FINAL REPORT

COLLABORATIVE AGREEMENT BETWEEN NIMR AND APPLIED CLIMATOLOGISTS

"An improved heat/health system for Seoul and the development of winter relationships for large cities in the Republic of Korea"

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November, 2011

GOALS OF YEAR 4 EFFORT

The main goals of the fourth year collaborative project are as follows:

- Developing a finer network for our HHWS for Seoul. We presently only have one system covering all of Seoul. We will divide Seoul into five regions, and develop a separate HHWS and associated website for each. Individual heat/health relationships will be developed for each region. Thus, a heat warning can possibly be called for one part of Seoul and not for another. It was suggested not to divide Seoul into too many small units, as this would be confusing to the general public and stakeholders

- Development of a cold weather/health evaluation for cities in Korea. Using the SSC to classify winter weather, we will evaluate our seven Korean cities to determine the links between the SSC and cold weather, using procedures we have employed for the hot season. We must keep in mind that there is a longer lag between the offending weather and the subsequent rise in mortality during the winter, and that the mortality "spikes" during winter are less pronounced than during summer. In addition, we will develop two cold/health warning systems (CHWS) for Korean cities. Seoul will be one of them and the other will be selected by mutual consent. Although similar procedures used in the development of heat/health warning systems will be employed, there are certain ancillary issues to be considered. Past research has shown that there are two weather/health relationships that are classifiable in winter: the mortality spikes from direct impact of very cold weather (e.g. hypothermia) and more subtle spikes that relate to inclement weather, particularly in late fall. The delineation of these factors will be part of our ongoing discussion.

Based upon our initial cold weather correlation work, the second goal was modified based upon mutual consent. We developed a cold weather/health evaluation for four cities: Seoul, Busan, Incheon, and Jaejeon. We then developed a full evaluation relating air pollution to air mass type in Seoul, based upon an initial finding that pollution concentration seems to explain more of the variance between mortality and air mass type than extremely cold weather. Finally, we developed a breakdown of deaths in Seoul and Busan based upon subdividing age (65+ years old) and cause of death (cardiovascular, cereborovascular, respiratory). We decided against the development of the CHWS at this point based upon our results.

THE REGIONAL HHWS FOR SEOUL

We were originally seeking a six-region solution for Seoul, but upon clustering of mean maximum and minimum temperatures for each month, a five-region solution was determined to be superior. The clustering solutions are shown below in Table 1. The three different clustering solutions came out rather similar, but after discussions with NIMR colleagues, we decided to utilize the 2-step clustering procedure, as it appeared more regionally homogeneous. We also agreed to move the Jongno district into cluster 5, based upon mutual discussion, and noting that the temperature deviations in Jongno are quite similar to the stations in cluster 5.

A map of the clusters shows that they are generally, but not completely, contiguous (Figure 1). The downtown districts are generally clustered together, and there seems to be a strong relationship between elevation of the region and the group it was clustered with (please note that region 108, Jongno, has been clustered with regions 412 and 414 in our five cluster solution). Although cluster 5 seems to contain areas that are far apart, three of the four regions in this cluster have the highest elevation in all of Seoul. So we are quite content that we have developed distinctive and cohesive climate districts in this clustering.

Once the five regions were identified, we were then able to determine synoptic/mortality relationships for each of these regions (Table 2). The numbers represent deviations in deaths from the standardized baseline, in rates per 100,000 for each air mass type. The regions are the rows (A2 is region 2, A3 is region 3, etc; please note that there is no region 1, which was originally Jongno) and the air mass types are the columns. MT+ represents more oppressive MT days, where both the 3AM and 3PM apparent temperatures are above the MT seed day mean. MT++, is even more oppressive, where both the 3AM and 3PM apparent temperature are at least one standard deviation above the MT seed day mean. So, as an example, for all the Seoul regions together, the mean standardized deviation in mortality for the MT++ air mass is 0.08 death/100,000. Considering that Seoul's population is about 10,300,000, you would multiply the 0.08x103, which equals 8.24...the average daily increase in mortality above the baseline for the city for the MT++ air mass is 8.24 deaths, certainly a significant number, since there are about 100 deaths per day in Seoul. It is clear that the largest increases in standardized mortality are in the MT+ and MT++ air masses, certainly the expected result. There is a smaller increase for air mass 3, DT, also not unexpected. The variation in response among regions is quite large and in a couple of cases,

