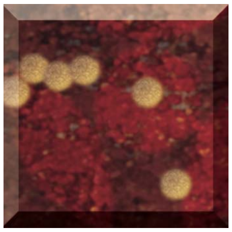

Weather and Climate Effects on Disease Background Levels

Steven M. Babin

Because weather and climate effects may result in spatial and temporal changes in human disease incidence, it is important to consider them when determining whether disease outbreaks are due to natural causes or to bioterrorism. Some diseases (e.g., vector-borne) respond almost directly to environmental parameters. Weather conditions also may result in increased disease incidence by stressing a person's immune defenses or by causing human behaviors that result in increased exposure to disease. In addition, extreme weather events may directly impact public health. Awareness of weather and climate factors can therefore help to detect bioterrorist-induced events against a natural disease incidence background.

BACKGROUND

When monitoring public health for anomalous incidences of disease such as those potentially caused by a bioterrorist attack, it is important to consider natural events that may change disease incidence. Weather and climate may affect human health in many ways. Weather conditions, especially low wind speeds, high temperatures, and temperature inversion, may exacerbate air pollution. In the National Capital Area (NCA), ground-level ozone—a potent oxidant that is extremely irritating to the respiratory system—is the primary pollutant. Even healthy people exposed to sufficient concentrations may experience chest pain, coughing and wheezing, lung and nasal congestion, labored or rapid breathing, nausea, eye and nose irritation, and sore throat. Ozone can also aggravate pre-existing conditions such as bronchitis, heart disease, emphysema, and asthma. Reactions vary, depending on such factors as ozone concentration, duration of exposure, climate, individual sensitivity, pre-existing respiratory disease, and socio-economic status. In a given populated region, these effects ultimately result in increased hospital and emergency department admissions[1–11] and have been observed to increase the sales of ambulatory respiratory drugs.[12]

Weather-related disasters may increase the incidence of illness as well. On 5 June 2001, Tropical Storm Allison made landfall around Galveston, Texas, and then made a slow loop over southeast Texas and south-central Louisiana during the following days, resulting in a large area of flooding. A study by the Centers for Disease Control and Prevention[13] showed significant increases in diarrhea and stomach ailments in the flooded areas. As another example of the effects of a significant rain event on public health, flooding can overload sewage treatment facilities, leading to water pollution. In the NCA, the District of Columbia Water and Sewer Authority operates a wastewater collection system composed of separate and combined sewers. Combined sewers use a single piping system for both storm water and sewage from homes and businesses. Combined sewers date from the early 1900s and serve about one-third of the District. During significant rain events, the capacity of this combined sewer system is exceeded and the excess flow, which includes untreated sewage, is discharged directly into local rivers and creeks.[14]

Climate features, such as the El Niño-Southern Oscillation (ENSO), may also impact the incidence of disease.[15] ENSO conditions cause increased rainfall in certain regions. These changes in rainfall patterns may lead to increases in populations of mosquito vectors and eventually to an increase in mosquito-borne diseases. In the southwestern United States, rainfall pattern changes have resulted in increased deer mouse populations and eventual increases in human Hantavirus infection.[16] Similar conditions have occurred in Paraguay.[17] An increased incidence of anthrax in bison has been reported to occur when a higher than normal rainfall in the spring was followed by drought conditions in late summer.[18] It was suggested that the earlier rainfall had washed pre-existing anthrax spores into low-lying areas where they became concentrated. Because male bison prefer low-lying wallows, they were therefore believed to have been exposed to increased concentrations of the anthrax spores.

Many other reports of disease increase caused by climate changes have been reported. In Sudan, the re-emergence of a particular type of woodland due to climatic rainfall changes resulted in an increase in the habitat of the sandfly vector of leishmaniasis, which then resulted in a human epidemic of this disease.[19] Cross et al.[20] showed how geographic information systems, weather data, and Landsat data could be used to predict the probability of leishmaniasis for a region. Large summertime toxic algal blooms along the Gulf Coast of Florida have been associated with increased nutrient iron deposition by aeolian dust originating from Saharan dust storms.[21] On a global scale, Patz et al.[22] summarized how climate change may impact emerging infectious diseases.

