

Atmospheric Circulation Types and Daily Mortality in Athens, Greece

Pavlos Kassomenos,¹ Alexandros Gryparis,² Evangelia Samoli,² Klea Katsouyanni,² Spyros Lykoudis,¹ and Helena A. Flocas³

¹Laboratory of Meteorology, Department of Astrogeophysics, University of Ioannina, Ioannina, Greece; ²Department of Hygiene and Epidemiology, University of Athens, Athens, Greece; ³Laboratory of Meteorology, Department of Applied Physics, University of Athens, Athens, Greece

We investigated the short-term effects of synoptic and mesoscale atmospheric circulation types on mortality in Athens, Greece. The synoptic patterns in the lower troposphere were classified in 8 *a priori* defined categories. The mesoscale weather types were classified into 11 categories, using meteorologic parameters from the Athens area surface monitoring network; the daily number of deaths was available for 1987–1991. We applied generalized additive models (GAM), extending Poisson regression, using a LOESS smoother to control for the confounding effects of seasonal patterns. We adjusted for long-term trends, day of the week, ambient particle concentrations, and additional temperature effects. Both classifications, synoptic and mesoscale, explain the daily variation of mortality to a statistically significant degree. The highest daily mortality was observed on days characterized by southeasterly flow [increase 10%; 95% confidence interval (CI), 6.1–13.9% compared to the high–low pressure system], followed by zonal flow (5.8%; 95% CI, 1.8–10%). The high–low pressure system and the northwesterly flow are associated with the lowest mortality. The seasonal patterns are consistent with the annual pattern. For mesoscale categories, in the cold period the highest mortality is observed during days characterized by the easterly flow category (increase 9.4%; 95% CI, 1.0–18.5% compared to flow without the main component). In the warm period, the highest mortality occurs during the strong southerly flow category (8.5% increase; 95% CI, 2.0–15.4% compared again to flow without the main component). Adjusting for ambient particle levels leaves the estimated associations unchanged for the synoptic categories and slightly increases the effects of mesoscale categories. In conclusion, synoptic and mesoscale weather classification is a useful tool for studying the weather–health associations in a warm Mediterranean climate situation. **Key words:** Athens, human mortality, mesoscale classification, synoptic classification. *Environ Health Perspect* 109:591–596 (2001). [Online 7 June 2001] <http://ehpnet1.niehs.nih.gov/docs/2001/109p591-596kassomenos/abstract.html>

It has been known for a long time that there is an association between weather and mortality (1). The pattern of seasonality associated with mortality reflects medium- and short-term effects of weather, both direct and indirect. Thus, respiratory disease epidemics and other cold weather related events lead to increased winter mortality (2), and the same appears to be true for behavioral factors related to clothing and heating (3). In contrast, extremely high temperatures are related to sharp, short-term increases in mortality (4–6). The short-term association of weather parameters with mortality over the whole range of variation (i.e., on an annual basis) has been addressed by only a few studies and those have mainly focused on temperature. The dose–response curve has been examined and, in some instances, a changing point was identified above and below the point where mortality rates rose. The form of the temperature–mortality relationship has often been referred to as “J-shaped” because of the asymmetrical pattern of association with a rise in mortality counts that is steeper and shorter for high than for low temperatures. The temperature with the lowest observed mortality varied by geographic region. Thus, the minimum mortality rates occurred when the average daily temperature was around 16.5°C in

the Netherlands (7) and 22°C in Athens, Greece (8). Temperature and humidity (relative or dew point) have often been used to control the confounding effects of weather in studies of air pollution and mortality (9).

Bioclimatologists believe that only one or two weather variables, such as temperature and humidity, cannot fully account for the impact of climate and weather on biological organisms and systems or for controlling their confounding effects. Treating temperature and humidity as separate variables in multiple regression analyses with a health outcome as the dependent variable ignores the natural association between weather elements, the combined effect of which may have the most important influence on human health. A series of composite indices have therefore been developed such as human discomfort indices (10), heat budgets (11), and synoptic climatologic classifications (12). Synoptic weather systems are considered to play an important role on human health over a specific area through their controlling effect on local meteorologic conditions. Some investigators have tried to correlate the prevailing large-scale (synoptic) weather systems (systems extending over an area of at least 1,000,000 km²) with human health. More precisely, Kalkstein (12) proposed a synoptic

weather system classification based on air mass type, and used this to evaluate the impact of meteorologic conditions on human mortality. Pope and Kalkstein (13) and Samet et al. (14) estimated the association between particulate air pollution and daily mortality in Utah Valley, Utah, and Philadelphia, Pennsylvania, using the synoptic meteorologic approach to control for potential confounding weather effects, but the objective of these studies focused on air pollution and not on weather effects. None of the above researchers have tried to correlate medium range weather systems (mesoscale; i.e. systems that cover an area of at most 10,000 km²) with health.

