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Dengue epidemics and the El Niño Southern Oscillation

Alexandre S. Gagnon[1,*], Andrew B. G. Bush[2], Karen E. Smoyer-Tomic[2]

[1]Department of Geography, University of Toronto, Rm 5047, 100 St. George St., Toronto, Ontario M5S 3G3, Canada
[2]Department of Earth and Atmospheric Sciences, 1–26 Earth Sciences Building, University of Alberta, Edmonton, Alberta T6G 2E3, Canada

ABSTRACT: The World Health Organization (WHO) reported that the 1997/98 El Niño might have been the cause of the dengue fever epidemics in many tropical countries. Because of the interaction between the atmosphere and the ocean, the warm El Niño and the cold La Niña phases of the El Niño Southern Oscillation (ENSO) engender significant temperature and precipitation anomalies around the world. This paper presents the results of a correlation analysis of past ENSO events with dengue epidemics across the Indonesian archipelago and northern South America. Our analysis shows that there is a statistically significant correlation at the 95% confidence level between El Niño and dengue epidemics in French Guiana and Indonesia and at the 90% confidence level in Colombia and Surinam. These regions experience statistically significant warmer temperatures and less rainfall during El Niño years. Public health officials could therefore strongly benefit from El Niño forecasts, and they should emphasise control activities such as insecticide sprayings and media campaigns concerning the potential breeding sites of dengue mosquitoes during these years.

KEY WORDS: El Niño · Dengue · Epidemics · Temperature · Rainfall · Indonesia · South America

1. INTRODUCTION

Interannual epidemics of dengue fever occur in many tropical countries and are thought to be linked with climatic anomalies (Kovats et al. 1999). The El Niño Southern Oscillation (ENSO) dominates interannual climate variability, and its warm El Niño and cold La Niña phases engender significant temperature and precipitation anomalies around the world (Stern & Easterling 1999). El Niño refers to a warming and La Niña to a cooling of sea surface temperatures (SST) in the eastern equatorial Pacific Ocean. Dengue is a viral mosquito-transmitted disease and is therefore likely to be influenced by ENSO-related climatic anomalies (Seghal 1997). Every year, tens of millions of people contract dengue world-wide, with approximately 500 000 hospitalised cases due to dengue haemorrhagic fever (DHF; WHO 1998). DHF is the most severe form of dengue; the risk of contracting it is greater if there is subsequent infection by another dengue virus (Frost 1991). The lack of drugs to prevent dengue infection (Gratz & Knudsen 1996) and the recent geographical expansion of this disease necessitate an understanding of the ENSO-dengue relationship in order to determine the possibility of using El Niño forecasts for improving disease control.

Comprehensive analyses of the impact of ENSO on the incidence of dengue have to date been sparse and limited to a few island states of the Pacific Ocean (Hales et al. 1996, 1999). Given the global nature of ENSO, and the vast area affected by dengue, a more global synthesis is desirable. In this paper, we present the results of a correlation analysis of past ENSO events with dengue epidemics in Indonesia and a number of South American countries and territories (Colombia, French Guiana and Surinam). These countries were selected because of the availability of their

*E-mail: alexandre.gagnon@utoronto.ca

epidemiological data and because their climate is significantly impacted by ENSO. Guyana and Venezuela were not included in our analysis because of the large number of missing values in the Guyanese time series and the near eradication of dengue in Venezuela between 1970 and 1988. A secondary objective was to determine the temporal and spatial consistency of ENSO-generated climatic anomalies. In countries where a statistically significant relationship exists between ENSO and dengue epidemics, the absence of anomalous climatic conditions during an ENSO event suggests an explanation for the lack of an epidemic during this particular event. The spatial consistency of the climatic anomalies within a country is important, as dengue cases are usually reported as a national average. Our research constitutes a basis for the development of a predictive tool that can incorporate climatic indicators in order to help forecast the spread of dengue.

2. METHODS

Annual dengue incidence data were obtained from the World Health Organization (WHO) and from national ministries of health. Although French Guiana does not report dengue cases to the WHO, suspected cases have been estimated (Reynes et al. 1993) and published in Fouque et al. (1995) for the period 1965–1993. Annual population estimates were obtained from the Monthly Bulletin of Statistics, published by the Statistical Office of the United Nations, and the annual reports of the Pan American Health Organization (PAHO), a regional office of the WHO. Also included in the latter reports are the annual number of house insecticide sprayings for countries of northern South America. We contextualised the dengue-ENSO relationship by tracing the evolution of the disease and public health responses to it over the past 30 to 40 yr using information obtained from the WHO, the PAHO, and national ministries of health.