Dry and moist weather cycles affect the presence of particulates and aerosols in the atmosphere. Increased amounts of particles (e.g., dust, mold spores, pollen) may worsen chronic lung disease and increase susceptibility to other diseases. Studies have shown the long-distance airborne transmission of viruses in aerosols.[23,24] Examples include pseudorabies[25,26] and foot-and-mouth disease[27] in animals. Bacteria and fungi may be transported on the dust over long distances and may be protected from ultraviolet inactivation by their location within interstices of the dust particle. For example, the fungus *Aspergillus sydowii* has been shown to survive transport across the tropical Atlantic from Africa to the western Caribbean, where it infected and caused significant mortality in the sea fan coral.[28] Retrospective studies have suggested that human airborne pathogens have been transported similarly (e.g., Refs. 29–31). Satellite data have revealed African dust being entrained into Atlantic hurricanes, which sometimes reach the United States. Figure 1 shows African dust entrainment into Hurricane Felix in 2001. While Felix did not make landfall in the United States, Hurricane Georges in 1998 originated in the same area and later made landfall in Key West, Florida. Even if not carried to the U.S. mainland by hurricanes, African dust often reaches the southeast United States.[32]

It should be noted that the U.S. mainland commonly receives dust from other sources besides Africa (e.g., Gobi desert in Asia), but no one has studied whether the bacteria and fungi associated with such dust survive the trip. Therefore, whether bacteria and fungi reach the mainland or coastal United States in this manner is speculative. Still, it is remarkable that fungi have survived trips from Africa to the western Caribbean and remained viable enough to cause significant disease.

Finally, cold weather may increase the incidence of disease by several mechanisms. When it is cold outside, people tend to spend more time indoors, and the resulting increase in indoor population density can promote the person-to-person transfer of disease. In addition, cold, dry air may cause drying of the respiratory mucosa.

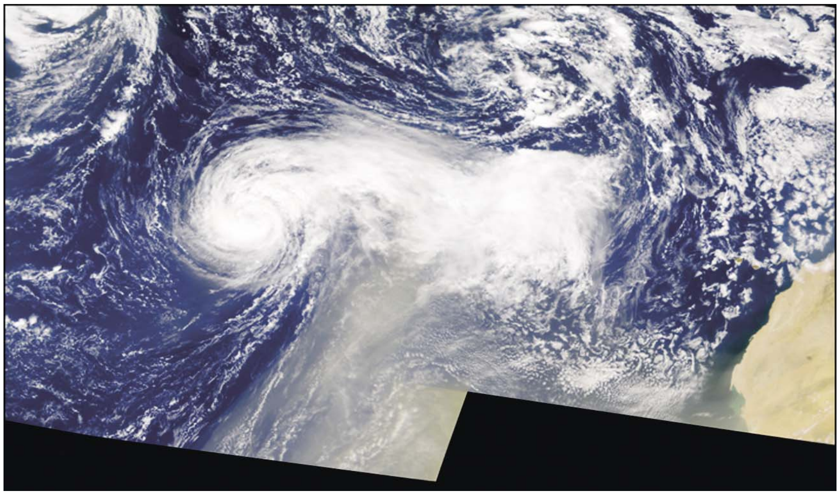

Figure 1. Hurricane Felix (2001) entraining African dust. (Image courtesy of the SeaWiFS [Sea-viewing Wide Field-of-View Sensor] Project, NASA Goddard Space Flight Center, and Orbimage [Orbital Imaging Corp.].)

The loss of moisture and heat from the bronchial mucosa may lead to increased disease susceptibility. Studies of exercise-induced asthma have also shown that cold, dry air may enhance bronchoconstriction, while rapid airway rewarming (e.g., entering a heated building) may cause vascular congestion and transient edema.[33] In addition, falling ambient temperatures may increase morbidity from chronic obstructive pulmonary disease.[34]

CORRELATION BETWEEN TEMPERATURE AND PATIENT DATA

As part of an effort to monitor human health in the NCA, APL, in collaboration with the DoD Global Emerging Infections System (DoD-GEIS), collects aggregated, completely anonymous patient data from all military treatment facilities around Washington, DC, including those providing inpatient, outpatient, and ambulatory care. The patient data consist of daily total counts of certain International Classification of Diseases, Ninth Revision (ICD-9) codes. These numeric codes were developed by the World Health Organization to classify morbidity and mortality information for storage and retrieval of diagnostic data and statistical analyses.[35] U.S. insurance companies also use these codes for medical billing purposes. For example, ICD-9 code 466.0 represents Acute Bronchitis.

For this study, APL compared daily counts of ICD-9 data with the maximum daily temperature at Reagan National Airport (DCA). DCA was chosen because of its central location relative to the military treatment facilities noted above. Daily temperature data from 1 March 1999 through 12 March 2002 were obtained from the National Weather Service Office in Sterling, Virginia. These data were compared with the daily ICD-9 counts shifted forward in time daily from 0 to 28 days. The idea was that a decrease in maximum daily temperature might precede an increase in the daily count of a particular ICD-9 code, and we were interested in how far in advance the maximum correlation occurred.

Calculations were made of the linear Pearson correlation coefficient, which ranges from −1 to +1, representing a perfectly negative linear correlation and a perfectly positive linear correlation, respectively. The Pearson correlation coefficient may be misleadingly small when the relationship between the two variables is nonlinear. For all of the data comparisons that follow, other types of mathematical correlation analyses (e.g., Spearman) were also performed, but the results were essentially the same. Therefore, only the numerical results of the linear Pearson correlation coefficient analysis are presented. Correlation analyses were also performed using minimum daily temperatures at the airport as well as daily rainfall and snowfall data, with results showing no significant correlation.