The objective of this study was to investigate the short-term relationship between both large and mesoscale weather systems occurring in the lower troposphere and daily mortality in Athens. We examined the daily meteorologic conditions over Athens using both the synoptic and mesoscale atmospheric circulation classification schemes proposed by Kassomenos et al. (15,16) and studied their relationship with mortality data for the years 1987–1991 in Athens.

Methods

Study area. Athens is situated in a small peninsula located in the southeastern edge of the Greek mainland. It covers about 450 km² and has 3,600,000 inhabitants. The built-up area is mainly located in a basin surrounded by high and rather stony mountains on three sides and open to the sea from the south (17). There are small openings connecting the metropolitan area of Athens with the Greek mainland on the north, northwest, and northeast sides of the basin. In Athens, more than 1,500,000 cars are registered; industrial activities are mainly located in the west and southwest of the basin.

Meteorologic data. We obtained the synoptic charts for 00 and 12 Greenwich mean time covering the period 1983–1995 on a daily basis from the archives of the European Meteorological Bulletin. In the Metropolitan

Address correspondence to K. Katsouyanni, Department of Hygiene and Epidemiology, University of Athens, Medical School, 75 Mikras Asias Str, Athens 115 27, Greece. Telephone: 30-1-7470577. Fax: 30-1-7704225. E-mail: kkatsoug@cc.uoa.gr

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area of Athens, a monitoring network of seven surface meteorologic stations has been operating. Five of these stations are located inside the Athens basin, whereas the other two are on the eastern and western sides of it, in the nearby Mesogia and Thriassian plains, respectively. The primary meteorologic parameters that are recorded are wind speed and direction, air temperature, relative humidity, and cloudiness (16).

Synoptic classification. The classification of the large-scale atmospheric circulation patterns in the lower troposphere was carried out at the isobaric levels of 850 and 700 hPa (hPa; about 1,500–3,000 m above mean sea level); the isobaric level of 700 hPa was used as auxiliary. These isobaric levels characterize the large-scale atmospheric circulation over the examined area, independently of topographic effects (the mountain tops around Athens are lower than 1,500 m). Regarding the synoptic circulation patterns over Athens, we defined *a priori* eight categories according to the general circulation patterns, the position of the synoptic systems with respect to Athens, and the orientation of the trough or ridge axis. These *a priori*-determined categories were shown to be statistically distinct with respect to their thermodynamic characteristics. Details of the classification have been previously published (16), but a brief description is presented in Table 1. The frequency of occurrence of most of the above synoptic categories displays seasonality.

Classification of mesoscale weather types

The methodology applied for the classification of mesoscale categories, using meteorologic parameters from the surface monitoring network operated in the area, has been extensively discussed and analyzed (15). The mesoscale surface airflow in the Athens basin can be divided in 11 categories that are briefly described in Table 2. Not all mesoscale types appear during both winter and summer. Some are exclusive to the warm period, while others are exclusive to the cold. The cold period is from approximately November to April inclusive, and the rest of the year is considered warm. Details on the definitions of the warm and cold periods of the year were presented by Maheras (18) and Lykoudis et al. (19).

Mortality data. The number of daily deaths for the period 1 January 1987–30 December 1991 (a total of 1,826 days) was recorded from the Athens Town Registry and the registries of all 19 towns contiguous to Athens. In July 1987 in Athens, there was a 9-day heat wave characterized by maximum daily temperatures > 35°C (> 40°C on 6 days) and open anticyclone winds (OA; northwestern cold, dry winds). The total number of daily deaths during this month increased by more than 100%, and this

period was excluded from all further analyses as a climatic outlier. After this exclusion, the mean (\pm SD) daily deaths during the study period was 37.2 ± 8.0 .

Air quality data. Particulate air pollution is associated with health effects (8,9,13,14). To measure ambient particles in Athens, we used the method of black smoke (BS), a photometric index assessed on the basis of black particles with an aerodynamic diameter < 4.5 μ m.