	Deviation of mean minimum temperature				Deviation of mean maximum temperature				Cluster	Cluster	Cluster
	May	Jun	Jul	Aug	May	Jun	Jul	Aug	Hier-6	2-step-6	K-mean-6
Jongno	-0.7	-1.0	-1.1	-1.0	-1.4	-1.5	-1.8	-1.8	1	1	1
Joonggu	-0.1	-0.2	-0.4	-0.3	0.1	0.0	-0.4	-0.4	2	2	5
Seongdong	0.0	0.0	-0.3	-0.4	0.0	0.1	0.1	0.1	2	2	3
Nowon	-1.0	-0.5	-0.1	-0.7	0.1	0.2	0.0	-0.1	2	2	2
Gangseo	0.1	-0.1	-0.1	0.0	-0.1	-0.4	-0.3	0.0	2	2	3
Guro	-0.3	-0.3	0.1	0.1	-0.5	-0.6	-0.2	0.0	2	2	2
Yongsan	0.3	0.1	-0.8	0.3	0.0	0.1	0.0	0.1	2	2	3
Dongjak	0.4	0.1	-0.9	0.4	-0.1	-0.1	-0.2	0.0	2	2	3
Eunpyeong	-1.2	0.0	0.3	0.4	-0.7	-0.2	0.3	0.2	3	2	2
Gwangjin	0.4	0.4	0.3	0.1	0.1	0.1	0.1	0.0	3	3	3
Dongdaemoon	0.4	0.3	0.4	0.3	0.4	0.4	0.4	0.6	3	3	3
Yangcheon	0.4	0.2	0.1	0.2	0.1	0.0	0.1	0.0	3	3	3
Gangnam	0.0	0.1	0.2	0.0	0.7	0.8	0.4	0.5	3	3	3
Songpa	0.6	0.5	0.3	0.2	0.6	0.4	0.3	0.0	3	3	3
Gangdong	-0.2	0.0	0.0	-0.2	0.6	0.6	0.4	0.2	3	3	3
Joongrang	0.8	0.8	0.7	0.7	0.6	0.6	0.5	0.5	4	4	4
Gangbook	0.6	0.7	0.7	0.7	0.6	0.6	0.6	0.5	4	4	4
Mapo	1.6	1.5	0.7	0.9	0.6	0.8	0.4	0.4	4	4	4
Yeongdeungpo	1.2	0.8	0.5	0.9	0.4	0.3	0.4	0.5	4	4	4
Seocho	0.4	0.4	0.5	0.5	0.8	0.9	0.9	1.1	4	4	4
Geumcheon	0.1	0.0	0.1	-0.2	-0.7	-0.5	0.0	-1.4	2	5	5
Seongbook	-0.6	-0.8	0.2	-0.8	-0.9	-0.9	0.1	-0.5	5	5	5
Seodaemoon	-0.6	-0.7	-0.4	-0.5	-0.3	-0.5	-0.6	-0.6	5	5	5
Gwanak	-0.8	-1.0	-0.5	-0.5	-0.8	-0.8	-0.8	-0.8	5	5	5
Dobong	-1.7	-1.3	-0.5	-1.1	-0.2	-0.4	-0.4	0.9	6	6	6
Mean	13.9	19.0	21.8	23.7	23.3	27.2	28.0	30.4			

Table 1. Meteorological parameters and clusters of the 26 districts in Seoul. Note that Jongno is now part of cluster 5.

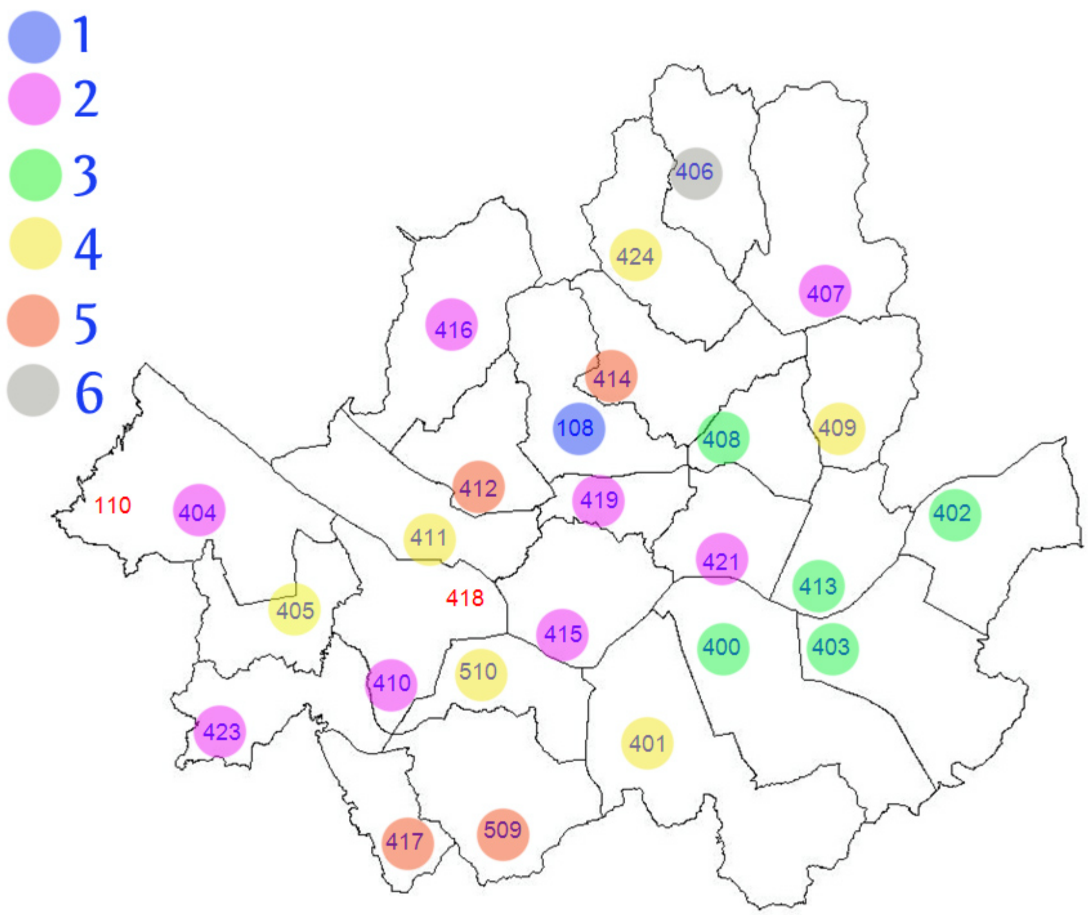

Figure 1. A map of the regions within the 26 Seoul districts. Note that district 108 is now part of region 5, and region 1 has been eliminated.

