Association of Normal Weather Periods and El Niño Events With Hospitalization for Viral Pneumonia in Females: California, 1983–1998

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Objectives. This study examined associations between weather and hospitalizations of females for viral pneumonia during normal weather periods and El Niño events in the California counties of Sacramento and Yolo, San Francisco and San Mateo, and Los Angeles and Orange.

Methods. Associations between weather and hospitalizations (lagged 7 days) for January 1983 through June 1998 were evaluated with Poisson regression models. Generalized estimating equations were used to adjust for autocorrelation and overdispersion. Data were summed over 4 days.

Results. Associations varied by region. Hospitalizations in San Francisco and Los Angeles increased significantly (30%–50%) with a 5°F decrease in minimum temperature. Hospitalizations in Sacramento increased significantly (25%–40%) with a 5°F decrease in maximum temperature difference. The associations were independent of season. El Niño events were associated with hospitalizations only in Sacramento, with significant decreases for girls and increases for women.

Conclusions. The results suggest that viral pneumonia could continue to be a major public health issue, with a significant association between weather and hospitalizations, even as the global mean temperature continues to rise. An understanding of population sensitivity under different weather conditions could lead to an improved understanding of virus transmission. (*Am J Public Health.* 2001;91:1200–1208)

Recent assessments of the potential health effects of climate variability and change concluded that the distribution and incidence of any disease associated with weather may change with a changing climate.[1,2] Climate variability and change may increase or decrease the distribution and incidence of weather-sensitive diseases. To estimate the potential size of this effect, we must start with an understanding of the existing associations between specific health outcomes and various weather variables. However, there are large gaps in our knowledge of the specific weather variables associated with weather-sensitive diseases, with the possible exceptions of heat waves and certain infectious diseases. For example, the fact that colds and influenza have seasonal patterns has long been known, but the reasons have not.

It is projected that by 2100, global mean surface air temperatures will increase by 1°C to 3.5°C relative to 1900.[3] The average rate of warming under the various scenarios considered by the Intergovernmental Panel on Climate Change will probably be greater than any seen in the last 10 000 years. The actual annual to decadal weather patterns will likely include considerable natural variability. Regional temperature changes could differ substantially from the global mean values. During the 1900s, the contiguous United States warmed by approximately 1°F and precipitation increased, with much of the increase due to increases in heavy precipitation events (>5 cm/day) and decreases in light precipitation events.[4,5] There is considerable interest, but a great deal of uncertainty, regarding whether increasing global mean temperatures will be associated with changes in the occurrence and intensity of El Niño Southern Oscillation events.[6,7]

The El Niño Southern Oscillation is a climate phenomenon that describes the periodic changes in oceanic and atmospheric circulation patterns in the tropical Pacific Ocean. El Niño and La Niña events are the 2 extremes of the El Niño Southern Oscillation. El Niño events, which are associated with a warming of the tropical Pacific sea surface temperature, occur approximately every 2 to 7 years. El Niño events can have a strong effect on local weather patterns. For example, in southern and central California, El Niño winters tend to get more rain than usual. During the years 1983 through 1998, there were 5 El Niño events (1982–1983, 1986–1987, 1991–1993, 1994–1995, and 1997–1998).

Although there is uncertainty as to whether the frequency and magnitude of El Niño events might change with increasing global mean temperatures, studying what happened during recent El Niño events provides information on the sensitivity of diseases to specific changes in weather patterns. El Niño events are "natural experiments" with worldwide impacts. Until recently, almost no research looked at how the distribution and rate of health outcomes varied, if at all, during El Niño events.[8] Understanding these relationships is useful for developing current public health responses, for evaluating population vulnerability to these events, and for designing future adaptation measures.

This project was designed to describe and compare the existing associations between certain weather variables and hospitalizations for viral pneumonia during normal weather periods and El Niño events. Changing weather variables do not cause pneumonia, but they may set up conditions that facilitate increased or decreased viral transmission.

METHODS

Weather Data

Weather is what a population actually experiences on a day-to-day basis. Climate is the weather expected in a particular region over a particular time period. In the United States, 30-year averages have traditionally been used to define regional and national climate. Data for the years 1961 through 1990 were the baseline until early 2001; the current baseline period is 1971 through 2000. Included in climate is the variability of the year-to-year fluctuations around the average for a given season of the year. El Niño events fall into this category. Climate change refers to a fundamental shift in the climate over longer time periods, such as decades.

