



# The Relationship Between Laoshan Winds and Respiratory and Cardiovascular Diseases in Hengchun Peninsula, Taiwan

Li-Wei Lai<sup>1,\*</sup>

<sup>1</sup>Centre for General Education, National Taipei University of Business, Taipei, Taiwan, R.O.C

\*Corresponding author: Li-Wei Lai, Associate Professor of Environmental Science, Centre for General Education, National Taipei University of Business, Taipei, Taiwan, R.O.C. Tel: +886-223226555, Fax: +886-223226427, E-mail: liweilai@ntub.edu.tw

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## Abstract

**Background:** The north-easterly monsoons originating from Siberia-Mongolia predominantly determine the weather patterns during the cold and dry seasons in Taiwan. Laoshan Winds (LWs), which have been recorded since 1894, can influence agricultural activities and cause an increase in the amount of dust during the dry period in the Hengchun Peninsula.

**Methods:** This study investigated the associations among weather changes, Particulate Matter (PM), LW, and public health impact in Hengchun Peninsula during January to April and October to December 2006 to 2010. The data regarding weather conditions, PM with aerodynamic diameters smaller than or equal to 2.5  $\mu\text{m}$  (PM<sub>2.5</sub>), PM with aerodynamic diameters smaller than or equal to 10  $\mu\text{m}$  (PM<sub>10</sub>), and hospital and clinic admissions for respiratory and cardiovascular diseases were obtained from several governmental sources in Taiwan. Disease admissions data were categorised to four age groups: zero to four: Infants, five to fourteen: Children, 15 to 64: Adults; and > 65: Elderly. The Australian apparent temperature, poisson regression model, and parametric test (z statistic for a one-tailed test) were used to analyse the data.

**Results:** The results showed that LWs cause a significant reduction in relative humidity and surface air temperature and a significant increase in air pressure and wind speed, which induces a significant decrease in the apparent temperature. Significant increases were noted in the mean number of admissions in the adults group for respiratory diseases; there was a 13.4% [95% CI, 2.13% to 25.8%] increase on the LW days ( $P < 0.05$ ).

**Conclusions:** These results imply that the LWs along with the cold weather and strong local winds caused an increase in the incidence of respiratory diseases, which was also associated with winter monsoon and topographical characteristics.

**Keywords:** Australian Apparent Temperature, Circulatory Diseases, Laoshan Winds, Particulate Matter, Respiratory Illness, Weather Conditions

## 1. Background

The prevailing monsoon flow determines the variations in rainfall throughout warm and cold seasons in Taiwan (1). The outbreak of cold air in relation to the Siberian-Mongolian high influences the East Asian winter monsoon (2), and the north-easterly monsoons, which predominantly originate from Siberia-Mongolia, define the weather patterns during the cold and dry seasons in Taiwan (3).

When the strong north-easterly monsoon (SNM) affects Taiwan, a specific type of local wind pattern, known as the Laoshan Winds (LWs), develops on the leeward side of the Hengchun Peninsula. Taiwanese local records (4) revealed that the LWs have been recorded since 1894, during the Chin Dynasty. This type of wind influences the agricultural activities in this region (5, 6) and causes an increase in the

amount of dust during the dry periods (7).

Although similar to the forces causing the Mistral winds in southern France, the Santa Ana winds in Southern California (USA), and the Chinook winds along the eastern slope of the Rocky Mountains (USA) (8, 9), the forces causing the LWs (10) differ from those causing other local winds.

The variable weather conditions as well as Particulate Matter (PM) can raise the risk to public health (11-13). Many studies suggested that the surface temperature extremes were the key environmental factors related to the incidence of stroke and cardiovascular diseases (14-16). In addition, several studies have suggested that PM with aerodynamic diameters of  $\leq 10 \mu\text{m}$  (PM<sub>10</sub>) and PM with aerodynamic diameters of  $\leq 2.5 \mu\text{m}$  (PM<sub>2.5</sub>) were associated with increases in respiratory and circulatory system diseases (17, 18). For example, Hansen et al. (19) indicated that the rela-

tionship between the concentrations of  $PM_{10}$  and  $PM_{2.5}$  and the number of cardiovascular hospital admissions was evident during the cool season in Adelaide, South Australia. Furthermore, Nakhle et al. (20) indicated that the concentrations of  $PM_{10}$  and  $PM_{2.5}$  were positively related to respiratory and circulatory system disease admissions in Beriut, Lebanon. Jones et al. (21) indicated that  $PM_{2.5}$  concentrations were positively related to respiratory hospitalizations in New York. However, most previous studies have focused only on the effects of  $PM_{2.5}$  (22).

The impacts of the LWs due to weather conditions, in combination with topography and PM, on public health have not been conclusively established so far. Although local wind patterns have been linked with health issues in certain sections of the population (23), a few studies have reported contrasting results (24, 25). In the present study, the authors analyzed the occurrence of LWs along with terrain characteristics, such as the altitude of the Central Mountain Range (CMR), in relation to circulatory and respiratory disease admissions.

