# Delayed Effects of Weather Variables on Incidence of Dengue Fever in Singapore from 2000-2010

Zhaoxia Wang, Hoong Maeng Chan, Tianyou Zhang, Pauline Aw Poh Kim, Martin L. Hibberd, and Gary Kee Khoon Lee

***Abstract*—In this paper we analyze the time-series data to study the association between dengue incidence and weather variables such as temperature and humidity while taking into account the delayed effects and further discussing the differences between using short term data (yearly) and long term data in Singapore from 2000 to 2010. The time-series analysis and statistical analysis method are employed to determine the delay in timing between the incidence of dengue fever and weather variables. The results are not only consistent with previous results of other researchers, but also provide new findings. We analyze the data from each year (short term time series data) and 10-year data (long term time series data) and find that the use of both the short term data and the long term data can provide complementary insights into the relationship between dengue incidence and weather variables.**

***Index Terms*—Dengue, temperature, time-lag, time series analysis.**

## I. Introduction

Dengue is a mosquito-borne infectious disease that occurs in many parts of the world mainly in tropical regions, and has become a major international public health concern. The World Health Organization (WHO) estimated that globally there are 2.5 billion people living in dengue endemic places and 70% of them are in Asia [1][2].

Singapore is one of the most densely populated countries in Asia, and has had thousands of reported dengue cases each year since 2001. Vector control programs have been implemented in Singapore since the early 1970s and there has been a change in emphasis from vector surveillance to case detection in the 1990s. Upon case detection, the National Environment Agency (NEA) would immediately deploy dengue control team(s) to perform source reduction, and various prevention activities according to standard operational procedures. Since the 2005 outbreak, NEA has revised its strategy and incorporated integrated dengue surveillance and control programs [3].

Several studies have investigated the impact of weather variation on dengue disease or the growth of mosquitoes [4] [5] [6] [7]. One such study has examined the relationship between *Aedes Aegypti* metric properties and weather variables, such as relative humidity and temperature [4] . This study took place in a dengue hyperendemic area of Thailand and the results highlight the importance of climatic factors on the growth of the *Aedes Aegypti*. The impact of small variations in temperature and humidity on the reproductive activity and survival of the *Aedes Aegypti* is also the subject of a study [5]. The study highlights the effects of such small variations on the fecundity, fertility and survival of the *Aedes Aegypti*. The results of the experiment suggest that *Aedes Aegypti* populations in hot climates can nearly double during periods of mild temperatures rather than in periods of high temperatures.

The impact of daily temperature fluctuations on dengue virus transmission by the *Aegypti* mosquitoes have been investigated and the research results indicate that large temperature fluctuations would reduce the probability of vector survival since mosquitoes are less susceptible to virus infection and die faster under a larger diurnal temperature range (DTR) of approximately the same mean temperature [6]. The associations between dengue incidence and mean temperature have been extensively studied and the results indicate that the weekly mean temperature are statistically significant relative to the increases in dengue incidence in Singapore and signifies the hazardous impacts of climatic factors on the increase in intensity and magnitude of dengue cases [7].

Another study has linked weather variables and mosquito (*Aedes Aegypti*) abundance in relation to the potential effects of weather variations on the pattern of dengue epidemiology in Taiwan from 2001-2008, and this study suggests that warmer temperature with 3-month lag, and elevated humidity with a high mosquito density, increased the transmission rate of human dengue fever infection in southern Taiwan [8].

In this paper, we study the association between dengue incidence and weather variables such as temperature and humidity, while taking into account the delayed effects and further discuss the differences in each year from 2000 to 2010. The result is not only consistent with the previous results of other researchers; it also provides new findings. We intend to share and further discuss the results with other researchers.

## II. Materials and Methods

For our study, weekly dengue data was collected from the Communicable Diseases Division, of the Ministry of Health Singapore (MOH) and the weekly epidemiological publications of the MOH from 2000–2010.

Weather variable data was obtained from the World Data

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Center for Meteorology, in Asheville, USA. The daily mean temperatures reported by the Changi meteorological station were extracted from the World Meteorological Organization (WMO) and NOAA National Climatic Data Center [9]. Daily relative humidity was calculated by using daily mean temperatures and mean dew point temperatures. The weekly mean temperature and mean relative humidity were aggregated and calculated by using their daily data, respectively.

Time series analysis and statistical analysis are employed in this paper. The time-lag parameter $\tau$ is introduced to Spearman's rank correlation coefficient (SRCC), hence deriving the correlation coefficient function with a time-lag parameter $\tau$ as a variable as the following equation:

$$R_{X\_Y}(\tau) = \frac{\sum_{t=1}^{N}(x(t+\tau)-\bar{x})(y(t)-\bar{y})}{\sqrt{\sum_{t=1}^{N}(x(t+\tau)-\bar{x})^2}\sqrt{\sum_{t=1}^{N}(y(t)-\bar{y})^2}} \quad (1)$$

where $N$ is the length of the selected sliding window and the value is less than $n$, $x(t)$ and $y(t)$ are the ranks of the variables $X(t)$ and $Y(t)$ respectively, $\bar{x}$ and $\bar{y}$ are the mean values of $x(t)$ and $y(t)$ respectively.