We obtained weather data from the National Climatic Data Center of the National Oceanic and Atmospheric Administration. Data included daily minimum temperature,

TABLE 1—Average Weather Data for October Through April, by Normal and El Niño Periods: Sacramento, San Francisco, and Los Angeles, California, 1983–1998

	October	November	December	January	February	March	April
Sacramento[a]							
Precipitation, in.							
Normal	0.9	13.0	11.6	10.6	17.2	15.6	5.4
Mild El Niño	4.4	3.8	10.9	17.6	2.4	4.7	1.4
Strong El Niño	4.3	12.8	7.9	19.7	24.8	11.0	4.1
Minimum temperature, °F							
Normal	44.5	38.8	38.9	43.3	44.2	47.3	51.9
Mild El Niño	50.8	42.1	37.3	39.3	42.6	46.0	48.4
Strong El Niño	52.3	44.4	38.3	39.3	42.9	45.0	47.7
Temperature difference, °F							
Normal	30.4	19.7	14.6	17.2	18.8	21.1	25.7
Mild El Niño	26.7	24.0	16.8	14.0	21.2	24.7	28.9
Strong El Niño	27.7	20.3	15.9	13.0	17.2	21.1	24.9
San Francisco[b]							
Precipitation, in.							
Normal	0.8	14.0	11.9	10.9	16.9	16.6	4.7
Mild El Niño	5.9	6.0	13.2	16.4	3.7	4.3	1.3
Strong El Niño	4.5	15.7	9.7	25.6	26.7	11.4	4.9
Minimum temperature, °F							
Normal	51.5	47.6	44.3	43.8	46.3	46.0	47.0
Mild El Niño	51.5	46.1	42.7	43.8	46.6	46.7	46.9
Strong El Niño	52.0	48.1	42.9	43.2	45.7	46.7	47.6
Temperature difference, °F							
Normal	20.2	15.9	14.3	15.5	15.2	16.4	17.8
Mild El Niño	18.2	18.2	14.8	13.2	17.0	18.6	17.4
Strong El Niño	19.0	16.2	15.0	14.3	14.9	15.8	17.0
Los Angeles[c]							
Precipitation, in.							
Normal	1.3	6.8	4.2	5.1	17.7	11.5	4.3
Mild El Niño	3.1	1.0	7.9	17.7	5.8	0.7	0.9
Strong El Niño	1.4	8.5	7.1	18.3	22.8	12.0	3.1
Minimum temperature, °F							
Normal	56.5	48.6	44.3	47.2	46.8	50.2	54.6
Mild El Niño	55.1	47.8	43.4	47.3	47.6	51.0	54.6
Strong El Niño	56.2	49.1	44.8	46.0	47.8	50.5	55.7
Temperature difference, °F							
Normal	23.0	21.3	23.2	23.2	20.3	21.0	21.2
Mild El Niño	21.6	24.6	21.9	19.6	23.3	24.4	22.0
Strong El Niño	22.8	22.9	21.6	20.9	19.4	20.2	21.7

[a]Includes Sacramento and Yolo counties.
[b]Includes San Francisco and San Mateo counties.
[c]Includes Los Angeles and Orange counties.

the difference between daily maximum and minimum temperatures, daily precipitation (in hundredths of an inch), monthly sea surface temperatures for 2 regions off the California coast, and monthly Southern Oscillation Index values. We focused on minimum rather than average temperatures because minimum temperatures are more informative for defining the cold season in California. We also included the maximum daily temperature difference, defined as the largest difference between the daily maximum and minimum temperatures.

The sea surface temperature data are from 10° quadrants of the world; one was centered on 40°N and 130°W (northern California), and the other was centered on 30°N and 120°W (southern California). Local sea surface temperatures are important predictors of general weather patterns in California and, as such, were used as markers of other weather variables not explicitly studied, such as wind and cloud cover. Southern Oscillation Index values (Niño Region 3.4 normalized air pressure differentials) were used to define normal weather periods (values of –0.5 to +0.5) and El Niño events (values of less than –0.5). We further categorized El Niño events as mild (less than –0.5 to –1.5) or strong (less than –1.5). By these definitions, during the study period there were 48 months with normal weather, 36 months with mild El Niño conditions, and 60 months with strong El Niño conditions.

The size of the data set required that we aggregate the weather data into larger units. We chose 4-day averages because large weather patterns typically take several days to move through the state and as a smoothing process. We defined 1 unit of temperature difference as a 5°F decrease, 1 unit of precipitation change as a 0.2-inch increase, and 1 unit of sea surface temperature change as a 1°C decrease. We chose these categories because they were about 1 SD from the mean. The maximum temperature difference was the largest difference between the maximum and minimum temperature for 1 day during the 4-day period.

We evaluated the associations between weather and hospitalizations, considering a 7-day lag period. The data were lagged before they were aggregated (i.e., hospitalizations on day 8 were associated with weather data on day 1; this was done for the entire data set before cutting the data into 4-day analysis units). The lag can be thought of as a temporal shift between 2 data streams. Because the 4-day grouping was not excessively broad relative to the lag, the 2 were largely independent of each other.