The classification of El Niño and La Niña years was according to Trenberth (1997), except that we omitted weak events, because they are less likely to generate significant climatic anomalies and hence to contribute to the spawning of epidemics (Table 1). An epidemic was defined as an anomalous increase in the rate of change of disease incidence from one year to the next. An increase in disease transmission had to be greater than one half a standard deviation above the mean to be considered an epidemic (e.g., Rossel et al. 1999). According to this definition, the epidemic years identified in Indonesia, for instance, are in accordance with those reported by the national ministry of health. The rate of change corresponds to the first-order derivative with respect to time of annual disease incidence. In other words, it signifies the change in the number of disease cases standardised by the population reported from one year to the next. Depiction of the rate of change facilitates the identification of epidemics, because it provides a time series with a mean close to zero and it compensates for the increasing trend in disease incidence.

Table 1. Major El Niño and La Niña episodes

El Niño	La Niña
1957/58	1955/56
1965/66	1964
1972/73	1970/71
1976/77	1973/74
1982/83	1975/76
1986/87	1988/89
1991/92	
1993	
1994/95	
1997/98	

To determine the statistical significance of the correlation between ENSO and dengue epidemics, we used contingency tables with Fisher's exact test. Fisher's exact test verifies the independence of the rows and columns of a 2×2 contingency table and is adequate for a small number of observations. Most El Niño events span 2 calendar years, and we refer to Niño (0) as the development phase of El Niño, and Niño (+1) as the year immediately following the peak of the El Niño event, which typically occurs near the end of the calendar year. The 3 statistical hypotheses tested were that dengue epidemics are not more likely to occur during: (1) Niño (0) versus other years, (2) Niño (+1) versus other years, and (3) La Niña years versus other years. Since the year of development and decay of the 1993 El Niño occurred within the same calendar year, 1993 is an exception to the present classification and is considered to be both a Niño (0) and Niño (+1) year in the statistical analyses.

Mean monthly temperature and total monthly precipitation data were obtained from a total of 23 ground-based meteorological stations. The selection process favoured weather stations whose records spanned a large interval and contained a small percentage of missing values. It was also desirable to optimise the geographical coverage of the country. Most data were acquired from the Global Historical Climatology Network (GHCN) of the National Climatic Data Center (NCDC). Because of the scarcity of the GHCN data in these countries, we supplemented them with additional climatic data as well as monthly river height data from 5 Colombian rivers provided by the national meteorological services of Colombia and Surinam.

Moreover, since none of the Indonesian weather stations included in the GHCN data set provides data after 1995, rainfall estimates were obtained from the US National Center for Environmental Protection's Merged Analysis of Precipitation (CMAP) grid-based data set for the period 1994–1998. NCEP computes total monthly precipitation using gauge observations, satellite estimates, and numerical model outputs (Xie & Arkin 1997).

The analysis consisted of calculating climatological and hydrological anomalies in terms of variance for all weather and gauging stations. This normalisation procedure was performed according to the equation

$$A = (X_i - M_{ij})/\sigma_{ij}$$

in which A refers to the resulting anomalies. The terms X_i, M_i, and σ_i refer to the observed value, the long-term mean value, and the standard deviation of a particular month i. The subscript j refers to the total number of months i in the time series. Missing values were approximated using a cubic-spline interpolation (Press et al. 1992), and all time series were smoothed with an 11 mo central moving average (i.e., 5 mo on either side) to emphasise interannual variations. Then we used cross-correlation to identify the greatest correlation coefficient at the best lag time (expressed in months; e.g., Poveda & Rojas 1997). Fisher's z-transformation was utilised to test for the statistical significance of the correlation coefficients using Quenouille's (1952) method to adjust for serial correlation (e.g., Alexander et al. 1999).

Since dengue cases are generally reported as national averages, national temperature, precipitation, and hydrological data time series were constructed by averaging all weather and gauging stations within each country. No form of areal weighting was used. If climatic anomalies associated with ENSO were not spatially consistent within a country, regional epidemiological data (where available) were used to demonstrate that epidemics originate from regions whose weather patterns are significantly impacted by ENSO. Since precipitation is highly variable, we computed an annual average of the standardised rainfall anomalies, hereafter referred to as a national rainfall composite index, to facilitate the identification of wet and dry years. We did not want to attribute the period of best correlation with ENSO to 2 calendar years. Since drier conditions usually appear in May (0) during an El Niño episode and persist until the following April in northern South America (Ropelewski & Halpert 1987), annual averages were calculated from May through April of the following year in this region. In Indonesia, however, rainfall anomalies appear in January (0) of an El Niño episode; the annual average was therefore calculated from January through December (Ropelewski & Halpert 1987).

