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INTRODUCTION

Interest in the impact of weather on human health has increased dramatically in recent years, both due to notable tragic events - such as the 1995 US heat wave which caused over 500 heat-related deaths in Chicago alone - and the prospect of increased frequency of such events in a changed climate (IPCC 1995). There is much evidence to support the role of weather conditions, especially excessive heat, in increasing morbidity and mortality in urban areas (Pennsylvania Emergency Management Council 1994).

Still, in much of the world, especially in developing countries, no watch-warning systems exist. In those places with operational systems, coordination between the entity that issues the warning and the health agency that directs mitigating intervention is not optimal (Kalkstein et al. 1996). Furthermore, mitigation effects in numerous locations are also inadequate, as many cities do not have adequate plans to deal with oppressive conditions (NOAA 1995).

Another problem with most current watch-warning systems is the choice of meteorological parameters on which to base a warning. Most systems rely on a single, arbitrarily-chosen weather element: either temperature or a "heat index", which is a function of temperature and relative humidity. Thus, it is implied that people respond solely to one or two meteorological variables. Numerous studies, however, have demonstrated the importance of other variables. For instance, cloud cover has been shown to be a statistically significant predictor of elevated human mortality during hot weather, as the extra solar energy from cloudless conditions substantially increases the heat load on buildings (Kalkstein and Davis 1989). Also, wind speed is a desiccating factor and adds heat load to the body when temperatures are excessive (Steadman 1979). Many watch-warning systems account for neither the negative impact of several consecutive days of oppressive weather, nor the fact that heat waves earlier in the warm season create more of a health danger than those later in the season (Kalkstein 1993). In many cases, the temperature or heat index threshold used to develop a watch or warning has no proven relation to morbidity and mortality. In the US, the threshold is not even regionalized to accommodate the sensitivity of the local population; the same 41°C heat index threshold used by the National Weather Service is applied equally in Boston and Dallas (Kalkstein and Valimont 1986).

People respond to the total effect of all weather variables interacting simultaneously on the body, rather than to individual meteorological elements. Therefore, it is advantageous to evaluate weather-health relationships via a holistic weather parameter: the *air mass*. Particularly "oppressive" air masses, which adversely affect human health, can be identified. Indeed, numerous studies have shown a clear relationship between certain oppressive air masses and human morbidity and mortality (e.g., Kalkstein and Greene 1997). Kalkstein (1991) found that one particular summer air mass in Saint Louis, Missouri, while relatively uncommon overall, possessed the highest mean mortality and occurred on many of the highest mortality days. As not all days within this air mass were associated with high mortality totals, it was possible to determine which meteorological as well as non-meteorological (e.g., consecutive day sequence, within-season timing) parameters were associated with the highest mortality.

How an urban area is affected by oppressive weather depends on several factors, including city location, heat island magnitude, and housing conditions. Cities in the middle latitudes, where oppressive air masses occur irregularly, demonstrate the strongest weather-mortality relationships. Regions where oppressive air masses are more common and behavioral and physiological acclimatization may occur show a smaller response. Especially in inner cities, housing type may play a role. Cities with older structures, typically multi-family, brick dwellings with poor ventilation and a high heat load, are especially at risk. One can easily understand how over 500 people perished in the 1995 Chicago heat wave (Kalkstein 1995). It is these cities especially that require the establishment of a weather-health watch/warning system, to permit city health departments to take mitigating action and to alert the public that dangerous weather is predicted.

The Center for Climatic Research at the University of Delaware has played a significant role in the development of health watch warning systems. This paper provides an overview of the work involved and relevant projects. The basics of the synoptic classification system development are described first. The Philadelphia Hot Weather-Health Watch/Warning System (PWWS), the first synoptic-based health watch-warning system to be fully implemented (in 1995) is outlined next. Both the framework of the system and the outreach are described. Plans for worldwide expansion of this system, under the guidance of the World Meteorological Organization and other agencies, are detailed. Concluding the paper is a brief description of the increased urgency of such systems in a future world of changed climate.