The air pollution measurements were provided by the Monitoring Network operated by the Ministry of Environment, Planning and Public Works. BS was measured by the method of the Organisation for Economic Co-operation and Development (20). For completeness of the pollution time-series data, we used the average daily measurements of three stations (Patision, Aristotelous, and Piraeus) for BS (24-hr level in micrograms per cubic meter). These stations cover the study area and are representative of the population exposure (8). During this period, BS exceeded the World Health Organization air quality guideline (21) on 42% of the days in the center of Athens (Patision), where the highest levels were observed for all pollutants. Missing values in each station were completed as described by Katsouyanni et al. (22).

Statistical methods. We applied generalized additive models (GAM), extending Poisson regression to model the nonlinear effects of the covariates; we used a LOESS

smoother to control for seasonal patterns and long-term trends and allowed for over dispersion (23).

To determine the smoothing parameter (i.e., the fraction of the data used for smoothing), we used diagnostic tools including partial autocorrelation plots and plots of residuals over time. We had decided in advance that the smoothing window should not be < 2 months in order to avoid eliminating short-term patterns, which may actually be due to the exposure under study. After controlling for seasonal and long-term trends, we incorporated temperature into the model. We investigated smoothed functions of the same day and of lags up to 2 days or those averaged over 1–3 days of daily mean temperature. Temperature on the same day was always included. The inclusion of lagged temperature variables and the choice of smoothing parameters were based on minimizing Akaike's information criterion. We added dummy variables to the model to control for day of the week. Finally, we included dummy variables for the synoptic and mesoscale categories alternatively. Because of the seasonal patterns displayed, the analysis was conducted for the synoptic categories, both for the whole period and separately by season. For the mesoscale categories we conducted analysis only by season. Finally, BS concentration was included as a linear term (average of lags 0 and 1) in the model to adjust for the potential confounding effects of air pollution.

Table 1. Description of synoptic weather types in the Athens area.

Synoptic weather type	Weather conditions
Open cyclone (OC)	Northwestern cold, dry winds
Southwesterly flow (SW)	Humid and warm air from the sea
Northwesterly flow (NW)	Cooler winds during summer, cold during winter; low relative humidity
Zonal flow (ZN)	Weak westerly/southwesterly winds
Closed cyclone (CC)	Strong, dry winds from the north
Open anticyclone (OA)	Persistent weak flows, moderate-to-low relative humidity, and enhanced temperature
Closed anticyclone (CA)	Humid weak winds and temperature extremes
Combination between a high pressure system and a low pressure system (HL)	Moderate to strong northern or northeastern dry winds

Table 2. Description of mesoscale weather types in Athens.

Mesoscale weather type	Weather conditions
Westerly flow (a)	Winds of medium intensity, reduced humidity, and moderate temperature
Easterly flow (b)	Very low temperatures, rather weak winds, and snow
Strong northerly flow during the cold period (c1)	Strong and cold dry winds from the north
Weak northerly flow during the cold period (c2)	Moderate and cold dry winds from the north.
Strong northerly flow during the warm period (c3)	Strong and cool, almost dry, winds from the north
Weak northerly flow during the warm period (c4)	Moderate and cool, almost dry, winds from the north
Strong southerly flow (d1)	Increased temperature and moist air masses
Pure sea breeze (d2)	Increased relative humidity and winds of moderate strength from the south
Weak sea breeze (d3)	Increased relative humidity and weak winds from the south
Very weak southerly flow (d4)	Humid, very weak winds from the sea
Flow without main component (f)	Moderate temperature and humidity; very weak winds blowing from various directions.

Results

In Figures 1 and 2 we present the frequency of occurrence of synoptic and mesoscale categories by season over the study period. Several synoptic categories display a seasonal pattern: closed cyclone (CC), southwesterly flow (SW), and zonal flow (ZN) occur more often during winter; high–low pressure system (HL) occurs more often during summer; whereas northwesterly flow (NW), open anticyclone (OA), and open cyclone (OC) display limited seasonality and closed anticyclone (CA) is equally distributed between seasons. The mesoscale categories have a stronger seasonal pattern: categories b (easterly flow), c1–c2 (strong or weak northerly flow during cold period), and d4 (very weak southerly flow) are only defined during winter; c3–c4 (strong or weak northerly flow during warm period), d2 (pure sea breeze) and d3 (weak sea breeze) are only

defined during summer; and only f (flow without main component) and d1 (strong southerly flow) appear in both seasons.

Table 3 shows the frequency of occurrence, the mean daily number of deaths, and the average BS concentrations for each synoptic weather category by season. There are seasonal differences in mortality and BS levels as well as differences among the different synoptic categories. The category most often observed in both seasons is OA, an extended anticyclone covering the eastern Mediterranean, which is typical for the area of interest; other often observed categories are SW, CC, and OC in the winter and HL in the summer.