3. RESULTS

In 1947, the PAHO launched a campaign to eliminate *Aedes aegypti*, the mosquito that carries dengue, which resulted in the near eradication of dengue in most Latin American countries (Gubler & Clark 1995). The end of the eradication programme resulted in the re-infestation of the South American continent in the 1960s. Dengue cases were first reported in 1965 in French Guiana (Fouque et al. 1995). By 1971, the entire Caribbean coast of Colombia was re-infested (WHO 1976), but no dengue cases were reported prior to 1980 (Pinheiro & Corber 1997). In Surinam, the first dengue cases were reported in 1978 (Gratz & Knudsen 1996), and epidemics have so far occurred about every 5 yr, more or less following the cyclical pattern of ENSO.

The number of dengue cases reported annually in French Guiana has been increasing since the confirmation of the first cases in 1965 (Fig. 1a). The time series of the rate of change in dengue incidence removes this increasing trend and clearly illustrates a strong relationship between El Niño and the occurrence of a dengue epidemic (Fig. 1b). Of the 6 El Niño

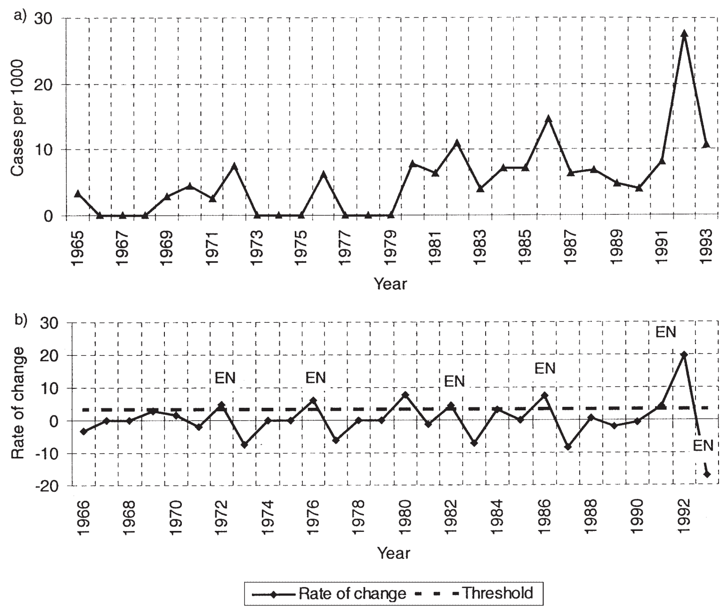

Fig. 1. Dengue in French Guiana. Time series of (a) annual number of cases per 1000 persons and (b) rate of change. Dashed line: the epidemic threshold value (i.e., 0.5 SD above the mean). EN: El Niño episodes

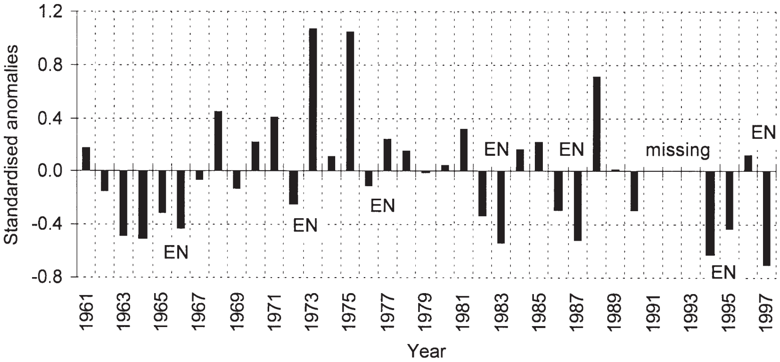

Fig. 2. Annual average of standardised anomalies of rainfall at Cayenne, French Guyana (May through April). Standardised anomalies referred to anomalies in terms of variance, as explained in text

episodes that occurred during the 1965–1993 period, only the 1993 El Niño was not associated with a dengue epidemic. In addition, dengue epidemics generally occur in Niño (0) years. During the 1991/92 El Niño, however, the epidemic started in July 1991, a Niño (0) year, and continued to peak in the following Niño (+1) year, when estimates indicate more than 3000 dengue cases for a total population of approximately 115 000. All these epidemics were associated with warmer temperatures and less abundant rainfall (Fig. 2).