### 1.1 Study Area

Surrounded by the sea, Taiwan Island is situated between the European and Asian continental plate and the Pacific Ocean (Figure 1A). This study focused on Hengchun Peninsula, Pingtung County, Taiwan. The CMR terminates in Pingtung county (Figure 1B). A line drawn between Dawu (x) and Fungshan (y) villages, shown in red in Figure 1b, indicates the point at which the mean height of the mountains decreases rapidly from ~3000 m to < 1000 m. The study area was located to the south of this line on the leeward side of the CMR, where the mean height of the mountains was < 1000 m (Figure 1C), with numbers 2 to 5 indicating area H, which includes Fangshan, Shizi, Chaozhou, and Chencheng Townships (Figure 1D). Area H is the study region present in the Hengchun Peninsula. Number one indicates other townships in Pingtung county. The red circle indicates the Environmental Protection Administration (EPA) air quality monitoring sites, and the blue triangle indicates the major Central Weather Bureau (CWB) meteorological site. The study region has an area of 597 km<sup>2</sup> and a population density of 87/km<sup>2</sup> (26, 27); agriculture and tourism are its main economic activities.

### 2. Objectives

The aims of this study were to establish the effects of LWs on air quality and weather conditions in areas with a specific type of topographical characteristics and also to determine the risk to public health associated with LWs.

### 3. Methods

This study was conducted during the months of January to April and October to December in 2006, 2007, 2008, 2009, and 2010. Daily and hourly meteorological data and hourly  $PM_{10}$  and  $PM_{2.5}$  concentrations were obtained from the Hengchun station operated by the Taiwan CWB and from the Hengchun air quality monitoring site operated by the Taiwan EPA. Hourly concentrations of  $PM_{2.5-10}$  were derived by subtracting the hourly  $PM_{2.5}$  concentrations from the hourly  $PM_{10}$  concentrations. An LW day was defined as a day, during which the daily instantaneous wind direction was north-easterly or north and north-easterly and the wind speed exceeded 15 m/s (10), as recorded at the Hengchun station.

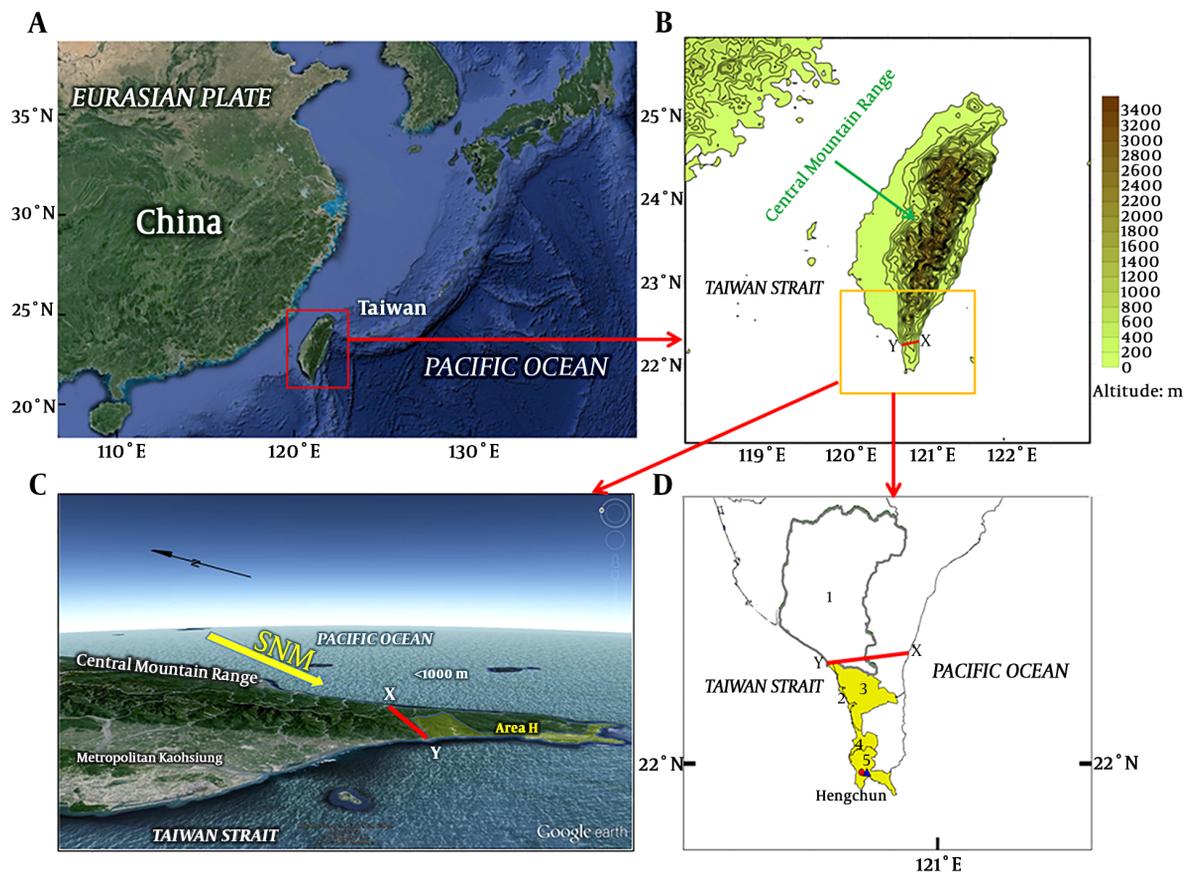
The air temperature perceived by humans is influenced by the surface wind speed and relative humidity. In 2001, Canada and the United States developed the current wind-chill index, which can estimate the degree of coldness perceived by humans (28). Due to the effects of wind, people may feel significantly colder than what they might have felt based on the actual temperature alone. This index is applied when the temperatures are at or less than 10°C and wind speeds are above 4.8 km/hour (29). However, in this study, the study area was a tropical climate region, where the mean air temperature in the coldest month was greater than 18°C. Therefore, in comparison with the current wind-chill index, the Australian apparent temperature was more useful for the present study. Equations 1 and the formulas used for the Australian apparent temperature (30), were used in identifying the thermal comfort level (31, 32). In this study, solar radiation was not considered in the formula because of the presence of trees and other devices, which provide cover in the tropical area and make the value of perceived temperature different from the evaluated values.

