month; Seoul, 2006–2010.

	MM			**MP**			**MT**		
	Mean Patients	Mean anomaly	*n*	**Mean Patients**	Mean anomaly	*n*	**Mean Patients**	Mean anomaly	*n*
November	**1.9**	-17%	*9*	**1.9**	-17%	*8*	**1.3**	-45%	*4*
December	**4.5**	-35%	*11*	**7.6**	8%	*10*			
January	**14.0**	-21%	*3*	**22.8**	28%	*6*			
February	**7.0**	-34%	*9*	**12.0**	13%	*1*			
May	**2.6**	-1%	*26*	**2.8**	7%	*6*	**3.3**	26%	*9*
June	**2.8**	-16%	*33*	**2.0**	-40%	*2*	**3.5**	6%	*15*
July	**3.6**	-26%	*62*	**2.0**	-58%	*2*	**7.2**	49%	*41*
August	**4.2**	-30%	*25*				**6.6**	11%	*67*
September	**2.9**	2%	*26*	**2.0**	-30%	*3*	**3.8**	35%	*17*
	DM			***DP***			***DT***		
November	**2.0**	-12%	*42*	**2.5**	10%	*28*			
December	**8.0**	14%	*40*	**7.3**	4%	*36*			
January	**14.5**	-18%	*28*	**19.3**	8%	*41*			
February	**7.6**	-29%	*29*	**15.3**	44%	*25*			
May	**2.3**	-13%	*55*	**3.4**	28%	*10*	**2.8**	7%	*18*
June	**3.4**	1%	*57*	**3.0**	-10%	*1*	**4.7**	41%	*17*
July	**4.5**	-6%	*20*				**3.0**	-37%	*2*
August	**4.9**	-18%	*23*				**6.9**	15%	*8*
September	**2.7**	-4%	*66*	**1.0**	-65%	*4*	**2.7**	-6%	*9*

numbers were considerably less than in winter; nevertheless, the most oppressive air masses stand out. Note that DT air had the most influence early in the season (as determined by the greater sample size) and the MT air mass types were most notable late in the summer during monsoon season. Thus, the July DT reading in Seoul, when this air mass is rare, is probably specious since there are only two days in the sample. DP, MP, DM, and MM were unimportant air masses in terms of patient numbers and were generally below the mean. Similar results were obtained for Busan in summer, but it should be noted that DT air is exceedingly rare in Busan. However, the influence of the MT, MT+, and MT++ air masses on patient numbers clearly stands out in this warmer and more humid city, as compared to Seoul.

The percentage of increase for MT+ and MT++ were quite dramatic, but note that, in some cases, sample size was insufficient to make important judgments about the results. However, Busan's July and August MT+ results, and Seoul's June DT results are strong because of substantial sample sizes.

Wintertime presented the highest number of hospital patients. The DP air mass consistently displayed the greatest number of patients in winter, with MP weather also demonstrating high positive patient anomalies. The mean anomalous morbidity in the DP air mass ranged from 10–59% for Busan, and 4–44% for Seoul. Hospitalizations on dry and moist moderate days (DM and MM) were consistently below the mean.

3.3 Relative Risk Analysis

The challenge, as expressed in the Section 2, was how to deal with the inordinate size of the 2011 patient population. Thus, we rely on the DLM RR method described above, with results for both cities and seasons presented in Tables 3–6, where bolded values represent a statistically significant increase or decrease. We evaluated RR the day of the oppressive air mass (0-day RR in the tables), as well as cumulative RR on the day of the oppressive air mass plus the three days following (mean 0–3 day cumulative risk in the figures).

For summer in Seoul (Table 3), RR values were higher, and in some cases statistically significantly higher, for the oppressive air masses. This was particularly true for the 3-day cumulative risk. In Seoul, DT days displayed an increase in 3-day cumulative risk of 1.44. For MT+, this value was 1.88, indicating that there is an 88% higher cumulative risk for increased morbidity during and up to three days after the presence of a MT+ air mass, as compared to a DM air mass. This is a striking

Table 2: Relationship between air mass type and mean daily standardized morbidity values for each month; Busan, 2006–2010.