In Surinam, the incidence of dengue was very low during the 1978–1992 period, when on average only 17 cases were reported annually. Dengue cases were obtained for only 2 years after 1992. The incidence of dengue during these 2 years was very large in comparison to the rest of the time series, showing the increasing importance of dengue in this country. Dengue epidemics affected Surinam in 1986 and 1991 when 60 and 40 cases were reported respectively (Fig. 3). As in French Guiana, these 2 epidemics occurred during Niño (0) years that experienced warmer temperatures and below-average rainfall. Another epidemic affected this country in 1981 and emergency control measures soon followed (Hudson 1986). The number of houses per 1000 persons that were sprayed annually from 1956 through 1991 (Fig. 4) depicts the intensification of insecticide sprayings immediately following the 1981 epidemic. Increased control measures are therefore likely to have prevented an epidemic during the 1982/83 El Niño.

A weakening of the South Pacific high-pressure cell during El Niño allows the Inter-Tropical Convergence Zone (ITCZ) to move further south, causing below-average rainfall in French Guiana, Surinam, and most of Colombia. Moreover, El Niño decreases the SST gradient between the Colombian coast and the normally cold waters off Peru and Ecuador, weakening the winds and moisture advection into western Colombia (Poveda & Mesa 1995).

In Colombia, all El Niño episodes, except for 1993, were associated with a peak in dengue incidence in Niño (+1) years (Fig. 5). The 1983 and 1987 peaks, however, are slightly below the epidemic threshold value. All peaks in dengue incidence occurred during years with warmer temperatures. Less abundant rainfall and lower river height were also recorded during all those epidemics, with the exception of 1995, when near-normal conditions prevailed (Fig. 6). El Niño generates warmer temperatures in all Colombian regions, but it does not significantly influence the hydrology of the northeastern Caribbean coast and the 2 departments located east of the Andes (Quesada & Caviedes 1992). The Guaviare River is located East of the Andes and is the only river analysed that does not show a statistically significant correlation with ENSO (Table 2). Although the number of dengue cases increased in almost all Colombian departments, regional data during the 1996–1998 period show that the majority of dengue cases in Colombia originate from regions where ENSO significantly affects rainfall variations (and where most of the population lives). In contrast to the other El Niño episodes, river height was increasing during the 1993 El Niño (see Fig. 6).

In order to capture some of the spatial variability of ENSO's climatic impact, the ENSO-dengue relationship was analysed over the Indonesian archipelago. Weakening of the easterly trade winds during El Niño displaces the centre of deep convection from the west-

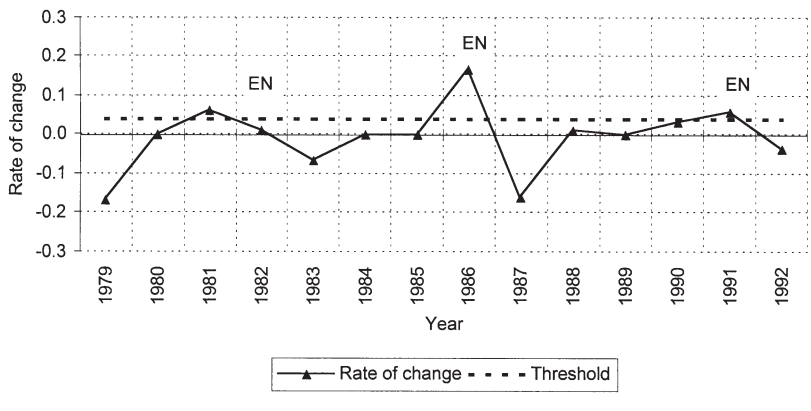

Fig. 3. Dengue in Surinam. Lines are as in Fig. 1

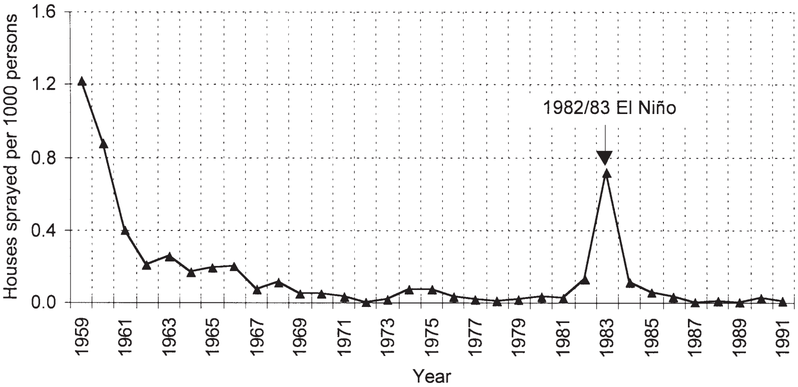

Fig. 4. House insecticide sprayings in Surinam normalised per 1000 persons

ern to the central equatorial Pacific Ocean, causing below-average precipitation over Southeast Asia (Roswintiarti 1993). Although drier conditions during an El Niño episode generally appear as early as January (0) and persist for at least 1 yr, they are strongest and most statistically significant from June (0) through November (0), when most of Indonesia experiences its dry season (Ropelewski & Halpert 1987).