The equation (1) is named the time-lag correlation coefficient between two variables. In this paper, the time-lag correlation coefficient is used to calculate the time lags between dengue cases and weather variables.

## III. Results

The characteristics of the three time-series data (Dengue Cases (DE), Temperature (T) and Humidity (H)) are shown in Fig. 1. It is obvious that there is a period about 51 weeks in temperature time series data. The relationships between these three time-series data are shown in Fig. 2 (a1 to a3) and the histograms of these three variables are shown in Fig. 3 (b1 to b3). The distribution of mean temperature and humidity are both observed as normal distributions.

Fig. 4 shows the time-lag correlation coefficient between dengue cases and temperature $R_{D\_T}(\tau)$, which is arrived at by analyzing each year's data respectively (short term data). Fig. 5 shows the time-lag correlation coefficient derived by analyzing the data of a period of more than 10-years (long term data).

As shown in Fig. 4, the time-lag correlation coefficients ($R_{D\_T}(\tau)$ ($\tau = 0,1,2,..., 25$)) vary from year to year. For higher values of the time-lag correlation coefficient, the P-value is mostly lower than 0.05. Time-lag correlation coefficients between dengue cases and humidity $R_{D\_H}(\tau)$, are analyzed in this paper. There are some similarities to $R_{D\_T}(\tau)$ in that for higher values of time-lag correlation coefficient $R_{D\_H}(\tau)$, the P-value is mostly lower than 0.05.

In order to compare the results of short term data with those of long term data, the time series of all available data (from 2000 to 2010) are used to calculate the time-lag. Fig. 5 shows the time-lag correlation coefficient between dengue cases and temperature $R_{D\_T}(\tau)$, derived by analyzing data of more than 10-years (long term). An approximately periodic pattern is observed. Similar to the results obtained from the short-term (year-on-year) data, the higher values of time-lag correlation coefficient overlap the P-values which are lower than 0.05.

## IV. Findings and Discussion

The simple relationships between these three time series variables and their characteristics are shown in Fig. 2 and Fig. 3. It is obvious that the two time series variables, temperature and humidity, have a linear correlation. In order to discover the relationship between dengue incidence and temperature in detail, we analyze the short term data as well as the long term data.

Fig. 4 (a0-a10) shows the time-lag correlation coefficient ($R_{D\_T}(\tau)$ $\tau = 0,1,2,..., 25$) in each year, ranging from 2000 to 2010. Fig. 4 (a5) shows the results of year 2005 and it is consistent with the study by B. Koh et al.[1] in which the long time lag of 17–20 weeks in 2005 was reported. The high association between dengue incidence and weekly mean temperature at a time-lag of 17-18 weeks in 2005 was also reported by Y. L. Hii et al.[7].

The time lag in years 2002 and 2009 can be estimated by using the same methodology which was employed in 2005. However, the results of 2001, 2007, and some of the other years as shown in Fig. 4, appear to be different from the results of 2002, 2005 and 2009. The minimum value was not obtained at about 0 time-lags (no time-lags). Especially in 2001, the maximum value was obtained at periods of no time-lags. The results shown in Fig. 4 suggest that it is difficult to ascertain the exact value of the delay (time-lag) from the short term data.

The time-lag correlation coefficients $R_{D\_H}(\tau)$ and $R_{D\_P}(\tau)$ which are arrived at by analyzing each year's respective data are calculated and analyzed. Similarly, $R_{D\_H}(\tau)$ and $R_{D\_P}(\tau)$ do not consistently increase from the lower values to higher values of time lags. Similar to the results of $R_{D\_T}(\tau)$, the results of $R_{D\_H}(\tau)$ and $R_{D\_P}(\tau)$ also suggest that it is difficult to ascertain the exact value of the time-lag from the short term data.

As shown in Fig. 4, the time-lag correlation coefficient $R_{D\_T}(\tau)$ is non-monotonic. The lagged (delay) effect of dengue incidence could be due to various factors about the vectors [10]. The results in Fig. 4 (a0-a10) suggest that the function $R_{D\_T}(\tau)$ may fluctuate between peaks and troughs with increasing $\tau$ values.