	DM	DP	DT	MM	MP	MT	TRAN	MT+	MT++
Average ALL	0.00	-0.02	0.03	-0.02	-0.02	0.01	-0.01	0.06	0.08
Average of A2	0.00	-0.01	0.02	-0.02	-0.05	0.01	0.00	0.07	0.01
Average of A3	0.00	-0.06	0.03	-0.01	-0.03	0.01	0.00	0.05	0.16
Average of A4	0.00	0.00	0.01	-0.02	0.01	0.01	-0.02	0.11	0.05
Average of A5	0.01	0.00	0.05	-0.03	-0.03	0.01	0.00	0.03	0.05
Average of A6	0.00	-0.04	-0.01	-0.01	0.05	0.02	-0.06	0.02	0.17

Table 2. Mean standardized mortality for each of the five regions, expressed as rates per 100,000.

the negative health response is larger for MT+ than for MT++ (subdivisions 2 and 4). But it is abundantly clear that MT+ and MT++ air masses are dangerous and contribute to excess mortality.

The next step is to develop algorithms that represent the relationship between mortality and a series of independent variables for each of the regions during offensive air mass intrusion (MT+, MT++, DT). Algorithm development was attempted for each region, using independent variables such as day in sequence, time of season, and certain meteorological variables. Statistically significant algorithms were uncovered for all but one of the regions (region 2), and are found at the top of Table 3. And we also uncovered a non-intuitive algorithm for region 6, where mortality decreases with increasing day in sequence. However, for four of the regions, day in sequence (DIS) was determined to be the most important independent variable, which is consistent with results for other cities including our current Seoul single-region system. For Zone 5, Julian date (JD) was statistically significant, and indicated that the impact of heat diminishes as the summer season progresses. For region 2, we determined that the mean increase in deaths (per 10 million people) was 5 for MT+ and MT++ air masses, and that increase was 2 for the DT air mass. We might want to consider this for the non-intuitive region 6 as well.

Thresholds for advisory and warning calls were developed for each of the regions, and then we evaluated how many advisory and warning days there would have been in each region if the system had been operating during the summers of 2009 and 2010. We also wanted to see if there was some spatial homogeneity between the regions; that is, would advisory and warning calls be issued during similar hot weather episodes? Obviously, we wouldn't want the regions to match perfectly, or there would be no need for a five-regional subdivision! On the other hand, it is important to make certain that things aren't so wildly different between regions which would suggest that the system is not robust.

With the exception of region 2, and somewhat for region 6, the correspondence between regions is rather good, albeit not perfect. For example, during the intense heat event of June 5-11, 2010, it is clear in Table 3 that most of the regions would have been under a heat warning, with the exception of region 2 and region 5, where advisories would have been called. Region 6 stood out as an outlier, again suggesting that we possibly abandon that algorithm and use the approach we developed for region 2. As you look at the various heat episodes highlighted in Table 3, there are clearly times when a warning would be called in one region, and only an advisory or possibly nothing would be called in another region. In our estimation, regional homogeneity is about what we'd expect, and it supports the need for a subdivision of Seoul into sections as we have done. We are generally happy with the result.

					IN DEATHS PER 10 MILLION						IN TOTAL DEATHS
Equation					0.9 + 1.5 DIS	MT+/++: 5 ; DT: 2	0.2 + 2.2 DIS	-2.4 + 3.7 DIS	8.2 - 0.1 JD	10.1-4.8 DIS	
Warning threshold->					**5**	**5**	**7**	**7**	**5**	**5**	**7**
Advisory threshold->					**3**	**2.0**	**3**	**3**	**3**	**1**	**3**
YEAR	**MONTH**	**DAY**	**SSC**	**DIS**	**ALL ZONES**	**ZONE 2**	**ZONE 3**	**ZONE 4**	**ZONE 5**	**ZONE 6**	**CURRENT SEOUL SYSTEM**
2009	5	6	DT	1	2	2	2	1	8	5	1
2009	5	7	DT	2	4	2	5	5	8	1	5
2009	5	8	DT	3	5	2	7	9	7	0	6
2009	5	9	DT	4	7	2	9	12	7	0	10
2009	5	20	DT	1	2	2	2	1	6	5	1
2009	5	26	DT	1	2	2	2	1	6	5	3
2009	5	27	DT	2	4	2	5	5	6	1	6
2009	5	28	DT	3	5	2	7	9	5	0	8
2009	5	29	DT	4	7	2	9	12	5	0	12
2009	6	1	DT	3	5	2	7	9	5	0	6
2009	6	5	DT	1	2	2	2	1	5	5	2
2009	6	27	DT	1	2	2	2	1	2	5	4
2009	8	14	DT	1	2	2	2	1	0	5	6
2009	8	16	DT	1	2	2	2	1	0	5	7
2010	5	21	DT	1	2	2	2	1	6	5	1
2010	6	5	DT	1	2	2	2	1	5	5	3
2010	6	6	DT	2	4	2	5	5	5	1	6
2010	6	7	DT	3	5	2	7	9	4	0	10
2010	6	8	DT	4	7	2	9	12	4	0	13
2010	6	9	DT	5	8	2	11	16	4	0	16
2010	6	10	DT	5	8	2	11	16	4	0	16
2010	6	11	DT	5	8	2	11	16	4	0	15
2010	6	25	DT	1	2	2	2	1	3	5	4
2010	7	6	DT	1	2	2	2	1	2	5	5
2010	8	3	DT	1	2	2	2	1	0	5	7
2010	8	5	MT+	1	2	5	2	1	0	5	0
2010	8	20	MT+	1	2	5	2	1	0	5	0
2010	8	21	MT+	2	4	5	5	5	0	1	1
2010	8	22	MT+	3	5	5	7	9	0	0	4
2010	9	7	DT	1	2	2	2	1	0	5	6
2010	9	15	DT	1	2	2	2	1	0	5	4
2010	9	16	DT	2	4	2	5	5	0	1	6
2010	9	18	DT	2	4	2	5	5	0	1	8

Table 3. An evaluation of regional homogeneity for the five regions, and the present Seoul system.