DHF is endemic in Indonesia and the national public health service limits its reporting system to this form of the disease, because it has a high incidence and is the only fatal form of dengue. In 1998, for instance, 1414 of the 72 133 DHF cases were fatal (R. Kusriastuti pers. comm.). Although DHF has a high incidence in Indonesia, its incidence is considerably lower than the classical form of dengue, and thus the number of DHF cases was standardised to per 100 000 persons as opposed to per 1000 persons. Four of the 6 epidemics in Indonesia were associated with an El Niño episode (Fig. 7). Furthermore, the national ministry of health identified 1973, 1983, 1988 and 1998 as the most important DHF epidemic years (R. Kusriastuti pers. comm.). With the exception of 1988, all these years are Niño (+1) years.

In Indonesia, warmer temperatures prevail during El Niño from September (0) through May (+1) (Kiladis & Diaz 1989). Except for the 1988 epidemic, rainfall was below average during all years that preceded DHF epidemics in Indonesia. From 1991 through 1998, only 5.3 % of the total number of DHF cases reported in Indonesia originated from the western provinces of the island of Sumatra, where the relationship between ENSO and rainfall variations is not statistically significant. During the 1986/87 El Niño, however, the national rainfall composite index should be used with caution, because rainfall anomalies were not spatially consistent throughout the archipelago. In 1987, a drought was reported at Jakarta and in southern Borneo, but not in other regions. In contrast to most El Niño episodes, the 1986/87 El Niño produced 2 peaks in SSTs. The first peak occurred at the average time of most El Niño events (December to January), but a second peak was also observed in July and August of 1987 (Wang 1995). This unusual behaviour of SST may be linked to the unusual rainfall anomalies on some islands in 1987. An outbreak of DHF affected Jakarta city in 1988, when 10 156 cases and 112 deaths were reported (Gratz & Knudsen 1996, Masyhur & Wiryowidagdo 1988). Thus, 1988 is no exception to the

Table 2. Correlation between the Southern Oscillation Index (SOI) and river height anomalies in Colombia. The SOI is the standardised difference in sea level atmospheric pressure between Darwin and Tahiti and is used as an indicator of ENSO activity. All correlation coefficients have their maximum value when the SOI precedes the river height anomalies by 1 to 2 mo with the exception of the Atrato and San Juan rivers (both located in the Pacific coastal region), which experience their maximum correlation in the same month. *Statistically significant at the 95 % confidence level

River	Gauging station	Record length	Pearson correlation
Magdalena	Puerto Berrio	1972–1995	0.55*
	El Banco	1976–1998	0.59*
	Calamar	1971–1997	0.65*
Cauca	La Pintada	1977–1997	0.65*
Guaviare	Candilejas	1982–1997	0.13
San Juan	Peñitas	1980–1997	0.67*
Atrato	Bellavista	1971–1998	0.67*