$$AT = T_s + 0.33 \times e - 0.70 \times WS - 4.00 \quad (1)$$

$$e = \frac{RH}{100} \times 6.105 \times \exp\left(\frac{17.27 \times T_s}{237.7 + T_s}\right) \quad (2)$$

where AT is the Australian apparent temperature,  $T_s$  is the surface air temperature (°C), WS is the surface wind speed (m/s), RH is the relative humidity (%), and e is the vapour pressure.

The current research used the International Classification of Diseases (Ninth Revision) Clinical Modification codes (ICD-9-CM) for hospital admissions data. Data on hospital admissions for the following diseases were obtained from the National Health Insurance Program, operated by the Taiwan National Bureau for Central Health



**Figure 1.** Geographical location of the study area. A) Location of Taiwan. B) Terrain of Pingtung County. C) Side view of the study areas. D) Location of the study areas. Satellite images were obtained from Google Earth version 7.02.

Insurance (BNHI): asthma (ICD-9-CM, 493), cerebrovascular diseases (ICD-9-CM, 430 - 437), circulatory diseases (ICD-9-CM, 390-459), respiratory diseases (ICD-9-CM, 460 - 519), respiratory diseases-influenza (ICD-9-CM, 487), and stroke (ICD-9-CM, 430 - 434). To determine the number of admissions for respiratory diseases other than influenza, the number of admissions for respiratory diseases-influenza (ICD-9-CM, 487) was subtracted from the number of admissions for respiratory diseases (ICD-9-CM, 460 - 519). The National Health Insurance Program provides most of the health insurance in Taiwan (99.6%); therefore, the admissions data was highly representative (33). Four age groups for hospital and clinic admissions data were studied: zero to four: Infants, five to fourteen: Children, 15 to 64: Adults, and > 65: Elderly.

In this study, in order to determine the relationship between respiratory and cardiovascular diseases admissions and the weather and the relationship between disease ad-

missions and PM ( $PM_{2.5}$  and  $PM_{2.5-10}$ ) concentrations, the researchers applied the Poisson regression, which is suitable for non-negative integer values of the dependent variables (34). Equation 3 shows the Poisson regression model:

$$\log y_i = a_0 + a_1 X_{1i} + a_2 X_{2i} + a_3 X_{3i} + \dots + a_k X_{ki} \quad (3)$$

where  $y_i$  indicates the daily number of disease admissions and the subscript  $i$  indicates the number of observation days ( $i = 1, 2, \dots, n$ ). Variable  $x$  indicates parameters, such as daily mean air temperature ( $^{\circ}C$ ), daily mean wind speed (m/s), daily instantaneous maximum wind speed (m/s), Australian apparent temperature, Asian dust storm (ADS), LW,  $PM_{2.5-10}$  ( $\mu g/m^3$ ),  $PM_{2.5}$  ( $\mu g/m^3$ ), weekends, and Mondays. The subscript  $k$  indicates the number of variables. In this model,  $y$  is a log-linear function of variable  $x$ .

The parametric method ( $z$ -test) for a one-tailed test was used for comparing parameter values recorded on the LW and non-LW days. Equation 4 was generally employed to

test the differences between the means of two large independent samples (35, 36):

$$Z = \frac{(\bar{\alpha}_1 - \bar{\alpha}_2) - (\mu_1 - \mu_2)}{S_{\bar{\alpha}_1 - \bar{\alpha}_2}} \quad (4)$$

$$S_{\bar{\alpha}_1 - \bar{\alpha}_2} = \sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}} \quad (5)$$

Where the subscript is one for non-LW days and two for LW days,  $\bar{\alpha}_1$  and  $\bar{\alpha}_2$  are the means of the parameters from sample sub-groups,  $\mu_1$  and  $\mu_2$  are the means of the parameters from total populations,  $S_1$  and  $S_2$  are the standard deviations of each sub-group, and  $n_1$  and  $n_2$  are the number of samples.