Hospitalization Data

Hospital admission data were provided by California's Office of Statewide Health Planning and Development for January 1983 through June 1998. Data are included from all nonfederal hospitals in the state. Records include data on patient demographics (age, sex, race, and zip code), date of admission, and disease diagnoses. We analyzed the broader category of viral pneumonia (*International Classification of Diseases* [*ICD-9*] 480, 487) instead of just influenza because of the possibility of misclassification from one category to another.

We analyzed data separately for males and females and considered 3 broad age groups: 0 to 17 years, 18 to 55 years, and 56 years and older. Here we show only the results for females. We analyzed total numbers of hospitalizations, not population rates, because using a rate would require adding the population as an offset parameter to the model described below. We felt this was unnecessary, because we included calendar year in the analysis to account for changes in hospitalizations over time due to changes in population age and density.

Statistical Methods

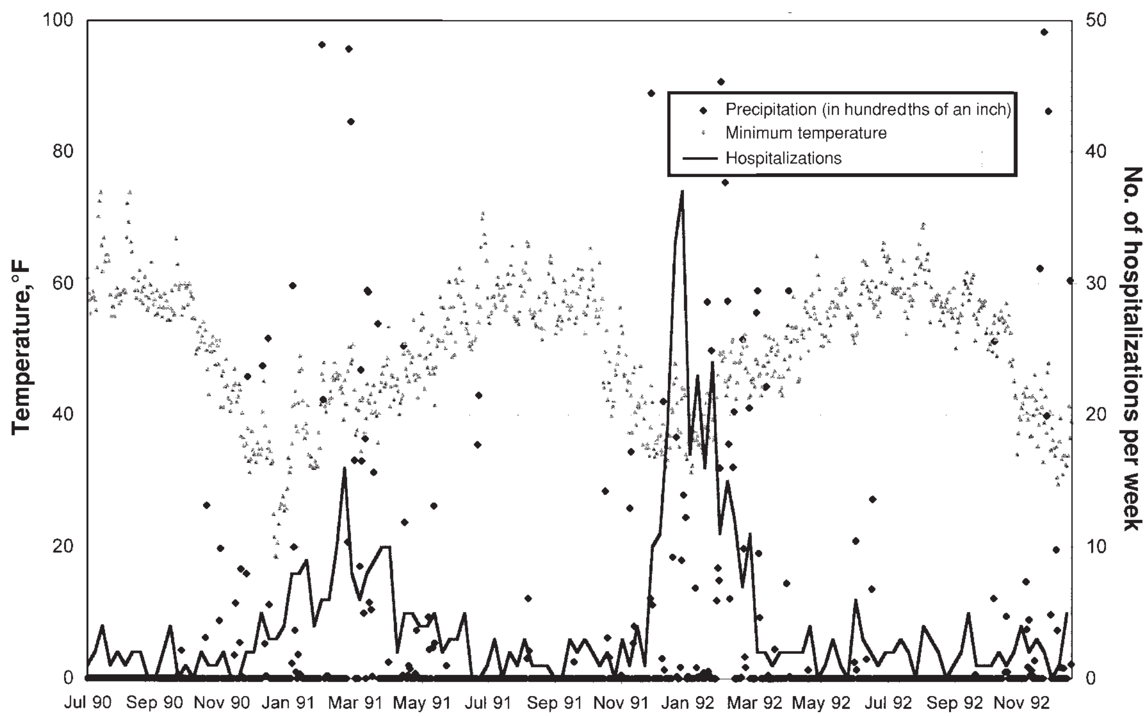
We evaluated the associations between weather variables and viral pneumonia hospitalizations in 3 geographic regions in California (the counties of Sacramento and Yolo, San Francisco and San Mateo, and Los Angeles and Orange, referred to as "Sacramento," "San Francisco," and "Los Angeles," respectively). These counties include portions of 3 of the major metropolitan areas in California. San Francisco and Los Angeles are coastal communities, about 400 miles apart, and Sacramento is inland, about 90 miles from San Francisco. Because weather patterns vary across the large geographic regions encompassed by the San Francisco and Los Angeles metropolitan areas, we decided to analyze only 2 counties in each area with similar weather.

We followed the statistical approach applied to air pollution and health outcomes by Morgan et al.[9] and a collaborative European project.[10] We used Poisson regression models that included a linear time factor to account

TABLE 2—Number of Hospital Admissions for Viral Pneumonia, 1983–1998, and 1990 Census Population: Females in Sacramento, San Francisco, and Los Angeles, California

	Age, y					
	0–17		18–55		≥56	
	Cases	Population	Cases	Population	Cases	Population
Sacramento[a]	951	134 492	270	289 659	359	107 450
San Francisco[b]	837	126 162	259	391 141	564	173 594
Los Angeles[c]	3743	1 420 913	2571	3 136 123	3656	1 081 226

[a]Includes Sacramento and Yolo counties.
[b]Includes San Francisco and San Mateo counties.
[c]Includes Los Angeles and Orange counties.