Conversations with Dae-Geun Lee have indicated that he has selected forecast stations for each of the regions. The data are available for the time intervals 00UTC and 12UTC, which will suit our purposes perfectly. These are inputted automatically within the websites. The websites are now operational and will be the new standard for synoptic-based HHWSs. This represents our first urban area subdivision among the almost 50 HHWSs that we have developed and are presently in operation.

COLD WEATHER-HEALTH EVALUATION: SEOUL RESULTS

The initial goal of this portion of our research agenda was to evaluate the relationships between offensively cold air masses and mortality for the major cities in Korea. We were then charged to develop two cold weather warning systems, one for Seoul and the other for a mutually agreed-upon city. We realized that it would be more difficult to find a cold weather-health link because of a lesser acute mortality peak which is typical of winter mortality verses summer, and also because of an increased lag time between the offending weather and the cold weather health response. However, in the cities where we have previously done this research (Toronto, the Peel Region of Canada, the San Francisco region), we had found such a link, although it was determined that cold, inclement weather was even more dangerous and contributed to higher levels of anomalous mortality than did extremely cold temperatures. We hypothesized that we would uncover similar relationships for the Korean cities; that proved not to be the case.

We evaluated 15 years of mortality data from January 1, 1995 through December 31, 2009 for the winter months of December, January, and February for Seoul. The mortality response during the day of a particular air mass was evaluated, as well as a seven-day period including and after the date of the air mass (Table 4). The results suggested no excess mortality response during the two coldest air masses (DP and DP+) and only a weak response during the cold, inclement air mass (MP). Many of the monthly

	DP			DP+			MP		
	1-day	7-day	n	1-day	7-day	n	1-day	7-day	n
Dec	-1.8	-0.9	155	-1.7	-0.5	52	2.9	1.2	29
Jan	-1.2	0.1	170	-1.8	0.9	58	-1.3	-1.1	35
Feb	-0.9	-0.3	144	-0.6	0.1	29	0.2	4.5	12

Table 4. Mortality response in Seoul on the day of each of the three cold air masses (1-day), and for a seven day period extending from the date of the air mass (7-day). "n" refers to the daily sample size.

relationships were actually negative; for example, all three 1-day relationships for DP and DP+ were negative. The results were slightly more positive for MP, particularly for December and February relationships (although the lack of response during January is curious), but we were still surprised by the general lack of response in mortality within the three cold air masses in Seoul.

We then looked at days in sequence to see if consecutive days of DP+ air masses would enhance acute mortality in Seoul (Table 5). Once again, the results proved inconclusive. Even three consecutive days of DP+ air masses produced generally negative mortality responses. By consecutive days 4 and 5, some positive values were uncovered, but sample sizes were so small that these numbers could not be considered conclusive. Thus, for the coldest air masses, even consecutive day runs indicated little negative health response from the population of Seoul. Similar results were uncovered for DP air.

	Day 1			Day 2			Day 3			Day 4			Day 5			Day 6		
	1-day	7-day	n	1-day	7-day	n	1-day	7-day	n	1-day	7-day	n	1-day	7-day	n	1-day	7-day	n
Dec	-2.1	-1.6	30	-1.6	0.3	12	-0.5	-0.4	4	-2.8	1.6	3	1.7	4.3	3			
Jan	-2.7	0.9	29	0.7	1.1	14	-7.0	1.2	8	3.3	2.2	3	2.8	-0.2	2	0.5	-0.6	2
Feb	-1.4	0.2	18	4.1	-0.1	8	-8.4	0.1	3									

Table 5. A consecutive day evaluation of DP+ air mass days for Seoul.

An evaluation of the other air masses related to excess mortality in Seoul led to some surprising results (Table 6). Two air masses, dry moderate (DM) and moist moderate (MM), demonstrate the largest positive mortality anomalies among all of the air masses. For DM, the mortality response on the date of the air mass is about 3 percent above the baseline (2.5 extra deaths, on average) during December, and a bit smaller but still positive in January. For MM, all three 1-day relationships are positive, particularly

	DM			MM		
	1-day	7-day	n	1-day	7-day	n
Dec	2.5	0.7	152	0.5	-1.9	27
Jan	1.4	-0.2	138	0.6	-0.3	28
Feb	-0.5	0.2	153	4.4	1.2	44

Table 6. Mortality response in Seoul on the day of DM and MM air masses (1-day), and for a seven day period extending from the date of the air mass (7-day). "n" refers to the daily sample size.

in February. These air masses are not distinctive from a thermal standpoint; in fact, DM is warmer than average, especially during the daytime, with a mean 1500hr temperature of 5.5°C in January. This represents the second warmest air mass in winter during the daytime hours. MM is rather mild overnight with a small diurnal range and a mean 0300hr temperature of 2.4°C in January. This represents the second warmest air mass in winter during the nighttime hours.

A consecutive day evaluation of both DM and MM also yielded surprises (Table 7). The positive mortality anomalies increased dramatically during longer consecutive day strings, particularly for the DM air mass. In fact, by day 4, mortality excesses exceed 6 deaths on average in December and almost 5 deaths in January. These numbers persist for even longer consecutive day periods, and reach a very high 14.3 excess deaths in January after 6 consecutive days (but please note the small sample size). During MM intrusions, the numbers remain positive for all the 1-day incursions whether on the first or second consecutive day (MM almost never occurs longer than a two day period in Seoul). These positive numbers contrast sharply with the unimpressive mortality values found with the three coldest air masses.