	MM			**MP**			**MT**		
	Mean Patients	Mean anomaly	*n*	**Mean Patients**	Mean anomaly	*n*	**Mean Patients**	Mean anomaly	*n*
November	**1.8**	0%	*13*				**0.0**		*3*
December	**8.7**	-20%	*14*				**7.0**	-35%	*1*
January	**20.4**	-8%	*17*	**32.0**	45%	*2*			
February	**6.4**	-57%	*11*	**17.0**	16%	*1*	**5.0**	-66%	*1*
May	**1.1**	-18%	*29*	**0.7**	-45%	*7*	**2.4**	81%	*19*
June	**1.1**	-31%	*52*	**1.1**	-31%	*7*	**2.6**	59%	*19*
July	**2.3**	-45%	*59*	**0.7**	-84%	*6*	**5.8**	38%	*43*
August	**2.6**	-48%	*18*				**5.2**	8%	*50*
September	**1.0**	-45%	*28*				**2.1**	21%	*36*
	DM			**DP**			**MT+**		
November	**1.5**	-14%	*46*	**2.8**	59%	*5*			
December	**11.8**	8%	*45*	**12.0**	11%	*14*			
January	**20.5**	-7%	*38*	**24.3**	10%	*21*			
February	**14.9**	2%	*35*	**22.3**	52%	*19*	**5.0**	-66%	*1*
May	**1.3**	-2%	*58*	**1.1**	-17%	*11*			
June	**1.9**	17%	*42*	**1.0**	-39%	*2*			
July	**2.8**	-35%	*4*				**10.6**	153%	*14*
August	**1.9**	-60%	*19*				**7.2**	48%	*30*
September	**1.6**	-8%	*41*				**4.6**	162%	*8*

risk estimate, and strongly suggests that these oppressive air masses are generally associated with higher patient visits.

Summer results from Busan (Table 4) were of greater magnitude and strength than that of Seoul. The DT air mass occurs very rarely in this southern coastal city, but for MT and MT+, the RR values were the strongest and statistically significant. The cumulative risk for MT+ of 2.78 represents that there is a dramatically higher RR for increased morbidity during the presence of this air mass. Cumulative risks of hospital visits demonstrated a significant increase in the MT+ air mass in both Seoul (RR = 1.88 (95% CI 1.05–3.37) and Busan (RR = 2.78 (95% CI 2.17–3.57)). Positive patient numbers and increased RR in the MT, MT+, and MT++ air masses were more prevalent and higher in Busan as compared to Seoul, which most likely relates to the warmer and more humid climate. The summertime air masses of DP, MP, DM, and MM were generally below the mean number of patient visits.

Table 3: ***Summer relative risk (RR) for increased morbidity, Seoul (2006–2011). Values represent probabilities of risk, with the DM air mass being the control.***

	Sample size	**0-day Relative risk**	**Mean 0-3 day cumulative risk**	***95% Confidence Int.***	
DM	*307*	1.00	1.00	*1.00*	*1.00*
DP	*20*	1.08	1.56	*0.89*	*2.73*
DT	*78*	1.10	**1.44**	***1.09***	***1.91***
MM	*247*	0.86	0.97	*0.78*	*1.21*
MP	*16*	0.77	0.74	*0.33*	*1.65*
MT	*202*	1.11	**1.63**	***1.33***	***2.00***
TR	*39*	0.82	1.01	*0.60*	*1.69*
MT+	*9*	1.18	**1.88**	***1.05***	***3.37***

Table 4: ***Summer RR for increased morbidity, Busan (2006–2011). Values represent probabilities of risk, with the DM air mass being the control.***

	Sample size	**0-day Relative risk**	**Mean 0-3 day cumulative risk**	***95% Confidence Int.***	
DM	*240*	1.00	1.00	*1.00*	*1.00*
DP	*15*	0.90	0.66	*0.29*	*1.50*
DT	*2*				
MM	*266*	**0.80**	**0.66**	***0.51***	***0.66***
MP	*29*	0.81	0.92	*0.45*	*1.87*
MT	*238*	1.30	**1.84**	***1.47***	***2.31***
TR	*59*	0.86	0.86	*0.52*	*1.45*
MT+	*69*	1.59	**2.78**	***2.17***	***3.57***

For winter, results were similar in strength for (Tables 5 and 6), with RRs equal to, or higher than those found during the summer. It is apparent that DP had a strong impact on mortality risk, particularly for cumulative risk. For Seoul, the cumulative risk for increased patients was slightly over double that for the DM control situation, and for Busan, the cumulative risk was slightly less than double. Further, the DP air mass demonstrated significant increases in cumulative risk of hospital visits for both cities (i.e., RR = 2.02 (95% CI

1.50–2.72) for Seoul; RR = 1.93 (95% CI 1.55–2.41) for Busan).