The null hypothesis,  $H_0$ , was that an insignificant increase in a parameter that existed on the LW days. The alternative hypothesis,  $H_1$ , was that a significant increase in a parameter existed on LW days. If the z value fell in the rejection region, the researchers rejected the null hypothesis at  $\alpha$  with 95% confidence.

#### 4. Results

Table 1 shows the discrepancies in weather parameters and PM concentrations occurring between the LW days and non-LW days during January to April and October to December of 2006 to 2010. The mean relative humidity, air temperature, and apparent temperature on the LW days were significantly smaller than that on the non-LW days, although the mean surface air pressure, wind speed, and instantaneous maximum wind speed were significantly greater. For example, on the LW days, the values of  $11.0 \pm 4.78^\circ\text{C}$  for the mean apparent temperature were significantly smaller than the values of  $24.5 \pm 3.79^\circ\text{C}$  on the non-LW days ( $P < 0.05$ ). The rate of occurrence of rainy days, minimum air temperature, minimum apparent temperature, and maximum  $\text{PM}_{2.5}$  and  $\text{PM}_{2.5-10}$  concentrations on the LW days were smaller than those on the non-LW days. In summary, the weather changed significantly on the LW days.

Table 2 shows the impact on public health based on the mean of the number respiratory and circulatory disease admissions during January to April and October to December in 2006 to 2010 due to the effects of weather and PM concentrations for general groups and for age-specific groups in Area H. These data were based on the Poisson model, using Equation 3. The results showed that in comparison with circulatory diseases, the incidence of respiratory diseases was more evident, and they all occurred after a lag period of the LW days. For example, the number of

respiratory disease admissions significantly increased by 2.29% (0.13% to 4.41%) in the Elderly group on the D+1 day for every  $1^\circ\text{C}$  fall in temperature and by 7.13% (0.84% to 13.0%) in the Children group on the D+2 day. The number of asthma disease admissions significantly increased by 1.43% (0.24% to 2.63%) in the Elderly group on the D+3 day for every one m/s increment in the mean wind speed. The number of asthma disease admissions significantly increased by 0.16% (0.01% to 0.30%) in the Elderly group on the D+3 day for every  $1 \mu\text{g}/\text{m}^3$   $\text{PM}_{2.5}$  increment. The ADS caused an increase in the incidence of respiratory diseases by 29.9% (3.68% to 54.9%) in the children group on the D+1 day. Significant influences of LWs on respiratory diseases included increases in the mean numbers of respiratory disease admissions by 13.4% (2.13% to 25.8%) in the adult group on the D+2 day.

#### 5. Discussion

The effects of the LWs can be obtained from quantitative analysis of weather conditions, air quality, and health effects rather than from qualitative statements in the historical records. The historical literature (4, 7) states that the LWs blew dust off the ground, yet it rarely mentions the impact on health due to LWs. This study found that LWs significantly changed the weather conditions in area H and that the evident weather change was similar to the effect of other kinds of local winds in different regions (24, 37, 38).

The LWs did not cause an increase in PM concentrations in Area H. This study showed that the mean  $\text{PM}_{2.5}$ ,  $\text{PM}_{2.5-10}$  or the ratio of  $\text{PM}_{2.5}$ , and  $\text{PM}_{2.5-10}$  did not increase during the LW period. Furthermore, all of the mean  $\text{PM}_{2.5}$  and  $\text{PM}_{10}$  concentrations on the LW and non-LW days did not exceed the World Health Organization (WHO) guidelines (39) for 24-hour mean concentrations of  $\text{PM}_{2.5}$  ( $25.0 \mu\text{g}/\text{m}^3/\text{day}$ ) and  $\text{PM}_{10}$  ( $50.0 \mu\text{g}/\text{m}^3/\text{day}$ ). However, this finding was in contrast with historical records (4, 7), which state that LWs can cause a huge amount of dust. This implies that the weather was favourable for good atmospheric dispersion, and the PM episodes occurring during the study period were just a few sporadic dust events.