	Day 1			Day 2			Day 3			Day 4			Day 5			Day 6		
	1-day	7-day	n	1-day	7-day	n	1-day	7-day	n	1-day	7-day	n	1-day	7-day	n	1-day	7-day	n
Dec	1.9	-0.2	61	1.3	0.1	35	4.6	1.6	20	6.6	5.0	11	6.5	5.3	9	2.5	-1.6	5
Jan	-0.3	-1.1	66	2.5	-0.6	32	0.6	0.2	20	4.9	2.5	13	3.6	0.7	4	14.3	10.8	3
Feb	-0.1	0.4	68	-0.1	0.4	40	-5.8	-0.4	18	0.9	-0.8	13	2.1	-0.9	10	-2.7	1.1	3

	Day 1			Day 2		
	1-day	7-day	n	1-day	7-day	n
Dec	0.1	-1.4	23	3.0	-4.3	4
Jan	0.5	-0.7	25	1.1	2.9	3
Feb	6.0	1.8	35	0.7	-0.2	8

Table 7. A consecutive day evaluation of DM (top) and MM (bottom) air masses for Seoul.

Of course, our next undertaking was to find out WHY the DM and MM air masses demonstrate rather impressive positive anomalies in mortality. We noted that, in general, these air masses are rather meteorologically stable, with poorer vertical atmospheric ventilation than the other air masses. This was confirmed when we evaluated pollution concentration for these air masses, and noted that they are generally the most polluted of the all the atmospheric situations in Seoul (Tables 8a and 8b).

	Total n		SO2 (PPB)			PM 10 (uG/M3)		
			Myeonmok	Seongsu	Yongdu	Myeonmok	Seongsu	Yongdu
	152	Dec	10	7	10	73	85	75
DM	138	January	11	8	11	83	94	82
	153	February	10	7	9	85	95	87
	155	Dec	7	5	7	55	64	53
DP	170	January	9	6	8	57	66	52
	144	February	8	5	7	60	59	52
	52	Dec	6	4	5	48	54	47
DP+	58	January	7	4	5	51	54	45
	29	February	6	4	5	48	45	34
DT	2	February	13	9	15	93	108	132
	27	Dec	10	7	10	88	95	89
MM	28	January	11	7	11	96	95	100
	44	February	8	7	8	83	91	84
	29	Dec	9	6	8	66	64	61
MP	35	January	9	6	8	71	80	74
	12	February	7	5	6	70	74	71
MT	4	January	2	2		46	66	
	49	Dec	8	5	7	52	65	55
TR	32	January	8	4	7	60	91	65
	36	February	8	6	8	68	79	72

Table 8a. SO_2 and PM10 mean monthly concentrations in Seoul. Red numbers represent highest values among the air masses, excluding the very small DT sample size.

	O3 (PPM)			NO2 (PPB)			CO (PPM)		
	Myeonmok	Seongsu	Yongdu	Myeonmok	Seongsu	Yongdu	Myeonmok	Seongsu	Yongdu
	0.005	0.005	0.005	51	44	50	1.0	0.9	1.3
DM	0.007	0.005	0.008	57	46	55	1.3	0.9	1.3
	0.011	0.007	0.011	54	49	52	1.1	0.8	1.1
	0.010	0.007	0.010	41	37	37	0.8	0.6	0.8
DP	0.010	0.008	0.012	45	35	40	0.9	0.6	0.9
	0.013	0.012	0.017	41	35	37	0.8	0.5	0.6
	0.011	0.014	0.015	29	25	23	0.5	0.4	0.5
DP+	0.014	0.011	0.018	30	28	29	0.9	0.5	0.7
	0.017	0.019	0.022	31	27	24	0.6	0.4	0.5
DT	0.005	0.003	0.006	75	66	74	1.3	1.3	1.0
	0.005	0.004	0.004	48	43	48	1.0	0.9	1.2
MM	0.005	0.004	0.004	54	41	55	1.1	0.9	1.4
	0.009	0.008	0.008	48	43	49	1.3	0.7	1.1
	0.007	0.006	0.007	40	34	38	0.9	0.7	0.9
MP	0.009	0.005	0.009	45	40	45	1.3	0.8	1.0
	0.011	0.014	0.016	46	36	36	0.7	0.5	0.9
MT	0.023	0.004		36	25		0.1	0.8	
	0.008	0.007	0.010	40	34	35	0.7	0.6	0.8
TR	0.014	0.008	0.014	44	29	36	1.0	0.5	0.7
	0.014	0.015	0.017	41	38	38	0.7	0.6	0.7

Table 8b. O_3, NO_2, and CO mean monthly concentrations in Seoul. Red numbers represent highest values among the air masses, excluding the very small DT sample size.

With the exception of ozone (O_3), which is a photochemical air pollutant and is most concentrated during a cloudless, highly transparent atmosphere day, the most polluted air masses are consistently the MM and DM air masses. MM generally demonstrates the highest particulate (PM10) concentration, while DM is dominant within all the other pollutant categories, particularly SO_2, NO_2, and CO. When evaluating consecutive days of the DM air mass, it appears that there is a general propensity for pollution concentration to increase as the number of consecutive days increases (Table 9; for PM10). Although the trend is not perfect, in the majority of the cases the cleanest conditions occur on the first day of this air mass and deteriorate after at least a few consecutive days. This coincides with the increase in mortality during consecutive day runs of DM and MM air. Thus, this suggests that the high mortality anomalies associated with these two air masses are probably attributed to the poor air quality, which is evidently more important in winter in Seoul than the thermal qualities of the air mass.