Source. Hospital admission data were provided by the Office of Statewide Health Planning and Development, Sacramento, Calif.

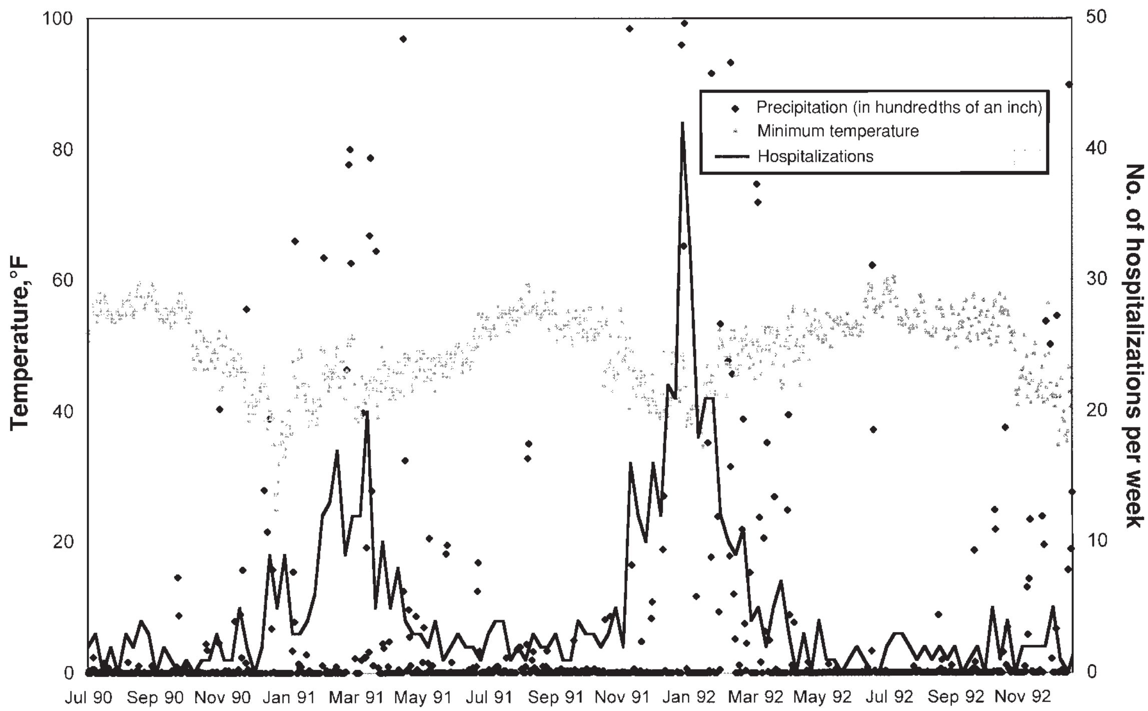
FIGURE 1—Precipitation, minimum temperatures, and hospitalizations of females for viral pneumonia: Sacramento and Yolo counties, California, July 1990–December 1992.

for trends in hospital admissions over the 16-year period. We applied the generalized estimating equations (GEE) of Liang and Zeger to adjust for autocorrelation and overdispersion.[11] Autocorrelation is an important factor that needs to be controlled for in time series data (weather measurements). Overdispersion may be present in count data (hospital admissions) that are assumed to follow a Poisson distribution.

The GEE approach is similar to generalized additive models in the use of a Poisson regression model to estimate daily hospital admission counts in relation to weather data. However, no a priori smoothing was performed for the weather time series. Instead, the GEE model allows for the removal of long-term patterns in the data by adjusting for overdispersion and autocorrelation. Furthermore, the analyst does not have to choose the optimal degree of smoothing by running a number of smoothing applications on the data. The main disadvantage of the GEE approach is that it can be computationally prohibitive when dealing with large databases. We used 4-day groupings for hospital admissions and weather variables both as a smoothing technique and to improve computational efficiency. All analyses were performed with SAS software (version 8.0; SAS Institute, Inc, Cary, NC).

The temperature and precipitation variables used in the statistical model may not fully account for all the important climatological factors during normal weather periods and El Niño events. To evaluate the impact of those latent factors on hospital admissions, we performed a sensitivity analysis by including a season indicator in our main model. Season was defined as winter (December, January, February), spring (March, April, May), summer (June, July, August), or fall (September, October, November). Our goal was to compare the association between weather variables and the El Niño indicator with hospital admissions, after adjustment for season, with the association without the season indicator included in the model. By the Fisher exact test, there was no association between season and El Niño events (P=.78). Therefore, inclusion of both season and El Niño indicators in our model should not introduce multicollinearity.