SYSTEM DEVELOPMENT

Meteorological data and air mass category development

The initial stage in watch-warning system development is the creation of an air mass-based climatological index to categorize days, based on its meteorological character, into groups that are relatively homogeneous. Six readily available weather elements are included: air temperature, dew point temperature, total cloud cover, sea level pressure, wind speed, and wind direction. Observations four times daily, at 01 h, 07 h, 13 h, and 19 h, local standard time are used; these 24 variables form the basis of categorization.

The temporal synoptic index (TSI; for a more detailed description, see Kalkstein et al. 1987), one of a family of *principal components analysis - clustering analysis* methods (Yarnal 1993) to develop a synoptic index, performs the categorization. In the first half of this procedure, non-rotated principal components analysis (PCA) effectively performs a reduction of variables (Daultrey 1976). PCA takes the initial 24-variable matrix, and creates new variables, all of which are orthogonal, or linearly independent. A small subset of these new variables can be chosen to explain the majority of the original data set's variability. In addition to reducing the overall number of calculations, this method also eliminates collinearity, a common problem to many meteorological data sets. Each day thus has a smaller number of "new" variables describing it. In the second stage of the TSI, average linkage clustering groups the days together; days with similar meteorological characteristics have similar values of the new variables. Once the clustering is complete, mean meteorological conditions of all days in each air mass group are assessed.

Mortality data

After the daily air mass classification, comparisons are made with available mortality data. For the PWWS, 17 years of mortality data (all available years between 1964 and 1988) for the entire Philadelphia Standard Metropolitan Statistical Area, are used. A tabulation of total deaths for each calendar day is made for the entire record. While cause of death is sometimes available, this is not included in the system, as there is considerable examiner-to-examiner variability in what causes a heat-related death.

All mortality data are first adjusted to account for a region's overall population change; this is accomplished by fitting a mortality trendline to the record. Mortality is then expressed as the deviation of a particular day from this temporal baseline value (Kalkstein 1991).

Relationship between air mass categories and mortality

The mean and standard deviation of mortality for each air mass category is determined to assess whether any particular categories exhibit distinctively high or low mortality rates. Potential lag times are accounted for by evaluating the daily air mass category on the day of the deaths, as well as one, two, and three days prior. The days of extremely high and low mortality are isolated, to determine whether certain categories prevail on extreme days. In many cities for which analyses have been performed, it is apparent that one or two "oppressive" air masses possess a much higher mean mortality than others; these air masses in general are also present on the majority of extremely high mortality days (Kalkstein 1991). For the Philadelphia system, results are listed in Table 1. The one air mass associated with high mortality, category 3, is characterized by very high afternoon temperature, high dew point, and party cloudy conditions. The highest mortality is found with no lag time.

Those air masses exhibiting mortality well-above the mean also possess a large standard deviation of mortality. Thus, not all days with these air masses possess elevated mortality totals. To account for this, a secondary step is undertaken to determine which days within the air mass are likely to contain elevated mortality totals. Stepwise multiple regression analysis is used to analyze which factors of the oppressive air mass are most related to mortality totals. For Philadelphia Air Mass 3, for example, the following three variables were identified:

- the number of consecutive days the air mass has been present;
- maximum temperature; and
- time of season (whether or not the air mass occurs early or late in the warm season).

The algorithm created from this last regression model is what is used to estimate mortality totals for a given day.

SYSTEM IMPLEMENTATION - THE PHILADELPHIA HOT WEATHER-HEALTH WARCH/WARNING SYSTEM (PWWS)

System procedure

The air mass-based Philadelphia Hot Weather-Health Watch/Warning System (PWWS), implemented in 1995, displaced the previous system, which was similar to that used in many US cities: health warnings were issued by the Philadelphia Health Commissioner if the local National Weather Service (NWS) office issued an excessive heat warning based on an elevated heat index.

Model forecast data from the Nested Grid Model (NGM), issued by National Center of Environmental Prediction (NCEP), contains the necessary meteorological variables to predict the arrival or persistence of an oppressive air mass up to two days in advance. As the air mass categories and their respective mean character have already been determined by the TSI, classification of a new day into the predetermined categories requires a new statistical procedure: discriminant analysis (Klecka 1980). Discriminant analysis is similar to the use of multiple regression; for each air mass type a discriminant function is developed based on the means of the 24 variables. For each forecast day, a discriminant score is calculated for each of the air mass categories. The day is classified into the category possessing the highest score, which represents the most similar situation.