	By DM Day In Sequence	Myeonmok	Seongsu	Yongdu
Dec	1	69	78	71
	2	77	93	82
	3	82	104	89
	4	79	93	80
	5	69	75	66
	6	75	90	77
	1	77	85	74
Jan	2	82	95	88
	3	98	117	94
	4	88	103	88
	5	81	102	70
	6	115	97	86
	1	77	90	80
Feb	2	86	92	86
	3	98	105	107
	4	95	109	100
	5	78	90	83
	6	139	131	157

Table 9. The impact of consecutive days of DM air on the concentration of PM10 (uG/M3). Green numbers indicate the smallest concentrations; red numbers indicate the largest.

COLD WEATHER EVALUATION: BUSAN RESULTS

The results from Busan differed somewhat from what we uncovered in Seoul. One point of similarity was the lack of response between cold weather and elevated mortality on either a one day or seven day level (Table 10); it is clear that there is no dramatic response at all. DaeGeun Lee, who is a long-time resident of Busan, confirms that there has been no important cold spell in the comparatively mild city for at least the past 25 years, which might partially explain the weakness of the cold/mortality relationship. That may very well be the reason, but even after looking at the coldest days in Busan, we see no evidence of persistent elevated mortality.

	DP			DP+			MP		
	1-day	7-day	n	1-day	7-day	n	1-day	7-day	n
Dec	0.4	0.6	96	-0.3	1.1	14	0.1	1.7	3
Jan	-0.7	0.0	141	-3.7	-0.8	8	1.4	-0.3	8
Feb	-1.1	0.0	100	1.5	0.0	6	-0.5	0.3	13

Table 10. Mortality response in Busan on the day of each of the three cold air masses (1-day), and for a seven day period extending from the date of the air mass (7-day). "n" refers to the daily sample size.

We then considered the possibility that other air masses, such as DM and/or MM, might be contributing to higher winter mortality in Busan, just as they had in Seoul (Table 11). This might suggest a pollution connection which we strongly suspect is leading to higher winter mortality in Seoul. An evaluation of Busan's other air masses and the relationship with mortality suggest that this is a possibility in Busan (Table 12). There are some weak relationships in December and January for the MM air mass, and a

	TR			DM			MM			MT		
	1-day	7-day	n	1-day	7-day	n	1-day	7-day	n	1-day	7-day	n
Dec	-1.7	-0.9	59	0.1	0.0	245	0.4	0.5	44	6.8	1.8	4
Jan	0.6	0.1	54	-0.4	-0.2	177	1.3	0.3	75	-2.5	-2.8	2
Feb	2.3	0.4	32	0.3	0.6	208	-0.1	-0.5	53	5.4	-1.4	12

Table 11. Mortality response in Busan on the day of other air masses (1-day), and for a seven day period extending from the date of the air mass (7-day). "n" refers to the daily sample size.

weak correspondence in February with the rapidly-changing TR air mass, and a somewhat stronger correspondence for December and February in the MT air mass (however, MT has a low sample size).

We then decided to sort out the very highest anomalous mortality days for December, January, and February in Busan to see if certain air masses stood out as more frequent. These results did uncover some interesting surprises. Among the 10 highest winter mortality days in Busan, 4 were MT, and they were all ranked in the top 7 days. The other 6 were split evenly between MM and DM, with none of the cold air masses appearing at all. MT only occurs on average 1.8 percent of all winter days in Busan, so its presence on 40 percent in the top 10 days is 20 times more frequent as one might expect. This is clearly a statistically significant result. MM was also highly represented, as it occurs on average 11 percent of all winter days. Thus the 30 percent appearance of MM in the top 10 mortality days is almost 3 times what might be typically expected. DM is a frequent air mass in Busan, occurring on average 45 percent of winter days, so its appearance in the top 10 is not a surprise.

The result for the top 25 mortality days in Busan was also of interest. MT appeared on 9 of these days, a 36 percent frequency. This is exactly 20 times more frequent than we might expect based upon typical winter frequencies of MT air in Busan. The other air masses, including MM, were more in line with their typical frequencies, with the exception of DP, which only occurred once in the top 25 mortality days in Busan (DP+ or MP did not occur at all). DP has a typical frequency of 27 percent during the three winter months in Busan, so its 4 percent appearance in the top 25 days is less than 1/6 of what might be randomly expected. Even when the evaluation is extended to the top 100 mortality days in Busan, 28 of those days are classified as MT, almost 16 times greater than might be expected! And DP is sorely underrepresented in those top 100 days, with only 8 presences, which is less than 1/3 of its expected frequency under random chance.

So the question arises: Why is MT so well-represented in the top mortality days in Busan? Is it possibly more polluted, much like DM and MM are in Seoul? We do not have pollution data at present for Busan, so we are not certain if this is the case. However, on the few days in winter when MT occurs in Seoul (only 0.7 percent of all days!), it was not highly polluted. MT is more frequent in Busan than in Seoul by a factor of over 3, so possibly a pollution evaluation for the MT air mass is in order for Busan.

COLD WEATHER EVALUATION: INCHEON AND DAEJEON

It was jointly decided to evaluate two more cities with more inland or northerly locations in the country: Incheon and Daejeon. We assumed that Incheon might have a similar response as Seoul, and Daejeon might be unique because of its position in the middle of Korea.

The Incheon results did have some similarity to Seoul (Table 12). Once again, the coldest air masses had, at best, modest relationships with positively anomalous mortality, with some small relationships appearing for MP, and possibly as well for DP+ in December and February. Since the average number of winter daily deaths in Incheon is about 25, these positive numbers ranged from about 2-5 percent increases above the baseline. Consecutive day evaluations for these air masses showed some slightly positive results for three consecutive days of DP+ and longer consecutive day strings for DP (Table 13).