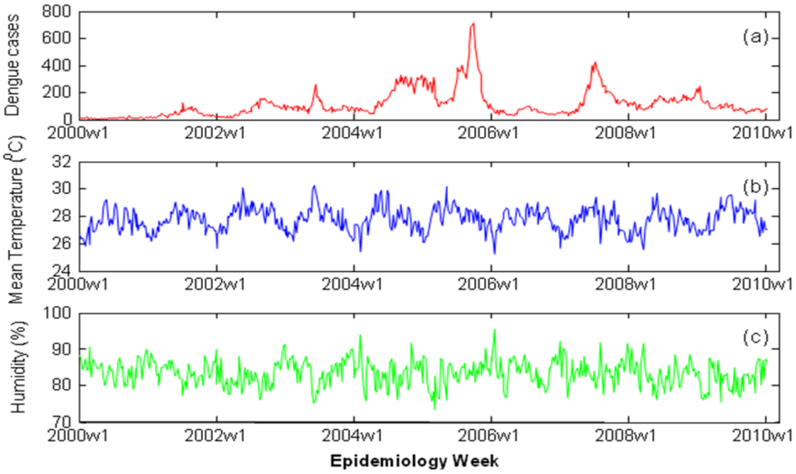


Fig. 1. The time series of weekly dengue cases, weekly mean temperature, weekly mean relative humidity in years 2000-2010 in Singapore

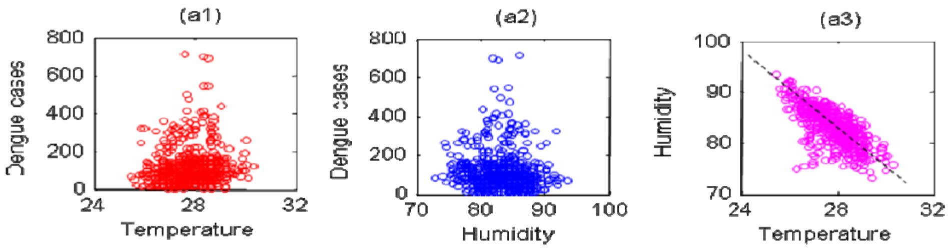


Fig. 2. the simple relationship between dengue cases, temperature and humidity in Singapore during 2000-2010

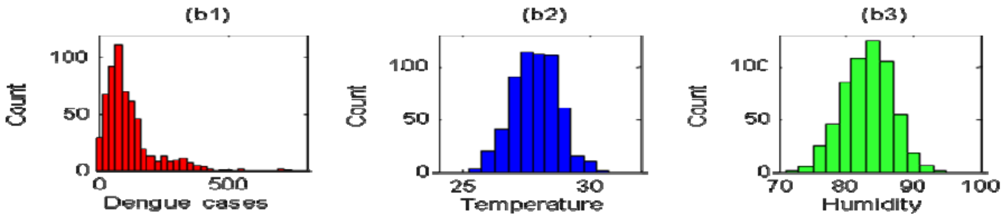


Fig. 3. Histograms of weekly dengue cases, temperature and relative humidity

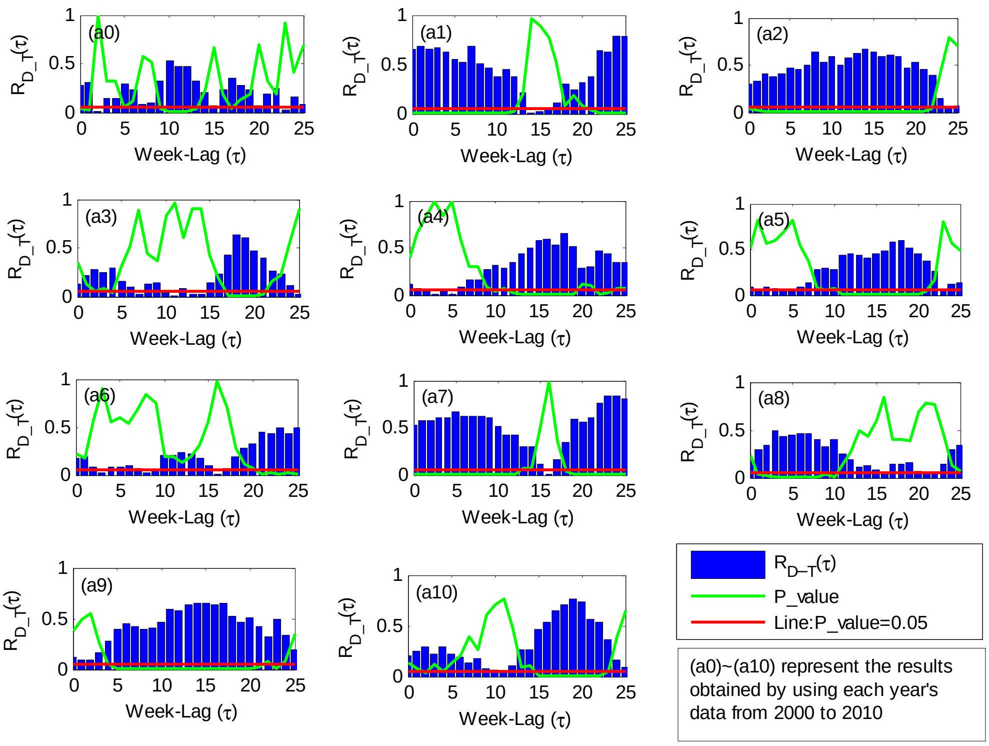


Fig. 4. Time-lag correlation coefficient between dengue cases and temperature by analyzing each year's data respectively