Topographical characteristics play an important role in the occurrence of LWs. Area H is located on the leeward side of the CMR, where the mean height of the mountains is  $< 1000$  m. The strong north-easterly monsoon has a mean vertical depth of 1500 m (10), and thus it is not impeded by areas of the CMR with heights smaller than 1500 m. Therefore, significantly higher wind speed values were recorded on the LW days, which caused good dispersal of the PM. On the contrary, the few high PM concentration days were likely to be caused by long-range transport-like ADS, owing to the lack of local anthropogenic emissions in

**Table 1.** Weather Parameters and Particulate Matter (PM) Concentrations for Laoshan Wind (LW) Days and Non-LW Days<sup>a</sup>

Hengchun Peninsula Parameters	LW (n = 165) (Mean ± SD)	Non-LW (n = 529) (Mean ± SD)
Rainfall, mm/day	0.60	0.58
Surface air pressure, hPa	1013 ± 3.57 <sup>†</sup>	1012 ± 3.44
Wind speed, m/s	5.55 ± 1.78 <sup>*</sup>	3.59 ± 2.07
Instant wind speed, m/s	20.2 ± 3.59 <sup>†</sup>	14.5 ± 6.05
Relative humidity, %	68.0 ± 8.25	70.9 ± 5.50 <sup>*</sup>
Air temperature, °C	21.2 ± 4.36	23.9 ± 1.84 <sup>*</sup>
Apparent temperature	11.0 ± 4.78	24.5 ± 3.79 <sup>*</sup>
PM <sub>2.5</sub> , µg/m <sup>3</sup>	14.3 ± 8.88	14.5 ± 9.59
PM <sub>2.5-10</sub> , µg/m <sup>3</sup>	12.7 ± 7.44	13.3 ± 6.20
PM <sub>10</sub> , µg/m <sup>3</sup>	26.9 ± 14.7	27.8 ± 14.7
PM <sub>2.5</sub> /PM <sub>10</sub>	0.51 ± 0.14	0.51 ± 0.10
	LW	Non-LW
Rate of rainy days	12.7%	16.6%
Minimum air temperature, °C	15.9	17.3
Minimum apparent temperature	10.9	13.2
Maximum PM <sub>10</sub> , µg/m <sup>3</sup>	78.5	93.1
Maximum PM <sub>2.5</sub> , µg/m <sup>3</sup>	44.0	56.1
Maximum PM <sub>2.5-10</sub> , µg/m <sup>3</sup>	41.2	68.4

<sup>a</sup>†Indicates that values are significantly different at  $\alpha = 0.05$ ; “-” indicates that data is unavailable.

Area H. Therefore, the effects of the LWs were thus considered to be associated with local topographic characteristics.

The respiratory diseases were related to the increase of PM<sub>2.5</sub> concentration and ADS. The results show that the incidence of asthma disease in the Elderly group was significantly related to the increase of PM<sub>2.5</sub> concentration, and the incidence of respiratory disease significantly increased on the ADS days. This relationship was evident in children and elderly groups on the lag days of the events and was not related to the local winds. These findings are partly in agreement with those reported by studies which suggested that PM was related to increases in respiratory and circulatory diseases (17, 18).

The evident weather change impacted the health of people. The apparent temperature was related to the increase of the incidence of respiratory diseases in the children and general groups and cerebrovascular diseases in the children and elderly groups. High wind speed was related to asthma and respiratory diseases, such as influenza in the elderly group. The evident weather change increased the risk of respiratory diseases and circulatory diseases. These results are partly in agreement with those reported by several previous studies (14, 16, 40), which indicates that changes in surface temperature affect the inci-

dence of circulatory diseases.

The effect of the LWs on health was group specific. On the LW days, the apparent temperature was significantly smaller than the mean surface air temperature. Under such conditions, the effect of wind chill, which considers the variation of relative humidity and wind speed, made people feel much colder than that indicated by the actual temperature alone (41). The significant influences of the LWs were marked by the evident increases in respiratory disease admissions in the adults group on the lag days. In comparison with other groups, the health impact of the LWs was highest for the Adult group. The likely explanation is that the adult group formed the major outdoor work force in the study area. The adults group has a greater chance of exposure to significant weather change.

Other local winds, such as Mistral, Chinook, and Mistral Ana, which are associated with wind and terrain features, can also induce evident weather changes (Table 3). Based on the effects of other local winds on health, the findings of this study were inconsistent with those of previous studies (24, 40, 41). The probable reason for this is the distinct weather conditions in the study area related to topographical characteristics.

In summary, the relationship between respiratory diseases and the LWs can be seen on the lag days. This was due

**Table 2.** Increases in the Mean Numbers of Hospital Admissions as Calculated by the Poisson Model for Weather Parameters and PM Concentrations<sup>a,b</sup>

Area H	D+1 (n = 1060)	D+2 (n = 1059)	D+3 (n = 1058)
<b>Apparent temperature</b>			
Cerebrovascular disease (ICD-9-CM Code 430-437)			
Elderly	-2.29% (-4.41% to -0.13%)		
Children		-7.13% (-13.0% to -0.84%)	
<b>Respiratory (ICD-9-CM Code 460-519)</b>			
Children	-7.09% (-13.0% to -0.77%)		
General	-8.99% (-16.6% to -0.69%)		
<b>Mean wind speed (m/s)</b>			
Asthma (ICD-9-CM, 493)			
Elderly			1.43% (0.24% to 2.63%)
<b>Respiratory-Influenza (ICD-9-CM Code 487)</b>			
Elderly		1.15% (0.10% to 2.19%)	
<b>PM<sub>2.5</sub>, µg/m<sup>3</sup></b>			
Asthma (ICD-9-CM, 493)			
Elderly			0.16% (0.02% to 0.31%)
<b>ADS</b>			
Respiratory (ICD-9-CM Code 460-519)			
Children	29.9% (3.68% to 54.9%)		
<b>Laoshan wind</b>			
Respiratory (ICD-9-CM Code 460-519)			
Adults		13.4% (2.13% to 25.8%)	

<sup>a</sup> Groups which are not significant at  $\alpha = 0.05$  not shown. "( )" indicates the 95% confidence interval.