The sensitivity analysis was performed for Los Angeles and San Francisco. Although the season indicator was significant, the percentage change in hospital admissions due to weather variables, after adjustment for season, did not change substantially. The changes in hospital admissions were in the same direction and of about the same magnitude for both models (with and without the season indicator). The only exception was for temperature variables



Source. Hospital admission data were provided by the Office of Statewide Health Planning and Development, Sacramento, Calif.

FIGURE 2—Precipitation, minimum temperatures, and hospitalizations of females for viral pneumonia: San Francisco and San Mateo counties, California, July 1990–December 1992.

for the youngest group (<18 years) in San Francisco. There was a larger but not statistically significant reduction in hospital admissions in the model without the season indicator. Furthermore, the predictive power of our model did not increase significantly with the inclusion of the season indicator. As a result of this analysis, we present results without adjustment for season.

We assessed the goodness of fit of our models via deviance and Pearson χ^2 statistics. We estimated the percentage change in hospitalization per unit increase for each of the variables in the model and computed the corresponding 95% confidence intervals.

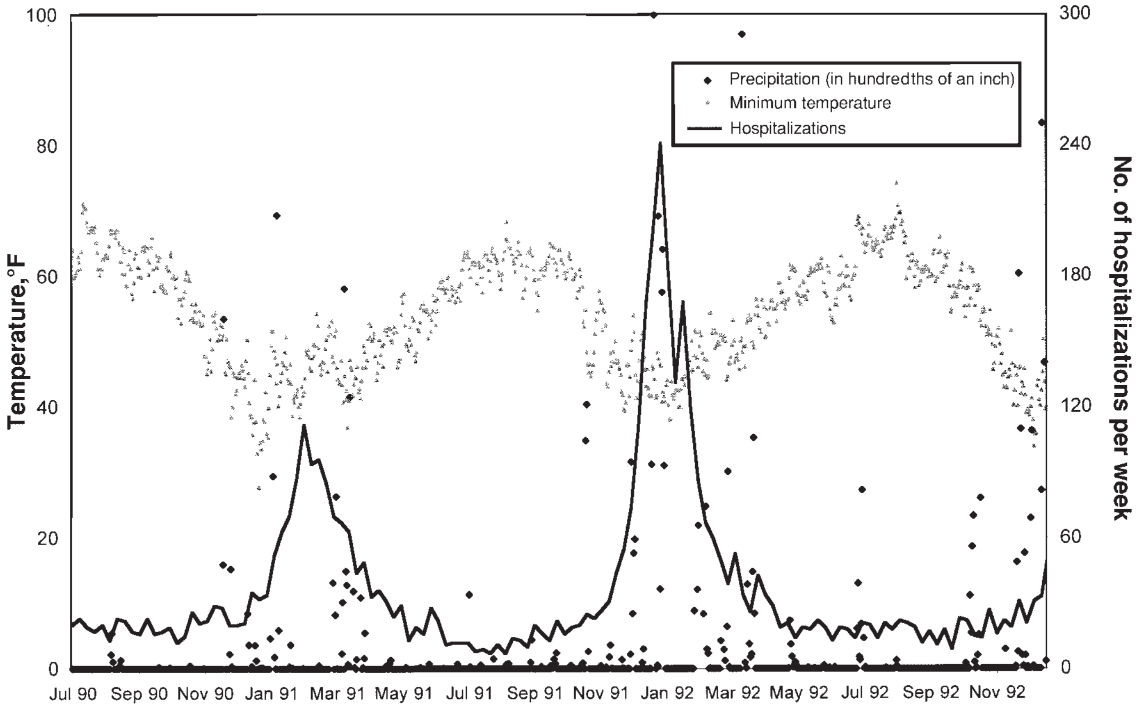
We performed 2 sets of analyses. The first set were strata-specific for normal weather periods and for El Niño events, to estimate the association of weather variables with hospitalizations for each of the periods separately. The second set included an El Niño indicator that defined mild and strong El Niño events and normal weather conditions. The purpose of this approach was to estimate the association of El Niño events with hospitalizations while controlling for other weather effects.

RESULTS

Table 1 shows weather data for normal weather periods and El Niño events for the months October through April for the 3 geographic regions. The strong effect of El Niño events on precipitation is evident. El Niño events changed the amount of precipitation, particularly in January and February, when 2 to 3 times the normal amount of rain fell in San Francisco and Los Angeles (there were smaller increases in Sacramento). During El Niño events, Sacramento tended to be warmer (higher minimum temperatures) during October and November and cooler in January through April. There were no consistent patterns in minimum temperature or temperature difference for El Niño events for San Francisco and Los Angeles.