Table 4 shows the frequency of occurrence, the mean daily number of deaths, and the average BS concentrations for the mesoscale categories. The categories most

often observed are c1 and c2 in the cold season and c3 and c4 in the warm season. These categories are associated with a prevailing northern flow (strong or moderate), which is the wind flow most often observed in Athens. In winter, this is followed by the occurrence of f, whereas in the summer it is followed by d2 and d3.

Table 5 shows the cross-classification of synoptic and mesoscale categories. Although there is considerable association, there is also a degree of independence in the two classifications. This is probably due to the fact that a synoptic system is larger than a mesoscale and the projection of this system to smaller scales could lead to more than one mesoscale system.

Tables 6 and 7 show the relative risks for daily mortality for each synoptic weather category for the time period and separately by season. The smallest number of daily deaths after adjusting for season, long-term trends, temperature, and day of the week was observed during days with weather characterized by HL (reference category) and NW synoptic weather categories. The highest number of daily deaths was observed during days with SW [increase in the daily number of deaths 10%; 95% confidence interval (CI), 6.1–13.9%, compared to the reference], followed by ZN (increase 5.8%; 95% CI, 1.8–10%), OC (increase 5.3%; 95% CI, 1.7–9%), and finally CC, CA, and OA categories. In seasonal analysis during the cold period, a similar pattern was observed, with days characterized by the SW category displaying the highest mortality, followed by ZN, CC, and OA and days with HL displaying the lowest. During the warm period, days with HL and NW had the lowest mortality and days with SW the highest, but days with ZN did not display increased mortality, whereas days with OC do (increase 6.6%; 95% CI, 1.3–12.2%).

After adjusting for ambient particulate levels, the relative risks for some synoptic categories remained practically identical (SW, CC, and NW). For other categories there was some indication of confounding and the relative risks decreased slightly, but the same pattern was preserved (CA, ZN, OC, OA). In seasonal analysis, there is no confounding by pollution levels.

Table 8 presents the relative risks for daily mortality for the mesoscale categories for each season. The differences in mortality for mesoscale categories are not as evident as for synoptic categories. In the cold period the highest daily number of deaths was observed for days in category b (increase 9.4%; 95% CI, 1.0–18.5%), especially after adjusting for BS (increase 11.1%; 95% CI, 2.6–20.3%); this is followed by days in category d1 (the increase becomes greater and statistically

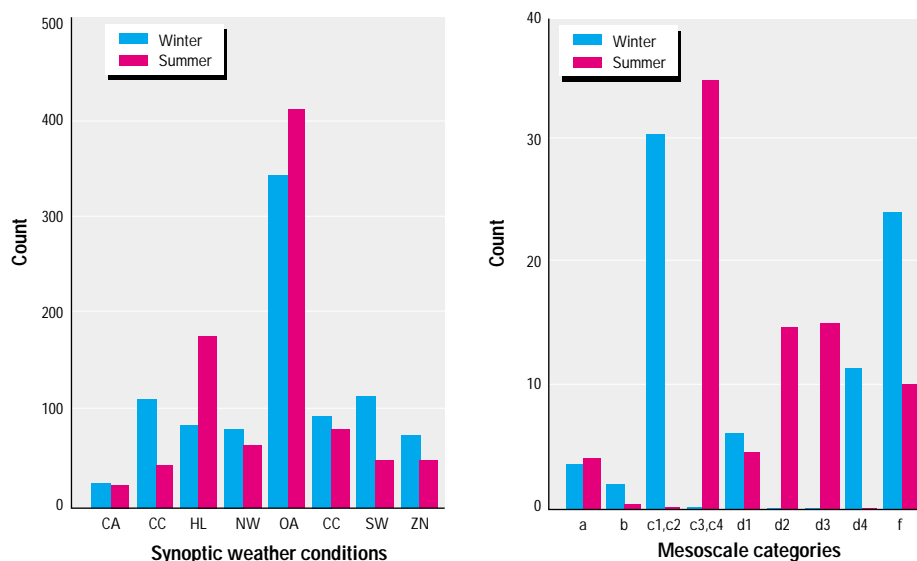


Figure 1. Occurrence of synoptic weather categories by season. Abbreviations: CA, closed anticyclone; CC, closed cyclone; HL, high–low pressure system; NW, northwesterly flow; OA, open anticyclone; OC, open cyclone; SW, southwesterly flow; ZN, zonal flow.