<sup>b</sup> ICD-9-CM Codes 460 - 519 excluding ICD-9-CM Code 487.

**Table 3.** Comparison of the Major Findings of Health Effects Due to Local Winds

Local Winds	Weather Features	Health Effect
<b>Laoshan winds (considered in this study)</b>	Drop in air temperature and relative humidity; gusty winds (22.50° to 45°)	The respiratory disease admissions increased by 13% (1.90% to 25.2%) in the adult group with a lag of 2 days after the Laoshan wind event in Hengchun Peninsula, Taiwan.
<b>Mistral wind</b>	Gusty winds (292.5° to 0°) and low rainfall amount	Tissot-Dupont et al. (40) indicated that the relationship between Q fever and mistral events existed in the Bouches-du-Rhone district of southern France.
<b>Chinook wind</b>	Drop in air temperature and relative humidity; gusty western winds (225° to 315°)	Field and Hill (24) indicated that there was no relationship between stroke occurrence and weather changes due to Chinook in Calgary, Canada.
<b>Santa Ana wind</b>	Increase in air temperature and drop in relative humidity; gusty winds	Corbett (41) indicated that the relationship between asthma incidence and Santa Ana wind was significant in southern California.

to significant increments in wind speed and reductions in air temperature, which induced substantial decreases in the apparent temperature index.

The limitations of this study were as follows. Firstly, the study population included only residents having health insurance, who visited clinics or hospitals for treatment. It

is therefore likely that other people also suffered from adverse health effects that were not officially recorded. Secondly, some patients were possibly counted twice if they were admitted more than once. It was not possible to resolve this issue because personal details, such as patient identification numbers and addresses, were not released.

In this respect, the number of admissions may have been overestimated.

This study only investigated the relationship between LWs and the number of circulatory and respiratory disease admissions. The mechanism of the process needs to be further studied.