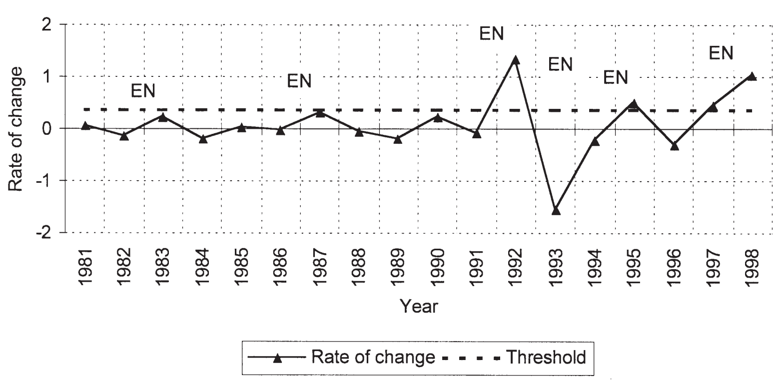

Fig. 5. Dengue in Colombia. Lines are as in Fig. 1

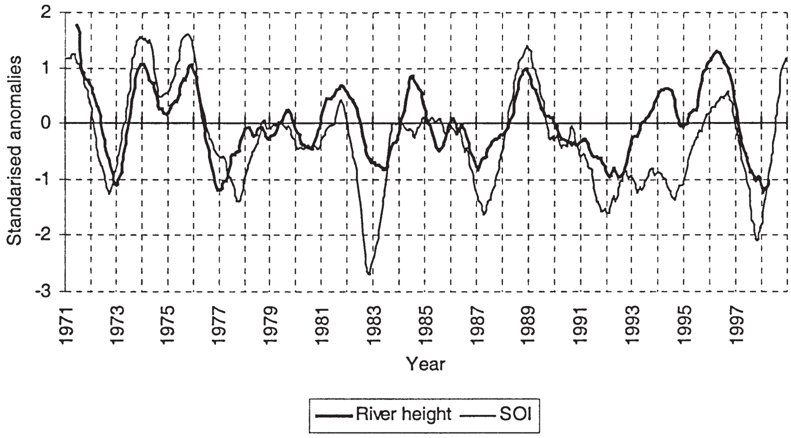

Fig. 6. Time evolution of the Southern Oscillation Index (SOI) and the national average of river height anomalies in Colombia. The Guaviare River, located in eastern Colombia, was excluded from the national average, because of its lack of correlation with ENSO. The SOI is the standardised difference in sea level atmospheric pressure between Darwin (Australia) and Tahiti (French Polynesia) and is used as an indicator of ENSO activity. A negative SOI refers to El Niño conditions and a positive SOI to La Niña conditions

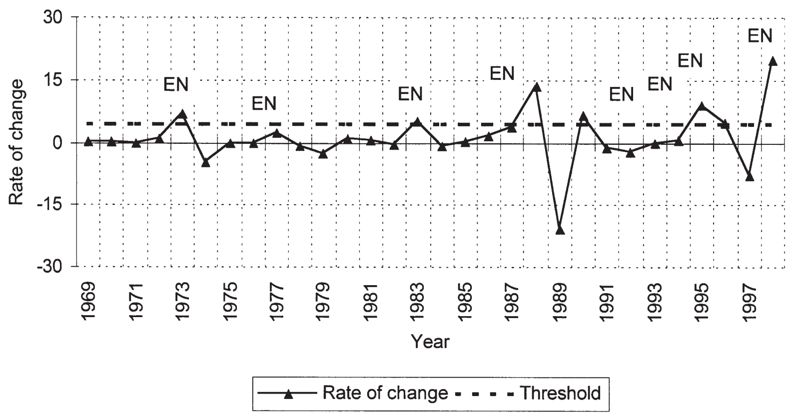

Fig. 7. Dengue haemorrhagic fever (DHF) in Indonesia. Lines are as in Fig. 1

above relationship, as the Jakarta outbreak was also preceded by a year with below-average rainfall.

Monthly epidemiological data and estimates of rainfall for the 1994–1998 period were analysed to determine the climatic anomalies associated with DHF epidemics in Indonesia. Using the CMAP grid-based data set, total monthly precipitation was estimated by averaging all grid cells over the island of Java, where the majority of DHF cases originate. A comparison of these rainfall estimates with the monthly incidence of DHF in Java indicates that every year, DHF transmission increases following the onset of the rainy season (Fig. 8). Likewise, the large 1998 epidemic occurred following the onset of rainfall, rather than during the drought, such as with the dengue epidemics in northern South America. Nevertheless, the magnitude of the epidemic does not appear to be related to rainfall amplitude. The evidence suggests that droughts lead to DHF epidemics in Indonesia at the onset of the following rainy season.

Contingency tables with Fisher's exact test reveal that only in French Guiana and Indonesia is the relationship between El Niño and dengue epidemics statistically significant at the 95% confidence level (Table 3). A statistically significant relationship also exists in Colombia and Surinam, but at the 90% confidence level. Moreover, the risk of a dengue epidemic is high in Niño (0) years in French Guiana and Surinam versus Niño (+1) years in Colombia and Indonesia.

In Colombia, the l983 and 1987 peaks in dengue incidence are slightly lower than the epidemic threshold value, which may explain the statistical significance of the relationship at the 90% rather than the 95% confidence level. These peaks are lower because there is higher variability of the rate of change of dengue incidence in the 1990s, which increases the standard deviation. Calculation of 2 mean values and 2 standard deviations (i.e., prior to and after 1991) indicates that the 1983 and 1987 peaks could be considered as epidemics under this type of definition. However, our results are not significantly influenced by these changes, so we conclude that the correlation between El Niño and dengue epidemics is robust in Colombia. The short length of the time series and the lack of an epidemic during the 1982/83 El Niño because of increased insecticide

Table 3. Results of Fisher's exact test determining the statistical significance of the relationship between ENSO episodes and dengue epidemics. Statistical significance: **95% confidence level; *90% confidence level. (–) not calculated because no epidemic occurred during the duration of the dengue time series

Country	Niño (0)	Niño (+1)	La Niña years
Colombia	1.00	0.08*	–
French Guiana	0.01**	1.00	1.00
Indonesia	–	0.03**	0.22
Surinam	0.09*	–	–