Figure 2. Occurrence of mesoscale weather categories by season. Abbreviations: a, westerly flow; b, easterly flow; c1, strong northerly flow during cold period; c2, weak northerly flow during cold period; c3, strong northerly flow during warm period; c4, weak northerly flow during warm period; d1, strong southerly flow; d2, pure sea breeze; d3, weak sea breeze; d4, very weak southerly flow; f, flow without main component.

Table 3. Daily total number of deaths and airborne particulate matter concentrations (as indicated by BS measurements) by synoptic weather categories and season.

Synoptic type	Winter			Summer		
	No. of days (%)	Daily no. of deaths	BS ($\mu\text{g}/\text{m}^3$)	No. of days (%)	Daily no. of deaths	BS ($\mu\text{g}/\text{m}^3$)
CA	23 (2)	38.1	106.0	22 (2)	35.5	96.9
CC	108 (12)	39.4	66.6	41 (5)	35.9	54.9
HL	82 (9)	35.9	76.6	174 (20)	33.7	59.6
NW	79 (9)	39.3	103.4	63 (7)	33.8	66.9
OA	339 (37)	39.4	108.3	408 (46)	34.6	79.3
OC	93 (10)	40.0	89.2	79 (9)	34.8	61.0
SW	114 (13)	40.1	93.5	48 (5)	36.4	64.5
ZN	73 (8)	41.4	121.8	49 (6)	33.4	73.6
Total	911 (100)	39.8	94.5	884 (100)	34.1	74.1

significant after adjusting for BS: 5.3%; 95% CI, 0.3–10.6%). During the warm period, days in category d1 also display higher relative risks (increase 8.5%; 95% CI, 2.0–15.4%). Adjustment for BS levels tends to increase the relative risks for mesoscale categories, especially during the winter period.

Table 9 shows the relative risks associated with a 10- $\mu\text{g}/\text{m}^3$ increase in daily BS concentrations in the different models, including synoptic and mesoscale categories. The risks for BS remain statistically significant in all models and are slightly higher during the summer compared to the winter season.

Table 4. Daily number of deaths and airborne particulate matter concentrations (as indicated by BS measurements) by mesoscale categories and season.

Mesoscale type	Winter			Summer		
	No. of days (%)	Daily no of deaths	BS ($\mu\text{g}/\text{m}^3$)	No. of days (%)	Daily no of deaths	BS ($\mu\text{g}/\text{m}^3$)
a	34 (4)	38.3	76.5	40 (5)	32.1	65.9
b	19 (3)	41.1	74.0	3 (0.5)	34.7	75.9
c1,c2	303 (39)	40.6	76.6			
c3,c4				346 (41)	33.8	62.8
d1	61 (8)	40.2	87.7	45 (5)	36.6	72.2
d2				147 (18)	35.4	91.4
d3				151 (18)	34.1	81.6
d4	114 (15)	39.4	118.6			
f	239 (31)	39.3	117.4	101 (12)	33.4	79.0
Total	770 (100)	39.9	96.3	837 (100)	34.2	73.9

Table 5. Cross-classification of synoptic and mesoscale categories.

Mesoscale category	Synoptic category							
	CA	CC	HL	NW	OA	OC	SW	ZN
a	1	7	4	8	20	11	10	13
b	0	4	2	3	6	1	3	3
c1,c2	5	68	37	32	103	36	11	12
c3,c4	5	25	140	18	135	17	1	5
d1	1	3	2	3	44	3	42	8
d2	6	3	9	12	67	15	11	24
d3	6	3	17	14	85	16	3	7
d4	0	5	4	13	54	10	18	13
f	13	17	19	23	165	41	39	23

Table 6. Relative risks (RRs) and associated 95% CIs for mortality from generalized additive Poisson models, for each synoptic weather category, for the whole year, before and after adjusting for ambient BS concentrations.

Synoptic category	Base model ^a RR (95% CI)	Adjusted also for BS RR (95% CI)
HL	Reference	Reference
SW	1.100 (1.061–1.139)	1.098 (1.060–1.138)
CC	1.035 (0.997–1.075)	1.038 (1.000–1.078)
CA	1.044 (0.987–1.104)	1.028 (0.971–1.087)
ZN	1.058 (1.018–1.100)	1.044 (1.004–1.085)
OC	1.053 (1.017–1.090)	1.046 (1.010–1.083)
OA	1.034 (1.008–1.062)	1.022 (0.996–1.049)
NW	0.998 (0.961–1.036)	0.994 (0.958–1.033)

^aAdjusting for season, long-term trends, temperature, and day of the week.