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## References

- Chen CS, Chen YL. The rainfall characteristics of Taiwan. *Mon Weather Rev.* 2003;**131**:1323–41.
- Chang CP, Lu MM, Wang B. *The East Asian Winter Monsoon World scientific series on Asia-Pacific weather and climate, Vol. 5. The global monsoon system: research and forecast.* Singapore: World Scientific Publishing Co. Pte. Ltd; 2011.
- Central Weather Bureau (CWB). *The introduction of characteristics of climate in Taiwan.* 2013. Available from: [http://www.cwb.gov.tw/V77/climate/climate\\_info/taiwan\\_climate/taiwan\\_1/taiwan\\_1\\_1.html](http://www.cwb.gov.tw/V77/climate/climate_info/taiwan_climate/taiwan_1/taiwan_1_1.html).
- Tu JS, Gao XZ, Hu C, Zhu SJ. *Taiwan Local Chronicle-Hengchun county annals.* Taipei: Zong Qing Press Inc; 1995. Chinese.
- Council of Agriculture. *Agricultural Meteorology Counselling Service.* 2016, [cited 2016 September 30]. Available from: <http://amis.tari.gov.tw/MapManager/PageContent.aspx?type=C&id=20>.
- Central Weather Bureau. *Q & A of meteorological basic common sense.* Taipei: CWB; 2010.
- Liu ZM. *Weather and Climate in Taiwan.* Taipei: Chang Min CO., Ltd; 1996. Chinese.
- Strahler AH. *Introducing physical geography.* 2nd ed ed. New York: Wiley; 1998.
- Ahrens CD. *Essentials of Meteorology.* 3rd ed ed. Pacific Grove, CA, USA: Brooks/Cole-Thomson Learning; 2001.
- Hong SS, Hu CY. Study of the Hengchun fall wind phenomenon-Analysis of the phenomenon. *Atmos Sci.* 1990;**18**(3):171–91. Chinese.
- Liang WM, Liu WP, Kuo HW. Diurnal temperature range and emergency room admissions for chronic obstructive pulmonary disease in Taiwan. *Int J Biometeorol.* 2009;**53**(1):17–23. doi: [10.1007/s00484-008-0187-y](https://doi.org/10.1007/s00484-008-0187-y). [PubMed: [18989710](https://pubmed.ncbi.nlm.nih.gov/18989710/)].
- Stevanovic I, Jovasevic-Stojanovic M, Stosic JJ. Association between ambient air pollution, meteorological conditions and exacerbations of asthma and chronic obstructive pulmonary disease in adult citizens of the town of Smederevo. *Vojnosanit Pregl.* 2016;**73**(2):152–8. [PubMed: [27071282](https://pubmed.ncbi.nlm.nih.gov/27071282/)].
- Tam WW, Wong TW, Wong AH, Hui DS. Effect of dust storm events on daily emergency admissions for respiratory diseases. *Respirolgy.* 2012;**17**(1):143–8. doi: [10.1111/j.1440-1843.2011.02056.x](https://doi.org/10.1111/j.1440-1843.2011.02056.x). [PubMed: [22092966](https://pubmed.ncbi.nlm.nih.gov/22092966/)].
- Chen VY, Wu PC, Yang TC, Su HJ. Examining non-stationary effects of social determinants on cardiovascular mortality after cold surges in Taiwan. *Sci Total Environ.* 2010;**408**(9):2042–9. doi: [10.1016/j.scitotenv.2009.11.044](https://doi.org/10.1016/j.scitotenv.2009.11.044). [PubMed: [20138646](https://pubmed.ncbi.nlm.nih.gov/20138646/)].
- Wolf K, Schneider A, Breitner S, von Klot S, Meisinger C, Cyrus J, et al. Air temperature and the occurrence of myocardial infarction in Augsburg, Germany. *Circulation.* 2009;**120**(9):735–42. doi: [10.1161/CIRCULATIONAHA.108.815860](https://doi.org/10.1161/CIRCULATIONAHA.108.815860). [PubMed: [19687361](https://pubmed.ncbi.nlm.nih.gov/19687361/)].
- Yang TC, Wu PC, Chen VY, Su HJ. Cold surge: a sudden and spatially varying threat to health? *Sci Total Environ.* 2009;**407**(10):3421–4. doi: [10.1016/j.scitotenv.2008.12.044](https://doi.org/10.1016/j.scitotenv.2008.12.044). [PubMed: [19162302](https://pubmed.ncbi.nlm.nih.gov/19162302/)]. [PubMed Central: [PMC3204666](https://pubmed.ncbi.nlm.nih.gov/PMC3204666/)].
- Linares C, Diaz J. Short-term effect of concentrations of fine particulate matter on hospital admissions due to cardiovascular and respiratory causes among the over-75 age group in Madrid, Spain. *Public Health.* 2010;**124**(1):28–36. doi: [10.1016/j.puhe.2009.11.007](https://doi.org/10.1016/j.puhe.2009.11.007). [PubMed: [20060145](https://pubmed.ncbi.nlm.nih.gov/20060145/)].
- Middleton N, Yiallourous P, Kleanthous S, Kolokotroni O, Schwartz J, Dockery DW, et al. A 10-year time-series analysis of respiratory and cardiovascular morbidity in Nicosia, Cyprus: the effect of short-term changes in air pollution and dust storms. *Environ Health.* 2008;**7**:39. doi: [10.1186/1476-069X-7-39](https://doi.org/10.1186/1476-069X-7-39). [PubMed: [18647382](https://pubmed.ncbi.nlm.nih.gov/18647382/)]. [PubMed Central: [PMC2517071](https://pubmed.ncbi.nlm.nih.gov/PMC2517071/)].
- Hansen A, Bi P, Nitschke M, Pisaniello D, Ryan P, Sullivan T, et al. Particulate air pollution and cardiorespiratory hospital admissions in a temperate Australian city: A case-crossover analysis. *Sci Total Environ.* 2012;**416**:48–52. doi: [10.1016/j.scitotenv.2011.09.027](https://doi.org/10.1016/j.scitotenv.2011.09.027). [PubMed: [22221868](https://pubmed.ncbi.nlm.nih.gov/22221868/)].
- Nakhle MM, Farah W, Ziade N, Abboud M, Salameh D, Annesi-Maesano I. Short-term relationships between emergency hospital admissions for respiratory and cardiovascular diseases and fine particulate air pollution in Beirut, Lebanon. *Environ Monit Assess.* 2015;**187**(4):196. doi: [10.1007/s10661-015-4409-6](https://doi.org/10.1007/s10661-015-4409-6). [PubMed: [25792024](https://pubmed.ncbi.nlm.nih.gov/25792024/)].
- Jones RR, Hogrefe C, Fitzgerald EF, Hwang SA, Ozkaynak H, Garcia VC, et al. Respiratory hospitalizations in association with fine PM and its components in New York State. *J Air Waste Manag Assoc.* 2015;**65**(5):559–69. doi: [10.1080/10962247.2014.1001500](https://doi.org/10.1080/10962247.2014.1001500). [PubMed: [25947314](https://pubmed.ncbi.nlm.nih.gov/25947314/)].
- Adar SD, Filigrana PA, Clements N, Peel JL. Ambient Coarse Particulate Matter and Human Health: A Systematic Review and Meta-Analysis. *Curr Environ Health Rep.* 2014;**1**:258–74. doi: [10.1007/s40572-014-0022-z](https://doi.org/10.1007/s40572-014-0022-z). [PubMed: [25152864](https://pubmed.ncbi.nlm.nih.gov/25152864/)]. [PubMed Central: [PMC4129238](https://pubmed.ncbi.nlm.nih.gov/PMC4129238/)].
- Strauss S. An ill wind: the Foehn in Leukerbad and beyond. *J R Anthropol Inst.* 2007;**13**(s1):S165–S81.
- Field TS, Hill MD. Weather, Chinook, and stroke occurrence. *Stroke.* 2002;**33**(7):1751–7. [PubMed: [12105347](https://pubmed.ncbi.nlm.nih.gov/12105347/)].
- Macey PM, Schluter PJ, Ford RP. Weather and the risk of sudden infant death syndrome: the effect of wind. *J Epidemiol Community Health.* 2000;**54**(5):333–9. [PubMed: [10814652](https://pubmed.ncbi.nlm.nih.gov/10814652/)]. [PubMed Central: [PMC1731671](https://pubmed.ncbi.nlm.nih.gov/PMC1731671/)].
- Department of Household Registration (DHR). *Population Density and Total Area for Counties and Cities in 2010.* 2010, [cited 2016 October 16]. Available from: [http://www.ris.gov.tw/zh\\_TW/346](http://www.ris.gov.tw/zh_TW/346).
- Department of Statistics. *Ministry of the Interior (DSMI). Number of Villages, Neighborhoods, Households and Resident Population.* 2016, [cited 2016 October 16]. Available from: <http://www.moi.gov.tw/stat/>.
- Environment Canada. *Wind chill-The chilling facts.* 2015, [cited 2016 September 30]. Available from: <http://www.ec.gc.ca/meteorweather/default.asp?lang=n&n=5FBF816A-1#wc6>.
- National Oceanic and Atmospheric Administration. *National Weather Service.* 2017, [cited 2017 February 18]. Available from: [http://www.nws.noaa.gov/om/cold/wind\\_chill.shtml](http://www.nws.noaa.gov/om/cold/wind_chill.shtml).
- Bureau of Meteorology Australian Government. *Thermal Comfort observations.* 2017, [cited 2017 February 25]. Available from: [http://www.bom.gov.au/info/thermal\\_stress/](http://www.bom.gov.au/info/thermal_stress/).