Ten ICD-9 codes were chosen for the comparison with temperature: 466.0 (Acute Bronchitis), 465.9 (Acute Upper Respiratory Infections of Multiple or Unspecified Sites), 487.1 (Influenza with Other Respiratory Manifestations), 486 (Pneumonia), 462 (Acute Pharyngitis), 465.8 (Acute Upper Respiratory Infections of Multiple Sites), 460 (Acute Nasopharyngitis or the Common Cold), 558.9 (Noninfectious Gastroenteritis), 485 (Bronchopneumonia), and 009.2 (Infectious Diarrhea). In addition to specific ICD-9 codes, syndrome groups containing multiple ICD-9 codes were compared: Lower Respiratory Infection, Upper and Lower Respiratory Infection combined, Upper Respiratory Infection, Fever, Upper and Lower Gastrointestinal Infection combined and separately, and Dermatological. Syndrome groups such as these were examined because ESSENCE II (Electronic Surveillance System for the Early Notification of Community-based Epidemics; see the articles by Lombardo and by Burkom, this issue), a syndromic surveillance system, examines variations in the syndrome groups of ICD-9 codes to detect a disease outbreak before a specific disease diagnosis is made.

Software was written to isolate the maximum absolute value correlation (i.e., positive or negative). Note that we were looking for a correlation between maximum daily temperature and a subsequent increase in daily patient counts. Because we expected that a decrease in temperature might precede an increase in daily patient data, we were looking for the maximum negative correlation. The ICD-9 codes and syndrome groups related to dermatological and gastrointestinal diseases were added to the study as a sanity check because, unlike respiratory diseases, they were not expected to show significant correlation with atmospheric temperature.

The results for the ICD-9-coded diseases and the syndrome groups are shown in Table 1. Although the individual correlations are not particularly high, they illustrate that some diseases and syndrome groups are more affected by weather than others. The total patient count for each category is also included because the correlations for categories with higher patient counts should be more significant than those categories with lower patient counts, all else being equal.

Among the ICD-9 codes, the largest negative correlation was –0.47 for both Acute Bronchitis and Upper Respiratory Infections, with lags of 10 and 2 days, respectively, following the maximum daily DCA temperature. Except for Bronchopneumonia, the respiratory diseases had more significant cross-correlations with temperature than the nonrespiratory diseases. It is not obvious why Bronchopneumonia had such a small correlation, but this may not be significant because there were an extremely small number of cases over the time period.

The syndrome groups combine diseases affecting the same organ systems, and this increases the size of

Table 1. Cross-correlations and lag times for ICD-9-coded diseases and syndrome groups.

Classification	Total patient count	Maximum absolute correlation	Coefficient of determination	Day lag
ICD-9 code				
Acute Bronchitis (466.0)	36,284	−0.47	0.22	2, 10
Upper Respiratory Infections (465.9)	152,349	−0.47	0.22	2
Influenza (487.1)	1,548	−0.42	0.17	17
Pneumonia (486)	14,113	−0.42	0.17	2
Acute Pharyngitis (462)	80,576	−0.40	0.16	24
Upper Respiratory Infections (465.8)	4,025	−0.33	0.11	3
Nasospharyngitis (460)	10,002	−0.32	0.10	3
Gastroenteritis (558.89)	22,687	−0.29	0.08	24
Bronchopneumonia (485)	79	−0.11	0.01	5
Infectious Diarrhea (009.2)	350	−0.07	0.00	2
Syndrome group				
Lower Respiratory	83,249	−0.44	0.19	2, 10
Upper and Lower Respiratory	432,274	−0.43	0.19	10
Upper Respiratory	349,025	−0.42	0.18	10
Fever	22,747	−0.29	0.09	23
Upper and Lower Gastrointestinal	66,512	−0.24	0.06	23
Lower Gastrointestinal	46,682	−0.24	0.06	24
Upper Gastrointestinal	19,830	−0.22	0.05	23
Dermatological	4,778	0.07	0.01	8

the samples. Among syndrome groups, the respiratory categories had the largest negative correlations. According to Mendenhall,[36] the square of the correlation coefficient (the "coefficient of determination") provides a more meaningful interpretation of the strength of the relation between two variables than the correlation coefficient itself. Therefore, the maximum daily airport temperature explains 22% of the total ICD-9 466.0 (Acute Bronchitis) daily count variance 2 and 10 days later and 19% of the total Respiratory Syndrome daily count variance 2 and 10 days later.