Table 7. Relative risks (RRs) and associated 95% CIs for mortality from generalized additive Poisson models, for each synoptic weather category, separately by season, before and after adjusting for ambient BS concentrations.

Synoptic category	Cold period		Warm period	
	Base model ^a RR (95% CI)	Adjusted also for BS RR (95% CI)	Base model ^a RR (95% CI)	Adjusted also for BS RR (95% CI)
HL	Reference	Reference	Reference	Reference
SW	1.102 (1.044–1.164)	1.104 (1.046–1.165)	1.104 (1.034–1.178)	1.096 (1.027–1.169)
CC	1.059 (1.004–1.118)	1.067 (1.011–1.126)	1.025 (0.962–1.091)	1.021 (0.959–1.087)
CA	1.083 (0.993–1.182)	1.072 (0.982–1.169)	1.016 (0.942–1.095)	1.003 (0.930–1.081)
ZN	1.089 (1.028–1.154)	1.081 (1.020–1.145)	1.011 (0.952–1.074)	1.002 (0.944–1.064)
OC	1.053 (0.997–1.112)	1.050 (0.994–1.109)	1.066 (1.013–1.122)	1.057 (1.005–1.112)
OA	1.056 (1.007–1.107)	1.048 (1.000–1.099)	1.017 (0.985–1.050)	1.007 (0.975–1.039)
NW	1.016 (0.960–1.075)	1.015 (0.959–1.074)	0.998 (0.943–1.056)	0.993 (0.939–1.050)

^aAdjusting for season, long-term trends, temperature, and day of the week.

Discussion

In this study we observed associations of daily synoptic and mesoscale weather conditions with the daily number of deaths in Athens, Greece, an area with typical Mediterranean climate. We also adjusted for confounding by air pollution using ambient particles concentrations. We found that both atmospheric circulation classifications and air pollution have independent effects on mortality. In this analysis we adjusted for seasonal patterns using LOESS smoothers to ensure adequate control of seasonality in annual and seasonal models.

Synoptic circulation systems We used the HL synoptic type as the baseline or reference category to which all the risks for mortality for the other synoptic categories were compared. This category induces strong northeasterly flow known as Etesians over the Aegean Sea and consequently over Athens, (18), mainly during the warm period of the year. This type of flow contributes significantly to the ventilation of the atmosphere over Athens and is associated with decreased mortality. We found that the most unfavorable synoptic circulation type was the SW type. This weather system is combined with southerly (especially southwesterly) flow. This flow is associated with a rapid increase of both temperature and relative humidity in the lower troposphere over the Aegean Sea due to the difference between the warm and moist air masses coming from North Africa, through the Mediterranean, and then through the relatively dry and cool air masses over the Greek mainland. The resulting high temperature (for the season) and humidity lead to intense thermal discomfort conditions. Especially during winter, the warm and moist weather of the SW type is very different from the normally expected weather conditions. The second most unfavorable synoptic type is the zonal flow (the normal westerly flow). This type of circulation results in usually weak westerlies over the Athens area and is mostly combined with surface anticyclonic circulation and warm air in the south. However, when the zonal flow is intense, it seems to contribute to the establishment of pleasant weather conditions. This is usually the case during the warm period. The cyclonic synoptic types CC and OC, characterized by strong winds and bad weather conditions, are also shown to result in unfavorable conditions for human health. The anticyclonic types, OA and CA, result on persistent weak flows and temperature extremes and are also associated with increases in mortality. The estimated relative risks for CA and CC are not statistically significant although they are comparable to those of OA and CA, but this could be due to the very limited number of occurrences of

these types. Overall, these categories are more favorable compared to the SW type; this is due to the lower humidity levels during the warm period. During the cold period, the anticyclonic systems result in cold—sometimes very cold—and rather dry weather, which is more or less in line with the overall winter weather pattern. The only type of circulation that is comparable to HL, as far as the associated mortality level is concerned, is the NW type. This type is characterized by strong cold advection from the north and northwest while the relative humidity remains quite low. Thus, the NW flow favors the development of good weather conditions.