31. Nasir RA, Ahmad SS, Zain-Ahmed A. Psychological Adaptation of Outdoor Thermal Comfort in Shaded Green Spaces in Malaysia. *Procedia Soc Behav Sci.* 2012;**68**:865–78.
32. Nasir RA, Ahmad SS, Zain-Ahmed A. Adaptive Outdoor Thermal Comfort at an Urban Park in Malaysia. *J Asian Behav Stud.* 2013;**3**(10):1–15.
33. Bureau of National Health Insurance (BNHI). *Beneficiaries by Beneficiary Category, The National Health Insurance Statistics.* 2009, [cited Cited 2012 August 29]. Available from: [http://www.nhi.gov.tw/English/webdata/webdata.aspx?menu=11&menu\\_id=296&WD\\_ID=296&webdata\\_id=3420](http://www.nhi.gov.tw/English/webdata/webdata.aspx?menu=11&menu_id=296&WD_ID=296&webdata_id=3420).
34. Allison PD. *Logistic regression using the SAS system: theory and application.* Cary, N.C: SAS Institute; 1999.
35. McClave JT, Sincich T. *Statistics 9th ed.* Upper Saddle River, NJ: Prentice-Hall Inc; 2003.
36. Wilks DS. *Statistical methods in the atmospheric sciences 3rd ed.* Oxford: Elsevier Inc; 2011.
37. WHO World Health Organization. *Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide, Global update 2005, Summary of risk assessment.* Geneva: WHO Press; 2005.
38. Ebi KL, Exuzides KA, Lau E, Kelsh M, Barnston A. Weather changes associated with hospitalizations for cardiovascular diseases and stroke in California, 1983-1998. *Int J Biometeorol.* 2004;**49**(1):48–58. doi: [10.1007/s00484-004-0207-5](https://doi.org/10.1007/s00484-004-0207-5). [PubMed: [15138867](https://pubmed.ncbi.nlm.nih.gov/15138867/)].
39. Ahrens CD. *Meteorology today: an introduction to weather, climate, and the environment 7th ed.* Pacific Grove, CA, USA: Brooks/Cole-Thomson Learning; 2003.
40. Tissot-Dupont H, Amadei MA, Nezri M, Raoult D. Wind in November, Q fever in December. *Emerg Infect Dis.* 2004;**10**(7):1264–9. doi: [10.3201/eid1007.030724](https://doi.org/10.3201/eid1007.030724). [PubMed: [15324547](https://pubmed.ncbi.nlm.nih.gov/15324547/)]. [PubMed Central: [PMC3323349](https://pubmed.ncbi.nlm.nih.gov/PMC3323349/)].
41. Corbett SW. Asthma exacerbations during Santa Ana winds in southern California. *Wilderness Environ Med.* 1996;**7**(4):304–11.