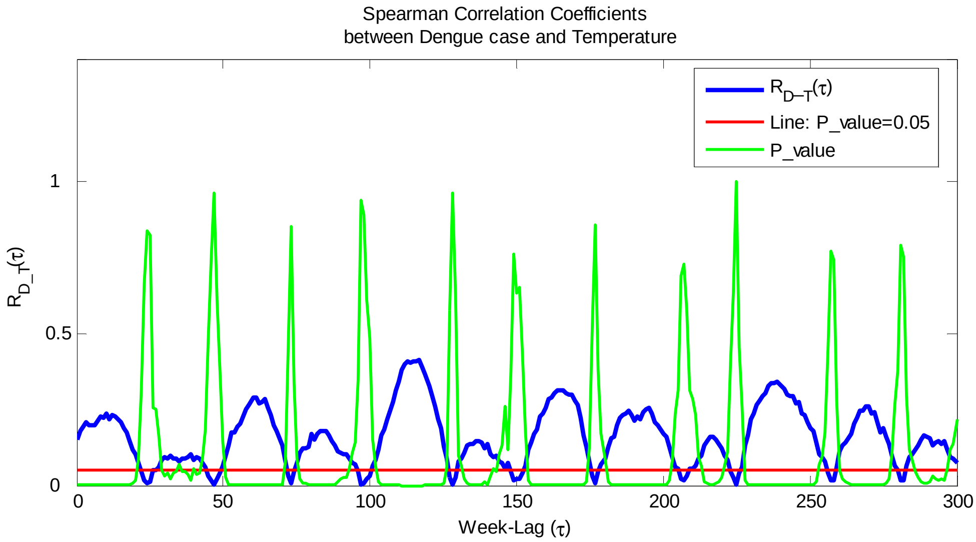


Fig. 5. Time-lag correlation coefficients between dengue cases and temperature by analyzing long term data (from 2000 to 2010)

In order to validate the above inferences and compare the short term results with the long term results, the time-lag correlation coefficients between dengue cases and temperature ( $R_{D\_T}(\tau)$ ), obtained by using data of more than 10 years can be found in Fig. 5. The results demonstrate that the function $R_{D\_T}(\tau)$ is non-monotonic and it fluctuates between peaks and troughs with increasing $\tau$ values just as suggested previously.

It can be seen from Fig. 5, that the interval between consecutive minimum and maximum values of $R_{D\_T}(\tau)$ is about 8~20 weeks. In other words, there is a duration of 8~20 weeks between the time lag of a minimum value and the time lag of the next maximum value. This is also an interesting finding as this shows that the results obtained by using long term time series data provide additional insights that are not obtained by using the short-term data.

In fact, there are incubation periods in the host–vector–pathogen transmission cycle as well as reproduction, maturation and the survival rates of the vector. Dengue cases are related to the incubation periods [7][10], but as illustrated in Figs. 4-5, they are also related to weather variables, such as temperature. Temperature is an approximately periodic time series. The periodicity of the temperature may also have an effect on the time-lag correlation coefficient.

In analyzing results obtained in this study, we find that the interval between consecutive minimum and maximum values of the time-lag correlation coefficient is between 1 and 20 weeks, and the time-lag correlation coefficient $R_{D\_T}(\tau)$ does not always increase from the lower value to higher values with increasing time lags. By using long term time series data, the interval between consecutive minimum and maximum values ranges from 8-20 weeks. The results map the time lag relationship between dengue cases and temperature.

## I. Conclusion

In conclusion, our results reveal the relationship between dengue cases and weather variables in Singapore from 2000 to 2010. The results of this study are consistent with the previous work which reports that dengue incidence is highly associated with weekly mean temperature at a time-lag of 17-18 weeks in 2005. In addition, both the short term data and the long term data are investigated. The results indicate that while it is difficult to ascertain the exact value of time-lag from the short term data alone in some years; it is helpful to also study the long term data, as it may provide additional findings not obtained from the short-term data.

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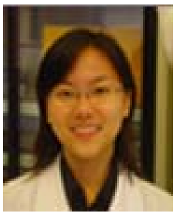

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