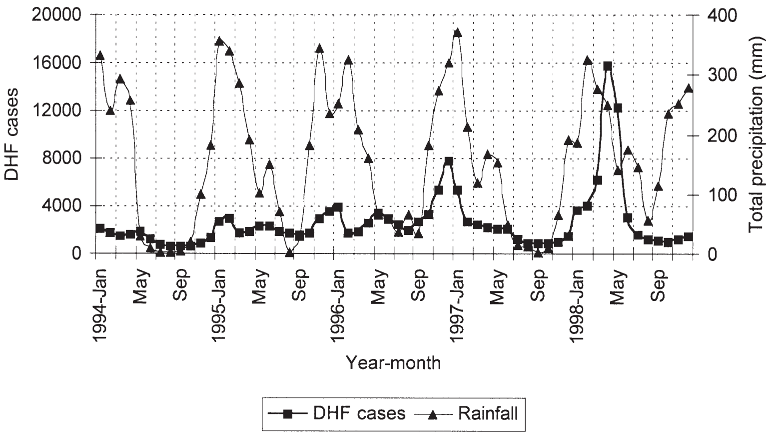

Fig. 8. The relationship between monthly DHF cases and total monthly precipitation on the island of Java (Indonesia)

sprayings might explain the statistical significance of the ENSO-dengue epidemics relationship at the 90% rather than the 95% confidence level in Surinam.

In Colombia and Surinam, La Niña appears to have little effect on the occurrence of dengue epidemics, as demonstrated by the lack of an epidemic in or following La Niña years. In French Guiana, only 1 of the 4 La Niña episodes that occurred during the 1966–1993 period was associated with a dengue epidemic, resulting in a probability of an epidemic during a La Niña episode of only 0.25, which is not statistically significant. In Indonesia, the 1973 and 1988 epidemics were associated with a La Niña episode, and thus the probability of a DHF epidemic during La Niña is higher, i.e., 0.50, but still not statistically significant. La Niña episodes are sometimes preceded by an El Niño event and thus Niño (+1) is occasionally the first year of a La Niña event. The 1988/89 La Niña is unlikely to have caused the 1988 epidemic, because of the gradual rise in DHF incidence in previous years. Thus the evidence indicates that La Niña does not increase the likelihood of dengue epidemics in any of the countries studied.

4. DISCUSSION

Our study reveals a statistically significant relationship between El Niño and dengue epidemics in Colombia, French Guiana, Indonesia, and Surinam. Moreover, the risk of a dengue epidemic is higher during Niño (+1) in Colombia and Indonesia, and during Niño (0) in French Guiana and Surinam. In addition, monthly temperature and hydrological (rainfall and river height) data show that dengue epidemics in northern South America are associated with warmer temperatures and drier conditions. Comparison of monthly DHF incidence data with rainfall estimates in Indonesia indicate that, in contrast to dengue epidemics in Latin America, large DHF epidemics in this country do not occur during the El Niño-related drought, but follow immediately after it.

Although a number of dengue cases are confirmed in the laboratory, the official number of dengue cases reported by national ministries of health includes cases that are identified according to clinical symptoms only. Laboratory tests confirm some of the suspected dengue cases and determine which of the 4 dengue serotypes prevail in a particular year. Some diseases, such as chikungunya, cause similar symptoms to dengue, and there is evidence from the past that a few of the reported dengue cases were, in fact, cases of other dengue-like diseases (Gratz & Knudsen 1996). Thus, some may argue that a clustering of clinical misdiagnoses could provide misleading results. However, in view of the serological confirmations of dengue cases in times of epidemics and the multi-country approach of our study, the probability for a temporally and spatially consistent clustering of clinical misdiagnoses in El Niño years is extremely low. In addition, we are aware that the number of reported dengue cases is under-estimated in many countries. Nevertheless, we are interested in changes in dengue incidence between years, and the WHO data provide a good indication of the magnitude of dengue incidence in a particular year.

Warmer temperatures are likely to increase dengue incidence by lengthening the life span of mosquitoes and by increasing the replication rate of dengue viruses (PAHO 1994). The magnitude of the temperature anomalies during El Niño, however, seems too small to spawn dengue epidemics without the contribution of rainfall variations. Globally, annual mean temperature is on average less than 1°C warmer during El Niño (Kiladis & Diaz 1989). Nevertheless, Patz et al. (1998) found that the potential for the spawning of a dengue epidemic would increase world wide with a temperature rise of approximately 1°C. Warmer temperatures also contribute to drought conditions that prevail in many regions during El Niño, because they increase potential evapotranspiration (the quantity of moisture that would evaporate and transpire if it were available; Christopherson 1994). Climate changes under global warming scenarios are therefore likely to increase the potential for dengue epidemics.