	DP			DP+			MP		
	1-day	7-day	n	1-day	7-day	n	1-day	7-day	n
Dec	-0.1	0.0	130	0.8	0.7	40	-1.2	-0.2	26
Jan	-0.5	-0.1	146	-1.4	-0.1	50	0.5	0.3	41
Feb	-0.3	0.3	136	2.1	0.2	25	1.2	0.9	22

Table 12. Mortality response in Incheon on the day of each of the three cold air masses (1-day), and for a seven day period extending from the date of the air mass (7-day). "n" refers to the daily sample size.

	Day 1			Day 2			Day 3+		
	1-day	7-day	n	1-day	7-day	n	1-day	7-day	n
Dec	1.0	0.0	23	-3.3	1.1	6	2.6	2.5	8
Jan	-1.4	-0.2	29	-3.1	0.8	10	5.8	2.1	2
Feb	2.2	0.4	18	-0.5	-0.9	5			

	Day 3			Day 4			Day 5			Day 6			Day 7+		
	1-day	7-day	n	1-day	7-day	n	1-day	7-day	n	1-day	7-day	n	1-day	7-day	n
Dec	1.4	0.3	18	0.8	0.1	14	-2.0	0.4	9	-0.9	-0.3	8	1.5	0.4	14
Jan	-0.5	0.2	25	-0.7	0.2	19	2.8	1.6	10	-0.3	0.8	5	1.3	0.3	12
Feb	-3.3	-0.4	24	-1.6	0.4	11	1.8	0.7	7	1.7	1.4	3	0.8	0.5	18

Table 13. Consecutive day results for Incheon DP+ (top) and DP (bottom).

The DP+ sample sizes are small, but the results are the most impressive thus far for the coldest air mass: between an 8 to 20 plus percent increase above baseline rates. For DP, the results are less impressive, although for 7+ consecutive day runs there are some modest to moderate increases.

For the other air masses in Incheon, the results are rather bland (Table 14). There are slightly positive responses for DM air masses, but these are all 2 percent or less above the baseline.

	TR			DM			MM			MT		
	1-day	7-day	n	1-day	7-day	n	1-day	7-day	n	1-day	7-day	n
Dec	-0.3	-0.2	78	0.5	0.1	141	-0.6	-0.4	50			
Jan	1.5	0.6	54	0.2	0.2	124	0.5	-0.8	48	-1.9	-0.3	2
Feb	-1.1	0.0	43	0.3	0.0	127	-0.5	-1.0	69	1.8	-0.2	1

Table 14. Mortality response in Incheon on the day of other air masses (1-day), and for a seven day period extending from the date of the air mass (7-day). "n" refers to the daily sample size.

An evaluation of the top 25, 50, and 100 mortality days in Incheon showed nothing remarkable. These were dominated by DP and DM air mass days, but they are, by far, the most frequent air masses in Incheon during the winter. A sort by temperature and dewpoint also did not yield anything of note. Thus, it appears that there is some consecutive day response between the cold air masses of DP and DP+ for Incheon, but we don't know if there is enough here as a basis for a cold warning system for the city.

Daejeon is a smaller city with a daily average number of deaths somewhere between 15-20 in the winter. Some days had as few as 6 or 7 deaths, so the city is less than half the population of Incheon. As has been the case with the other locales, the results were not very impressive (Table 15). For the three

	DP			DP+			MP		
	1-day	7-day	n	1-day	7-day	n	1-day	7-day	n
Dec	0.2	0.0	128	-0.9	-0.3	31	0.0	0.1	47
Jan	0.5	0.1	141	-1.4	-0.2	20	-0.4	0.1	43
Feb	-0.2	0.1	97	1.0	-0.3	12	0.5	1.4	6

Table 15. Mortality response in Daejeon on the day of each of the three cold air masses (1-day), and for a seven day period extending from the date of the air mass (7-day). "n" refers to the daily sample size.

coldest air masses, there were some modestly positive results for DP in January and MP in February. The coldest air mass, DP+, showed somewhat counterintuitive results. The other air masses were also not impressive (Table 16), with none of them demonstrating anomalously positive results, even DM.

	TR			DM			MM			MT		
	1-day	7-day	n	1-day	7-day	n	1-day	7-day	n	1-day	7-day	n
Dec	0.1	-0.1	49	0.0	0.0	190	-0.1	0.2	18	-0.5	2.1	1
Jan	-0.4	-0.2	59	0.0	0.0	168	0.2	-0.2	32	-1.6	0.3	2
Feb	-0.8	0.2	64	0.2	0.0	202	0.4	-0.7	37	-1.5	-2.2	2

Table 16. Mortality response in Daejeon on the day of other air masses (1-day), and for a seven day period extending from the date of the air mass (7-day). "n" refers to the daily sample size.

There were some slightly positive results for long consecutive day runs of DP and DP+ air masses (Table 17), but these were not dramatic, and probably not large enough to be the basis of a cold weather warning system.

	Day 3			Day 4			Day 5			Day 6			Day 7		
	1-day	7-day	n	1-day	7-day	n	1-day	7-day	n	1-day	7-day	n	1-day	7-day	n
Dec	0.3	0.3	20	0.2	0.6	12	0.8	0.1	9	0.9	0.0	8	-0.6	0.2	8
Jan	0.3	0.0	22	-0.5	0.2	11	-1.4	0.8	8	2.6	0.9	7	-0.4	0.6	12
Feb	0.0	0.2	16	-1.9	0.7	4	2.5	0.5	2	0.0	0.3	2	1.3	0.1	8

Table 17. Consecutive day runs of DP and DP+ combined for Daejeon.