Table 2 shows, for each of the 3 regions, the 1990 census population and the number of hospitalizations for viral pneumonia between January 1983 and June 1998. As expected, there were considerably more hospitalizations in Los Angeles, with its larger population base. More hospitalizations occurred in the youngest and oldest age groups.

Figures 1 through 3 show precipitation, minimum temperatures, and hospitalizations for viral pneumonia in the 3 regions for July 1990 through December 1992. This period was chosen to show both a normal weather period and an El Niño event and because it was representative of the entire time period; compressing the full record in 1 figure resulted in too small a scale to see the patterns.



Source. Hospital admission data were provided by the Office of Statewide Health Planning and Development, Sacramento, Calif.

FIGURE 3—Precipitation, minimum temperatures, and hospitalizations of females for viral pneumonia: Los Angeles and Orange counties, California, July 1990–December 1992.

The seasonality of viral pneumonia was clearly evident, particularly in Sacramento (Figure 1) and Los Angeles (Figure 3), as was the increase in hospitalizations when minimum temperatures dropped. The decrease in minimum temperatures occurred before the increase in hospitalizations. Figure 2 shows a similar but less dramatic pattern for San Francisco, partly because minimum temperatures varied less.

Tables 3 through 5 show, for each of the 3 regions, changes in number of hospitalizations for viral pneumonia by weather variables. The tables give the percentage change and 95% confidence intervals for normal weather periods, for El Niño events, and for the comparisons of mild and strong El Niño events with normal weather periods. There were 2 consistent findings across the 3 regions. First, there was little change in the number of hospitalizations following increases in precipitation. Second, patterns of associations with temperature, precipitation, and sea surface temperature tended to be similar during normal weather periods and El Niño events.

In Sacramento (Table 3), a decrease of 5°F in the maximum temperature difference increased hospitalizations in all 3 age groups by more than 25% for both normal weather periods and El Niño events. Changes in minimum temperatures also were associated with viral pneumonia hospitalization, but the confidence intervals were wide and the associations were not consistent across age groups. During El Niño events, a 1°C decrease in sea surface temperature was associated with a 14% to 22% increase in hospitalizations. During normal weather periods, changes in sea surface temperature were more strongly associated with hospitalizations in the 2 younger age groups, with no association in the oldest age group. Some of the variability was due to small numbers in particular cells, as evidenced by the wide confidence intervals.

In the comparison between El Niño events and normal weather periods in Sacramento, hospitalizations decreased for children by 21% to 28% and increased for adults by 10% to 48%. The associations were more pronounced during mild El Niño events.

The patterns of association were different in San Francisco (Table 4). In this region, minimum temperature was strongly associated with hospitalizations; decreasing the minimum temperature by 5°F increased viral pneumonia hospitalizations by more than 30% in all age groups during both weather periods. As was found in Sacramento, sea surface temperature had a stronger association with hospitalizations in the younger age group (a 25% increase in hospitalizations during normal weather periods for each 1°C decrease in sea surface temperature); there was no significant association in adults. Maximum temperature

TABLE 3—Percentage Change (95% Confidence Interval) in Hospital Admissions for Viral Pneumonia,[a] by Weather Variables in Normal and El Niño Seasons: Females in Sacramento and Yolo Counties, California, 1983–1998

	Patients Aged 0–17 y		Patients Aged 18–55 y		Patients Aged ≥56 y	
	Normal	El Niño	Normal	El Niño	Normal	El Niño
Precipitation[b]	2.2 (1.8, 2.6)	−3.0 (−4.1, −2.0)	−7.6 (−11.0, −4.0)	−9.6 (−15.3, −3.5)	−3.8 (−5.2, −2.3)	−4.2 (−4.7, −3.8)
Sea surface temperature[c]	30.7 (29.0, 32.4)	15.4 (11.8, 19.0)	11.3 (6.1, 16.8)	14.4 (9.5, 19.6)	−4.5 (−9.5, 0.8)	22.0 (16.5, 27.6)
Temperature difference[d]	26.4 (19.0, 34.4)	28.1 (20.0, 36.8)	41.9 (36.9, 47.2)	48.3 (22.7, 79.3)	30.8 (1.9, 68.0)	37.2 (22.9, 53.2)
Minimum temperature[d]	24.2 (8.2, 42.5)	12.5 (3.9, 21.7)	−0.6 (−12.7, 13.1)	−2.5 (−3.8, −1.1)	13.8 (−14.5, 51.6)	14.5 (3.4, 26.7)
Mild El Niño vs normal[e]	−21.5 (−26.2, −16.4)		48.0 (38.6, 58.1)		35.8 (32.0, 39.7)	
Strong El Niño vs normal[e]	−28.3 (−28.6, −28.1)		10.3 (6.4, 14.4)		14.5 (−2.5, 34.5)	

[a]Four-day totals with a 7-day lag.
[b]One unit of precipitation change is defined as an increase of 0.2 in.
[c]One unit of sea surface temperature change is defined as a decrease of 1°C.
[d]One unit of temperature change is defined as a decrease of 5°F.
[e]With adjustment for weather variables and year.

difference was more important for adults (slightly decreased hospitalizations during normal weather periods, with increased hospitalizations during El Niño events). Hospitalizations did not change much between normal weather periods and El Niño events.