The seasonal variations of the relative risks associated to each synoptic category are a result of differences in frequency, persistence, and intensity of occurrence. The SW type presents the same relative risk during the two seasons. The zonal flow presents higher relative risks during the cold period than during the warm period. This circulation type is more frequent but less intense during the cold period compared to the warm period. A combination of weak wind flow, increased humidity, and increased temperature is responsible for unpleasant weather conditions during the cold period. The medium flow intensity during the warm period allows for local flows of reduced humidity and moderate temperature levels, leading to pleasant weather conditions over Athens, which may be the cause of the marked change of the associated relative risk. The anticyclonic types, CA and OA, conserve the meteorologic conditions. During the cold period, they are mostly associated with low intensity winds and temperature extremes. Temperature can be high or low depending on the previous synoptic conditions. Especially unfavorable conditions are developed when the Siberian anticyclone extends southerly over the Balkans, and extremely low temperatures are established for significant time periods. During the warm period, the very high temperatures are usually combined with moderate humidity levels, resulting in moderately unpleasant conditions. In the cold period, the NW type is frequently associated

with very strong advection of polar air masses over Greece and the occurrence of cold outbreaks that produce health problems. During the warm period, the NW type is combined with pleasant weather conditions characterized by a medium intensity NW flow that ventilates the basin.

The synoptic classification used here differs from that employed by Kalkstein (12). Kalkstein (12) used an air-mass objective classification scheme based on surface meteorologic data. The number of distinct categories and the actual classification were derived using principal component analysis and clustering techniques, and weather maps were used only to further illustrate differences between the identified categories. The classification scheme used by Kalkstein (12) in St. Louis, Missouri, resulted in 10 synoptic categories. The classification that we used in this paper is based on the position and orientation of synoptic scale geopotential height patterns with respect to the area of interest (Athens) (15). Although it is a subjective scheme, two researchers performed the classification independently using the 850 and 700 hPa synoptic weather maps to assign each day into 1 of the 8 predefined categories; there was good agreement (80%) between results of both researchers. The categories were later shown to be statistically distinct by discriminant analysis (15).

The classification used by Kalkstein (12) is directly related to the surface thermohygro-metric (TH) conditions of a large area around the point of interest, whereas our classification is based on the atmospheric circulation patterns resulting from the vertical TH structure of the atmosphere, which in turn is inter-linked with the surface conditions. A unique relationship between synoptic category and surface weather conditions, as is the case with Kalkstein's classification (12), is possible only under strong synoptic flows (e.g., SW, NW, CC). Under weak synoptic conditions, local circulations become the dominant factors that shape surface weather conditions.

Observed synoptic weather systems are not the same all over the world, so it is

expected that the weather systems identified for the central United States will be quite different from those identified for Greece. This is especially true because both the land–sea distribution and the physiographical characteristics of the two areas are very different, despite the fact that they lay in similar latitudes. In contrast, similar surface weather conditions are expected to produce similar effects on human health. Athens is a city built on the Mediterranean coastline close to the Sahara desert; as a result, air masses coming from the south are very warm and wet because they have to cross the Mediterranean before reaching Athens. It is therefore expected that the southwestern flow is the most unfavorable category for human health because it is also combined with an abrupt temperature change. For St. Louis, the worst categories are also characterized by winds from the southern sector. These wind flows have their origin in the Caribbean, but in order to reach St. Louis, they have to cross an extended land mass, losing significant amounts of water yet remaining wet. These categories appear with similar frequencies (7–10%) in both cities. The synoptic category characterized with the lowest risk of death both in Athens and in St. Louis is associated with NW wind combined with cold northern flows. The frequency of occurrence of this synoptic category is about 6% for St. Louis and a little higher (8–9%) for Athens. The anticyclonic categories, which represent a moderate risk for mortality, occur in Athens on more than 40% of the days, but in St. Louis they occur on about 30% of days.

Mesoscale circulation systems. As outlined above, the synoptic systems are closely associated to surface weather only when they represent intense flows. The mesoscale atmospheric circulation patterns correspond to smaller areas and thus are directly related to surface weather. We used these circulation patterns to better illustrate the effect of local flows (dominant under weak synoptic conditions) on health.

To study the association between mesoscale circulation patterns and mortality, we used the flow without main component (f) as a baseline because it occurs frequently

Table 8. Relative risks (RRs) and associated 95% CIs for mortality from generalized additive Poisson models for each mesoscale category by season, before and after adjusting for ambient BS concentrations.