Sorts by anomalous mortality, 0300 and 1500 temperature, and dewpoint did not reveal any unusual findings. DM and DP air masses did dominate the top mortality days, but these air masses are, by far, the most frequent in Daejeon in winter. When subdividing each air mass by temperature, again nothing emerged that was outstanding. Even the coldest days were not necessarily associated with the highest anomalous mortality totals.

The conclusion of this work will include two other action items. First, we will subdivide the mortality data by age (developing a separate evaluation for the 65 and older age group), to see if the more vulnerable portion of the population is more susceptible to excessive cold. Then we will evaluate separately two causes of death that are known to be commonly associated with excessive heat events: circulatory and respiratory illnesses. It is possible that the results will be more robust when we remove portions of the mortality data that are traditionally less correlated with cold-related causes.

RECOMMENDATIONS AND CONCLUSIONS

The following represents a summary of findings for the research performed in year four.

- We divided Seoul into five regions to develop a more detailed heat/health warning system network for the city.

- Algorithms were developed for each of the regions, although in one region (2) we had difficulty developing a statistically significant algorithm, and in another region (6) one of the key independent variables proved counterintuitive.

- Thresholds were developed for all the regions to designate advisory (less severe) and warning (more severe) conditions.

- Looking at heat event data for 2009 and 2010, there was good correspondence in when advisories and warnings would have been called among all the regions. There were discrepancies, but this is desirable since there are clearly times when a warning should be called in one region but not in another.

- The Seoul system represents our first subdivided urban area HHWS worldwide, and should prove to be the prototype for other subdivided systems in major cities around the world.

- The relationship between cold air masses and mortality was determined for four cities in Korea. The results were not as robust as we expected, nor were they as clear-cut as we have found in other cities.

- In Seoul, two mild air masses, MM and DM, proved to demonstrate the most positive relationships with anomalous winter mortality, while the coldest air masses, DP, DP+, and MP, showed very little relationship. Consecutive days of DM air masses increased the likelihood of positive mortality anomalies in statistically significant fashion.

- A pollution evaluation of the air masses indicated that in winter in Seoul, MM and DM have the poorest air quality of any of the air masses. We suggest that the increased winter mortality associated with these air masses is at least partially attributed to the air quality problem.
- For Busan, cold air masses also had little impact on daily winter mortality, similar to the result we discovered in Seoul. However, unlike Seoul, DM and MM air masses demonstrated only modest increases in mortality. The one air mass in Busan that was associated with significant increases in mortality was the warm, humid MT air mass. Although it occurs on less than 2 percent of days in an average winter, it was prominent in the top 25 mortality days, occurring on 36 percent of these.
- Even in the top 100 mortality days in Busan during winter, the MT air mass occurred on 28 percent of these days, 16 times the expected appearance of this air mass based on chance. It is important to determine why MT air plays such an important role during the highest winter mortality days in Busan. At present, we do not possess air quality data for Busan, so we can't determine if this is a possible cause.
- Incheon mortality responded to cold weather in a similar manner to Seoul, with the cold air masses seemingly having a limited impact. However, there were some slight elevations in mortality during long consecutive day episodes of DP and DP+ air masses.
- DM showed some increase in mortality in Incheon, but not to the extent that we found in Seoul.
- Results for Daejeon were weak, and no air mass demonstrated any marked increases in mortality. Sorts based upon temperature and dewpoint also demonstrated no real relationships and the consecutive day evaluation of cold air masses was not meaningful.

There are some thought-provoking results that were uncovered in our year four investigations. We have concluded that the subdivision of the Seoul HHWS was generally successful, and offers a better solution than the single area-wide system. We may want to abandon the algorithm for region 5 and develop a descrete estimate for DT and MT+ air instead, much like we did in region 2. This should be discussed.

As for the winter results, key questions remain:

1. Why are urban Koreans not particularly vulnerable to excessive cold weather? Is it possible that most people remain indoors during the coldest and most inclement weather and are not subject to the intensity of the atmospheric condition? Why is this result different from those we uncovered for North American cities in winter?

2. What does the DM/MM mortality link in Seoul indicate? Circumstantial evidence implicates poor air quality, and if this is the case, should we develop a winter air quality system for Seoul? DM mortality numbers become particularly high after several consecutive days, and pollution levels within this air mass show an upward trend during consecutive day strings. Does this not strongly implicate high atmospheric pollution in winter as a major health problem?

3. Why did we uncover a robust MT/winter mortality relationship for Busan? We do not have the air quality data at present to see if MT is a polluted air mass in Busan's unique climate. If not pollution, what else could be contributing to this anomaly?

4. Will the age and cause of death subdivisions lead us to improved and more intuitive winter results? That will be determined in short order.

These intriguing questions that arise from our winter analysis all warrant further consideration and possibly more detailed investigation. However, it is our strong opinion that cold weather/health warning systems do not appear to be feasible for major Korean cities, at least systems that are based upon acute daily (or seven day) mortality totals. The use of raw temperature or other meteorological data do nothing to improve the results, and the use of a synoptic methodology turned up certain very interesting relationships that would not have been uncovered using raw data alone. We look forward to determining the impact of weather on the mortality subdivisions and will provide an addendum to this report upon the completion of that work.

ADDENDUM

At least four presentations will be delivered in Auckland, New Zealand at the International Congress of Biometeorology in early December, 2011 that are based upon this work or upcoming projects. Colleagues from NIMR will be delivering three presentations which are co-authored by all of us, two posters on HHWS operation and validation, and one oral presentation on the Seoul HHWS subdivision. We will also be collaborating on an oral presentation that we have developed relating to our multi-year climate change project that will commence in 2012. The PowerPoint presentations are available upon request.