One would expect seasonal rainfall variations to affect the incidence of dengue through changes in the availability of mosquito breeding sites (Aiken et al. 1980). However, such a relationship is unclear, because *Aedes aegypti*, the mosquito that carries dengue in South America and DHF in Indonesia, is a domestic species that breeds in artificial water containers such as water storage containers, plant pots and discarded car tires (Frost 1991). Therefore, in some regions, non-climatic factors such as the collection of rainwater due to the non-accessibility of piped water and poor garbage disposal influence the availability of mosquito habitats and hence dengue transmission (PAHO 1994). However, during prolonged droughts, such as in El Niño years, water supply is a problem in Colombia and storage of water increases, thereby increasing the number of mosquito habitats (Poveda et al. 1999). Likewise, there is evidence of increased storage of water during droughts in a Brazilian city (Pontes et al. 2000), and Ungchusak & Kunasol (1988) associated the large 1987 DHF epidemic in Thailand with the dry conditions that existed during the summer season, because the drought forced people to store water. A similar explanation is possible in French Guiana and Surinam.

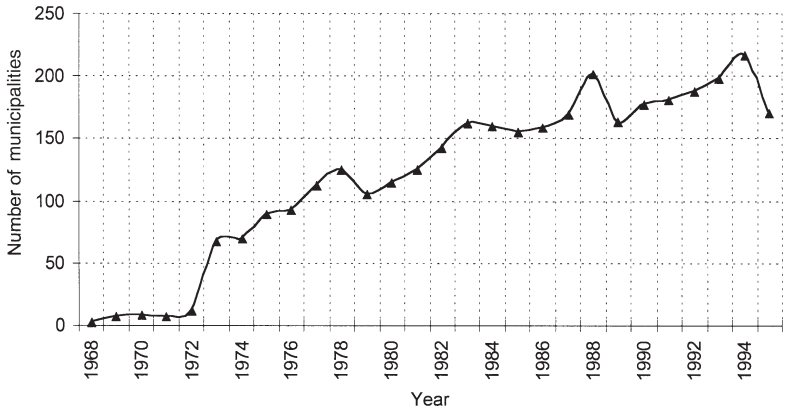

Fig. 9. Number of municipalities reporting DHF cases in Indonesia. Data were provided by the regional office of the WHO for Southeast Asia

Our results indicate that DHF epidemics tend to occur following a drought in Indonesia. Previous research has determined that the highest DHF incidence in Indonesia is usually reported during the rainy season (Sumarmo 1987, Nathin et al. 1988). Our results are in agreement with these seasonal analyses and further show that the number of DHF cases is highest when a prolonged drought precedes the rainy season. The relationship between El Niño and DHF is temporally consistent and is further supported by the precipitation data. Such a relationship is unlikely to occur by coincidence over 4 different El Niño episodes. Nevertheless, further research is required to elucidate the mechanisms underlying precipitation patterns and mosquito population dynamics in order to explain why the onset of the rainy season following drought is associated with DHF epidemics.

An increasing trend-line is present in the dengue time series of all countries studied. Population growth is not an explanation, as the disease cases were normalised by the population. Rapid urbanisation may explain part of the increase, because water supply and other basic public services such as sewage and waste management do not keep pace with rapid urban growth in many developing countries, increasing the availability of mosquito breeding sites. Moreover, the deterioration of the public health services in Latin America and increased air travel, which allows for the introduction of new dengue viruses, provide other explanations (Gubler & Clark 1995). In addition, expansion of the geographical range of dengue might be one of the most important factors. In Indonesia, for instance, the number of municipalities reporting DHF cases has been increasing since identification of the first DHF cases in 1968 (Fig. 9).

5. CONCLUSION

There is a temporally consistent and statistically significant relationship between El Niño and dengue epidemics in Colombia, French Guyana, Indonesia, and Surinam. Guyana and Venezuela, the other 2 countries of northern South America, were omitted from this study, because of their short data time series. We also found that drought conditions trigger dengue epidemics in all countries studied. This information, when coupled with El Niño forecasts, can be useful in identifying high-risk years for the spawning of dengue epidemics. Therefore, the public health sector is a potential user of El Niño and associated climate forecasts, and it could facilitate early interventions when climatic anomalies favouring the spawning of epidemics are forecast. Examples of early intervention to avoid dengue epidemics are media campaigns concerning the breeding sites of *Aedes aegypti*, which could instruct people to cover their household water containers, and neighbourhood clean-ups (i.e., removing tires and other garbage that create breeding grounds for these mosquitoes). Other interventions include increased insecticide sprayings during times with high epidemic risk. Finally, field research would be useful in order to provide evidence of increased mosquito density during droughts in northern South America and following them in Indonesia.

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