Mesoscale category	Cold period		Warm period	
	Base model ^a RR (95% CI)	Adjusted also for BS RR (95% CI)	Base model ^a RR (95% CI)	Adjusted also for BS RR (95% CI)
f	Reference	Reference	Reference	Reference
a	1.007 (0.946–1.071)	1.025 (0.963–1.092)	0.994 (0.929–1.063)	1.006 (0.940–1.076)
b	1.094 (1.010–1.185)	1.111 (1.026–1.203)	—	—
c1,c2	1.004 (0.971–1.039)	1.017 (0.983–1.052)	—	—
c3,c4	—	—	0.993 (0.954–1.035)	1.009 (0.968–1.051)
d1	1.039 (0.990–1.091)	1.053 (1.003–1.106)	1.085 (1.020–1.154)	1.094 (1.028–1.164)
d2	—	—	1.036 (0.988–1.086)	1.039 (0.992–1.089)
d3	—	—	1.019 (0.973–1.066)	1.023 (0.977–1.070)
d4	1.020 (0.981–1.060)	1.020 (0.982–1.060)	—	—

^aAdjusted for season, long-term trends, temperature, and day of the week.

Table 9. Relative risks (RRs) and associated 95% CIs from generalized additive Poisson models for BS, adjusted for synoptic or mesoscale weather categories.

Adjusted for	RR (95% CI) per 10 µg/m ³
Synoptic categories	
All year	1.008 (1.006–1.010)
Cold period	1.005 (1.002–1.012)
Warm period	1.008 (1.003–1.012)
Mesoscale categories	
Cold period	1.006 (1.003–1.009)
Warm period	1.008 (1.003–1.012)

in both seasons. This mesoscale pattern is characterized by low intensity winds blowing from various directions, and moderate temperature and humidity. Due to the slight movement of the air, the meteorologic conditions associated with it are pleasant. Among the mesoscale circulation patterns, the one associated with the highest relative risk for mortality in the summer in Athens is d1. This pattern is associated with strong southerly winds responsible for the transportation of warm and moist air masses from the Aegean Sea over Athens. The increased temperature combined with the moist air masses create uncomfortable conditions in Athens.

The mesoscale weather type associated with the highest relative risks in the winter is type b, representing easterly winds. The easterly winds are a very rare pattern appearing during the cold period of the year and are associated with cold outbreaks, very low temperatures, rather weak wind, and snow. Type d4 is also associated with elevated relative risks in the winter, and d2 is associated with elevated relative risks in the summer. d4 is a cold period circulation pattern combined with southern winds of low intensity, which carry moist air masses from the sea. During the winter there is increased humidity in the air compared to the summer, so relative humidity reaches high values. The increased relative humidity in association with very low intensity of winds and the increased temperature (for the season) creates unpleasant weather conditions. d2 is a circulation pattern, characterized by southern winds, that appears during the warm period and is associated with moderately unpleasant conditions. The mesoscale patterns a and c are not associated with elevated relative risks. The c1 and c2 types occur only during cold months. They are associated with good ventilation of the atmosphere in Athens and they result in the formation of pleasant weather conditions. The only difference between them is the intensity of the northern flow. Circulation pattern a is associated with western winds of medium intensity and reduced humidity; the temperature remains moderate and results in rather pleasant weather conditions.

Although the mesoscale circulation types refer to a layer closer to the ground, they do not appear to improve our understanding of the association between weather types and mortality. This is probably because the local

circulation is frequently associated with more than one synoptic condition. Although some intense synoptic categories successfully transfer their characteristics to some of the associated mesoscale categories (e.g., SW to d1), this is not generally the case. Further investigation is needed to obtain a better understanding.

Ambient particle levels. The relative risks for mortality associated with exposures are comparable (or slightly higher) to the ones reported before in studies where control of confounding for weather variables was done using the mean daily levels of temperature and relative humidity (9,13). Thus, on the basis of an analysis of 12 European cities, Katsouyanni et al. (9) reported an increase of 0.6% in the daily number of deaths associated with a change of 10 $\mu\text{g}/\text{m}^3$ in BS levels. In seasonal analysis, the summer relative risks were reported to be higher (9). This is not due to the actual pollutant concentration (as BS measurements peak during the cold period in Athens), but a likely explanation may be that summer BS levels affect the average population exposure more because people spend more time outdoors and tend to keep the windows open. It seems that using the synoptic or mesoscale categories to control for weather does not affect, to any considerable extent, the estimated relative risks found for particle exposures. This is consistent with the findings of Pope and Kalkstein (13).

In conclusion, in this paper we provide evidence that synoptic and mesoscale weather classification is a useful tool for studying the weather–health associations in a warm Mediterranean climate situation. The correlation between the two types of classification used here and the interactions involved need to be further investigated.

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