The accuracy of the forecast data, and the performance of the discriminant analysis, are verified by "backcasting", in which archived model forecasts are used as predictors. The same procedure outlined above is used; for the summer of 1988, the 24-h forecast identifies 89 percent of oppressive days; the 48-h forecast identifies 71 percent. This latter reduction reflects more on the limitations of model forecasting than on the backcasting technique.

Three tiers of forecast are issued: a *health watch*, a *health alert*, and a *health warning*. The system is coordinated with the local Philadelphia region NWS office in Mount Holly, New Jersey, who now run the index. After consultation with the Center for Climatic Research and the NWS office, the health commissioner makes the final decision on the issuance of health advisories.

The framework of the PWWS is depicted in Figure 1. The system is initiated with analysis of the model output; air mass category is predicted for the current day and the subsequent two. If the procedure forecasts the arrival of an oppressive air mass for Day 3 (48 h from time of forecast), a *health watch* is issued by the health commissioner. If the oppressive air mass is forecast for Day 2, the health commissioner issues a *health alert* 24 h in advance.

As mentioned above, not all days in an oppressive air mass category are associated with elevated mortality. Therefore, the next level of this system - the *health warning*, issued for Day 1 (either the morning of or the afternoon before an oppressive air mass day) - involves identification of those days predicted to be associated with high daily mortality. This is accomplished by the use of the algorithm described above. A health warning is issued *only* if elevated mortality is predicted by the algorithm. In addition, the local NWS office must agree to issue an excessive heat warning. Depending on the number of excess deaths predicted, one of three levels of health warning is issued. For Philadelphia, there is an issuance of

- a level-one warning when one to four excess deaths are predicted;
- a level-two warning when five to 14 deaths are predicted; and
- a level-three warning when 15 or more deaths are predicted.

Intervention activities

The City of Philadelphia Department of Public Health and other agencies and organizations conduct a series of intervention activities, including:

- **Media announcements.** Television and radio stations and newspapers are informed of all declarations by the health commissioner and provided with information on how to avoid heat-related illnesses during oppressive weather. The media have been cooperative, supportive, and active, both in reporting PWWS declarations and in providing information useful to the general public, including features on other intervention activities.
- **Promotion of the "buddy" system.** Media announcements encourage friends, relatives, neighbors, and other volunteers to make daily visits to elderly persons during hot weather. The "buddies" make sure that the most susceptible individuals have sufficient fluids, proper ventilation, and other amenities to cope with a heat wave.
- **Activation of "Heatline".** "Heatline", a hotline operated in conjunction with the Philadelphia Corporation for the Aging, is activated whenever a warning is issued, to provide information and counseling to the general public on avoidance from heat stress. The Heatline phone number is publicized by the media and by a large display seen over much of Center City Philadelphia.
- **Home visits.** Department of Health field teams make home visits to persons requiring more attention than can be provided over the hotline, but still not those requiring emergency intervention.
- **Nursing- and personal care boarding- home intervention.** When a warning is issued, the Department of Public Health contacts these facilities to inform them of a high-risk heat situation, and to offer advice on the protection of residents. In addition, during warning periods, field teams make inspection visits to those homes to ensure adequate hot weather care for residents.
- **Halt of utility service suspensions.** The local electric company and water department halt service suspensions during warning periods.

- **Increased medical emergency staffing.** The Fire Department Emergency Medical Service utilizes the PWWS declarations to schedule increased staffing in anticipation of increased service demand.

- **Daytime outreach to the homeless.** The agency for homeless services activates intensive daytime outreach activities to assist the homeless on the street.

- **Air-conditioned service facility capability.** Senior centers extend their hours of operation to evenings and weekends during warning periods. In addition, the Department of Public Health has the capability to more persons at high risk out of dangerous living situations, and into an air-conditioned facility.