Although Figs. 2a and 2b illustrate how well these disease classes correspond to maximum daily temperature, it is obvious that other factors are involved. Note in Fig. 2 that there is a 1-month gap in the patient data in June 2001, so the correlations quoted herein may have been slightly different were it not for these missing data. Note also that these coefficients of determination varied with lag time. For Acute Bronchitis, there are peaks at lags of 2–3, 9–10, 15–16, and 23–24 days, although the two peaks at lags of 2 and 10 days were the largest and had almost the same values. For the Respiratory Syndrome, the largest peaks occurred at the same number of lag days, with the 9- to 10-day and 2- to 3-day peaks being virtually the same values. While the maximum daily temperature is obviously periodic annually, it is not typically periodic over time intervals of a month or less. In contrast, the daily patient counts do tend to show some periodicity over time intervals of a month or less owing to a day-of-the-week effect. Some of this effect is simply caused by clinic closures on weekends and the rest by human behavior effects on the popularity of certain days of the week for office visits.

CONCLUSION

Based on the results of the analysis presented here, the maximum daily DCA temperature appears to explain as much as 22% of the increased incidence of Acute Bronchitis seen 2 and 10 days later and as much as 19% of the increased incidence of diseases categorized together as Respiratory Syndrome seen 2 and 10 days later. The lag days could be the result of incubation periods of various diseases. For example, the incubation period is around 12 to 24 h for the common cold, 1 to 4 days for influenza, and anywhere from 1 to 28 days for different types of pneumonia. For some of the ICD-9 disease and syndrome groups, there were multiple peaks in the coefficient of determination, often about a week apart. This is likely related to a well-known day-of-the-week periodicity in the patient data.

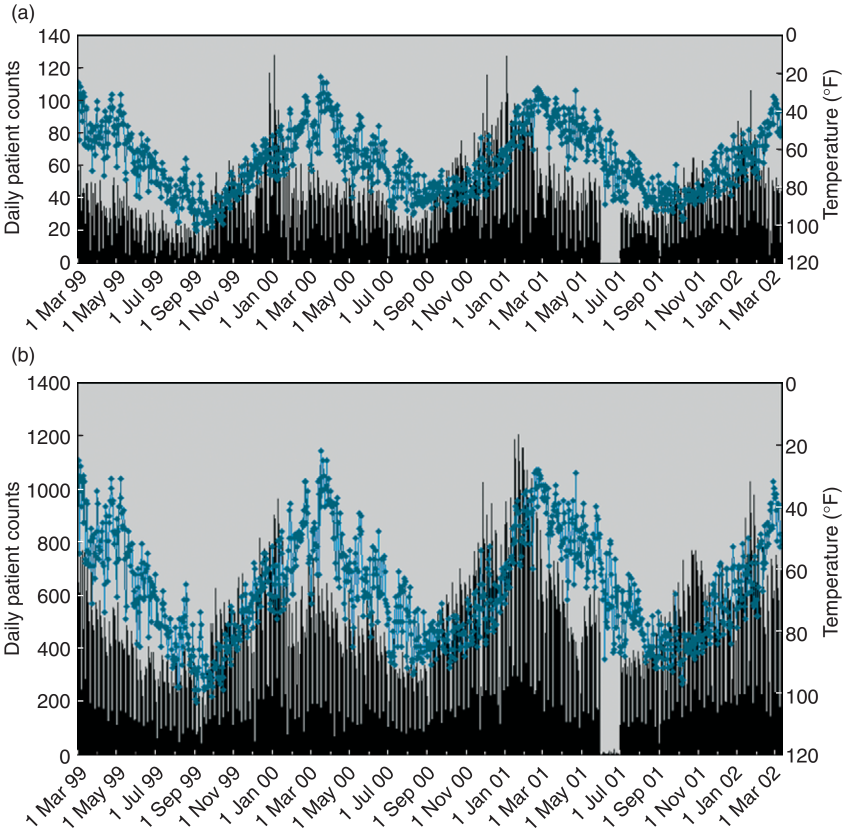

Figure 2. Plot of maximum daily temperature and daily incidence of (a) Acute Bronchitis (ICD-9 466.0) and (b) Respiratory Syndrome between 1 March 1999 and 12 March 2002. Temperature data are shown in blue; Acute Bronchitis and Respiratory Syndrome data are shown in black.

The main conclusion of this simple demonstration study is that the maximum daily atmospheric temperature may explain ≈20% of the variance in our patient data for respiratory diseases in general. Any effects on gastrointestinal and dermatological diseases are much less significant. Although the increased incidence in respiratory disease is not fully explained by a simple drop in temperature, there is enough of a correlation with temperature change that one should be aware of a possible increase following a period of cold weather. Such awareness should be incorporated into biosurveillance systems to minimize false alarms. Indeed, awareness of a variety of environmental factors (e.g., severe storms, flooding, climate changes, etc.) affecting human health is important when one is trying to determine whether an increase in illness is caused by bioterrorist activities.

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