Similar patterns were found for Los Angeles (Table 5), with 2 exceptions. First, weather variables had a weaker association with hospitalizations in Los Angeles than in San Francisco, although the association was still strong for decreasing minimum temperature. Second, the patterns for sea surface temperature and maximum temperature difference were weaker and inconsistent in adults. As was found for San Francisco, El Niño events had little additional association with hospitalizations in Los Angeles.

DISCUSSION

Hospitalizations for viral pneumonia showed the expected seasonal pattern.[12] The associations of hospitalizations with specific weather variables varied by geographic region, except for precipitation and sea surface temperature. Precipitation was not associated with hospitalizations. This was interesting because precipitation, rather than changes in temperature, is more likely to drive Californians indoors, where viral transmission is expected to occur.[12,13] Decreased sea surface temperature, used as a marker for weather effects other than those analyzed, was associated with increased hospitalizations in the youngest age group during normal weather periods in all 3 regions. The association was weaker during El Niño events. It would be interesting to learn which weather factors captured by this variable are important for predicting hospitalization patterns.

One temperature variable could not describe the hospitalization patterns found in

TABLE 4—Percentage Change (95% Confidence Interval) in Hospital Admissions for Viral Pneumonia,[a] by Weather Variables in Normal and El Niño Seasons: Females in San Francisco and San Mateo Counties, California, 1983–1998

	Patients Aged 0–17 y		Patients Aged 18–55 y		Patients Aged ≥56 y	
	Normal	El Niño	Normal	El Niño	Normal	El Niño
Precipitation change[b]	1.5 (−1.8, 4.8)	1.2 (−1.6, 4.0)	3.5 (0.3, 6.8)	0.3 (−0.8, 1.4)	0.3 (−8.3, 9.7)	−2.1 (−6.1, 2.2)
Sea surface temperature change[c]	24.6 (9.9, 41.2)	17.4 (15.3, 19.5)	6.7 (−12.3, 29.8)	8.2 (0.3, 16.8)	5.6 (−4.3, 16.5)	13.5 (5.2, 22.4)
Temperature change[d]	0.0 (−2.3, 2.3)	10.5 (−0.7, 23.0)	−13.6 (−20.9, −5.6)	14.6 (4.2, 26.1)	−6.9 (−24.4, 14.6)	20.8 (19.4, 22.3)
Minimum temperature[d]	46.2 (33.2, 60.3)	30.3 (25.5, 35.3)	57.4 (17.9, 110.1)	46.8 (46.1, 47.6)	56.2 (51.7, 60.9)	49.9 (35.7, 65.5)
Mild El Niño vs normal[e]	−1.9 (−32.6, 42.8)		2.3 (−7.4, 13.0)		25.7 (7.3, 47.3)	
Strong El Niño vs normal[e]	−10.5 (−17.5, −2.9)		5.4 (−21.9, 42.3)		4.9 (−12.5, 25.8)	

[a]Four-day totals with a 7-day lag.
[b]One unit of precipitation change is defined as an increase of 0.2 in.
[c]One unit of sea surface temperature change is defined as a decrease of 1°C.
[d]One unit of temperature change is defined as a decrease of 5°F.
[e]With adjustment for weather variables and year.

TABLE 5—Percentage Change (95% Confidence Interval) in Hospital Admissions for Viral Pneumonia,[a] by Weather Variables in Normal and El Niño Seasons: Females in Los Angeles and Orange Counties, California, 1983–1998

	Patients Aged 0–17 y		Patients Aged 18–55 y		Patients Aged ≥56 y	
	Normal	El Niño	Normal	El Niño	Normal	El Niño
Precipitation[b]	1.0 (0.9, 1.1)	0.0 (–0.2, 0.3)	2.3 (2.3, 2.4)	0.9 (0.7, 1.1)	–1.4 (–2.1, –0.7)	0.8 (–0.1, 1.7)
Sea surface temperature[c]	21.6 (16.4, 27.1)	8.5 (7.9, 9.1)	–4.3 (–14.8, 7.5)	0.2 (–0.0, 0.3)	6.6 (6.6, 6.6)	18.4 (16.2, 20.7)
Temperature difference[d]	–1.3 (–5.4, 2.9)	–0.7 (–1.0, –0.5)	–2.9 (–3.8, –2.0)	–1.7 (–5.5, 2.3)	–10.5 (–12.1, –8.8)	0.5 (0.4, 0.5)
Minimum temperature[d]	30.4 (23.9, 37.2)	18.4 (11.2, 26.0)	31.9 (19.4, 45.6)	30.9 (23.9, 38.2)	31.7 (30.6, 32.9)	16.5 (13.7, 19.4)
Mild El Niño vs normal[e]	–3.0 (–4.4, –1.6)		–4.6 (–6.6, –2.6)		1.3 (–1.6, 4.4)	
Strong El Niño vs normal[e]	–4.6 (–8.6, –0.5)		–4.2 (–9.7, 1.6)		–0.9 (–13.0, 12.9)	