Table 5: ***Winter RR for increased morbidity, Seoul (2006–2011). Values represent probabilities of risk, with the DM air mass being the control.***

	Sample Size	0-day Relative Risk	Mean 0-3 *day cumulative* Relative Risk	*95% Confidence Int.*
DM	*195*	1.00	1.00	*(1.00-1.00)*
DP	***243***	**0.99**	**2.02**	***(1.50-2.72)***
DT	*2*			
MM	***49***	**0.67**	**0.35**	***(0.16-0.79)***
MP	*45*	0.82	1.09	*(0.64-1.84)*
MT	*4*			
TR	*60*	0.82	0.74	*(0.41-1.35)*
MT+	*3*			

Table 6: ***Winter relative risk for increased morbidity, Busan (2006–2011). Values represent probabilities of risk, with the DM air mass being the control.***

	Sample Size	0-day Relative Risk	Mean 0-3 *day cumulative* Relative Risk	*95% Confidence Int.*
DM	*285*	1.00	1.00	*(1.00-1.00)*
DP	***145***	**1.04**	**1.93**	***(1.55-2.41)***
DT	*0*			
MM	***88***	**0.98**	**0.69**	***(0.46-1.03)***
MP	*9*	0.98	0.63	*(0.27-1.45)*
MT	***12***	**0.68**	**0.14**	***(0.02-0.81)***
TR	***60***	**0.80**	**0.66**	***(0.43-1.03)***
MT+	*2*			

The results from this risk analysis on patient admittance demonstrates with strength that this approach can help in the determination of when increased morbidity can be expected during a variety of weather situations in both summer and winter. The statistical significance of the results also suggests that there may be use of this information as a forecast tool regarding numbers of patients that might converge on emergency rooms during extreme hot or cold weather. For example, for both cities, there is almost double the risk of increased patients during DP air mass intrusions on the day of the DP air mass and up to three days afterward as compared to other air masses. We also demonstrated the importance of accounting for cumulative exposures, as the impact of weather type is cumulative, and there were no significant values for 0-day RR, yet strength and significance in select results for 3-day cumulative exposure. For cold weather analysis, the time of maximum health impact from the cold had been found to be approximately two weeks of cumulative exposure (Braga et al., 2001); hence, applying 14-day lags could provide additional information on the effects of the coldest air on human health. Future work can use similar methods to assess factors that act synergistically with weather on human health exist due (e.g., air pollution, socioeconomics, duration, time-lags (Vanos et al, 2014; Rocklov et al. 2011)).

4. Conclusions

Our findings suggest that the number of hospitalizations is statistically related to variations in synoptic weather patterns, being significantly higher in cases of oppressive air masses. There was a strong relationship between air mass type and patient admissions using both a standard approach for the 2006–2010 data, and a relative risk model for the 2006–2011 data. The most extreme warm and cold season air masses displayed significant cumulative effects on patient numbers through a 3-day cumulative lag.

The RR approach allowed for the control of time confounders in the DLM, and is hence a better way to assess the strength and significance of results. For summer, the cumulative 0–3 day RR was statistically significantly higher for MT and MT+ air masses, with lesser response for DT, which is rare, particularly in Busan. For winter, the cumulative RR was statistically significantly higher for the cold, dry DP air mass in both cities. By season, the total number of patients was much higher in winter than summer, and the patient numbers increased dramatically from 2006-2011.

These results can add vital information to the heat-health warning systems already present in the two cities, which are based upon variations in mortality and not morbidity. Further, city-specific forecasting of such weather in Korea can provide more accurate projections of the numbers of patient visits, as well as the relative risk of morbidity due to weather

Future research involves the consideration of a possible morbidity system, similar to our existing mortality-based heat/health warning systems, to help stakeholders prepare for larger numbers of patients during certain offensive air mass days in both seasons. There is also potential to adapt heat/cold health warning systems to morbidity in addition to mortality for Seoul. The type of illness is also dependent of air mass; hence, addressing which morbidity type (CVD, Respiratory) can give more specific answers to public health officials.

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