FUTURE IMPLEMENTATION

The need has been recognized for an increased effort to mitigate climate-related mortality worldwide. The World Meteorological Organization (WMO) Commission on Climatology, working with the Center for Climatic Research and members of the International Society of Biometeorology, have developed an agenda for a Showcase Study, creating and implementing systems similar to the PWWS outlined above. The goals of this project are to develop several weather - health watch/warning systems for cities in the developed and developing world using procedures that emphasize climate - health outcomes, and based on guidance from these systems, to assist in the implementation and intervention of mitigation methodologies.

The first stage in development is the identification of the initial target cities most suitable for index development. Several considerations must be addressed. First, cities for which an index is most useful are those whose climate features irregular, intense heat waves. Model forecast data must be available for the city, and archived meteorological data (as described above) must be available. In addition, the city must be large (more than one million persons), in order to provide a large sample size for the mortality data. Mortality data must be available for at least a 10-year period; population statistics over the same period need to be present as well. Last, there must be expressed interest and cooperation of local health and meteorological authorities.

It has recently been decided that three cities from the following list would be selected: Athens, Madrid, Rome, Calcutta, Delhi, Shanghai, Singapore, Cairo, Mexico City, Melbourne, Sydney.

Following city selection, the data acquisition and system development, similar to that outlined above, will take place at the Center for Climatic Research. At the same time, an assessment of each city's health agencies and other local organizations will occur. Determination of optimal cooperation strategies, of a scope similar to those outlined above for Philadelphia, will be made. Once the development and assessment are complete, implementation can take place. The technology will be transferred to local authorities for operation; initial target commencement date is the local warm season of 1999. After the system has been in place, evaluation will then occur to see if the system is indeed saving lives.

CONCLUSION

The Philadelphia Department of Public Health has assessed the impact of the PWWS, and has suggested that numerous lives have been saved by its implementation. Thus, it seems feasible that similar systems should be developed on a national, and even international, scale. Although system design can vary, all hot weather/health systems should have two attributes in common. First, the systems should be relative - they should be tailored to each particular urban area. Our research has strongly suggested that responses to heat vary considerably on a regional scale. Conditions conducive to health problems are very different in Cairo than they are in Paris. Thus, system parameters must match the population response within each area, requiring studies that relate heat-related death and illness to weather at each individual site. Second, the system should be based on a health outcome, rather than some arbitrary meteorological variable. The definition of a "heat wave" from a health standpoint is the condition which produces stress on the population. The success of a synoptic methodology to define the mass of air which surrounds us is perfectly suited in this regard.

The scientific consensus indicates that the globe will likely warm over the next century. Thus, the frequency of days with conditions which might pose stress on the population will likely increase. This makes development of hot weather/health watch-warning systems more timely. For this reason, the World Meteorological Organization, the World Health Organization, and the United Nations Environment Programme are instituting projects to evaluate more precisely the impact of heat on human health. The University of Delaware will serve as a "collaborating center", and will provide the technology to develop watch/warning systems for vulnerable cities worldwide. Considering the success of the Philadelphia system, it behooves health officials in large urban areas to cooperate in the development of successful plans to lessen the number of heat-related deaths, one of the leading weather-related health problems in the world today.

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Table 1. Air mass categories and associated statistics, for Philadelphia. See text for details.

Cat. No.	Description	Frequency (percent)	13 h Temp. (°C)	13 h Dew Pt. (°C)	13 h Clouds (tenths)	Mean Daily Mortality	St. Dev. Daily Mortality
1	anticyclonic, mild	9.5	26	16	7	-4.4	10.4
2	cool, maritime	4.4	24	18	9	-2.6	11.5
3	maritime tropical, oppressive	11.5	32	21	4	+8.8	17.0
4	cyclonic, very humid	11.3	28	21	8	+1.6	12.5
5	maritime tropical, cloudy and humid	8.7	29	21	8	-1..9	12.7
6	cyclonic, cloudy and humid	7.0	30	20	6	+3.9	17.3
7	anticyclonic, warm and dry	6.2	30	18	3	+2.4	12.4
8	weak transitional	4.7	29	16	3	+0.1	12.1
9	modified continental	6.8	27	17	7	+0.0	12.0
10	anticyclonic continental, cool and dry	12.9	25	10	3	-4.1	12.8
11	transition to continental	6.2	24	11	5	-4.5	12.5