[a]Four-day totals with a 7-day lag.
[b]One unit of precipitation change is defined as an increase of 0.2 in.
[c]One unit of sea surface temperature change is defined as a decrease of 1°C.
[d]One unit of temperature change is defined as a decrease of 5°F.
[e]With adjustment for weather variables and year.

the 3 geographic regions. In San Francisco and Los Angeles, a 5°F decrease in the minimum temperature was associated with a large increase in hospitalizations (about 30%–50%). In Sacramento, a 5°F decrease in the maximum temperature difference was associated with a large increase in hospitalizations (about 25%–40%).

There appeared to be no association of El Niño events with hospitalizations in San Francisco and Los Angeles, possibly because temperatures did not change much in these regions during El Niño events. In Sacramento, where seasonal temperatures did change during El Niño events, hospitalizations decreased among children and increased among adults. There is no obvious explanation for these patterns. Further investigation is required to understand the differences among the age groups in terms of changes in behavior, potential exposures, and other factors during El Niño events and normal weather periods. The recently developed capability to predict El Niño events means that public health interventions could be devised once these differences are understood.

More analyses are required to elucidate the relative importance of weather variables and specific weather patterns in the context of other factors associated with virus transmission.[13] We did not have data on viral isolates and so were unable to determine whether patterns varied by virus type. Also, we did not have data on air pollution. Air pollution exposures could confound the associations present here, but it is not clear in which direction. For example, the increased precipitation during El Niño events may result in decreased exposure to some air pollutants. Much of the literature on air pollution and respiratory diseases has treated weather as a confounding variable to be controlled for in the analysis. Further analysis is warranted to discern the joint and separate associations of weather variables and air pollution with hospitalizations for viral pneumonia. Such analyses should take El Niño events into account where appropriate.

These data underscore the difficulties inherent in trying to understand the potential health effects of climate variability and change. The associations between viral pneumonia hospitalizations and specific weather factors varied across geographic regions. A model based on either the inland region or one of the coastal regions would not be predictive for the other regions.

There is interest in predicting how winter influenza mortality could change with warmer winters.[1,2] There are, of course, significant problems with speculating on what might happen in a future world. Apart from weather, many social and economic changes are likely that could influence disease patterns. However, to inform decision makers and to prioritize research areas, it can be useful to consider what would happen if only the weather changed. In that unlikely event, if the current weather–hospitalization pattern found in Sacramento is similar to that for regions experiencing colder climates, then the results from El Niño events suggest that warmer winters may decrease hospitalizations for viral pneumonia in children and increase such hospitalizations in adults. El Niño events are short-term weather fluctuations, and the response of a population to these events may be different from the acclimatization response to long-term climate change. Different patterns could lead to different conclusions.

Although El Niño events were not associated with hospitalizations for viral pneumonia in San Francisco and Los Angeles, regions known for their moderate climates, there were associations with minimum temperature changes during both normal weather periods and El Niño events. These results do not directly address the question of whether warmer global temperatures could reduce winter influenza mortality. However, they do suggest that viral pneumonia would continue to have a seasonal pattern and a significant association with hospitalizations even as cities in colder climates begin to experience warmer temperatures.

Although it is not possible to directly intervene to alter the weather, understanding why specific weather factors are associated with increased or decreased hospitalizations can lead to an improved understanding of the dynamics of virus transmission, which can lead to better efforts to control disease outbreaks. One concern is how to reduce population vulnerability to the potential adverse consequences of climate variability and change. Vulnerability is a function of the sensitivity of a population to climate change and the ability of the population to adapt in anticipation of or in response to adverse impacts.[14] A knowledge of ways to minimize risk or maximize adaptive capacity can be used to develop anticipatory adaptation measures. These results are a first step in understanding population sensitivity under different weather conditions. ■

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Contributors

K.L. Ebi planned the study and took the lead in writing the article. K.A. Exuzides developed the analysis approach, which was implemented by K.A. Exuzides and E. Lau. M. Kelsh contributed to the study design and analysis. A. Barnston provided climatological expertise and data. All authors contributed to evaluating the results and writing the paper.

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