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El Niño and the Dynamics of Vectorborne Disease Transmission

Simon Hales,¹ Phil Weinstein,¹ Yvan Souares,² and Alistair Woodward¹

¹Department of Public Health, Wellington School of Medicine, Wellington, New Zealand; ²Community Health Programme, Secretariat of the Pacific Community, Noumea, New Caledonia

The objective of the study was to investigate the relationship between reported incidence of dengue fever and El Niño southern oscillation (ENSO) in 14 island nations of the South Pacific. Using a mixed ecological study design, we calculated correlations between annual averages of the southern oscillation index (SOI), local temperature and rainfall, and dengue fever. We also calculated temporal correlations between monthly reports of dengue fever cases on different islands. There were positive correlations between SOI and dengue in 10 countries. In five of these (including all of the larger islands) there were also positive correlations between SOI and estimates of local temperature and/or rainfall. There were temporal correlations between monthly reports of dengue cases within two groups of countries. Climate changes associated with ENSO may trigger an increase in dengue fever transmission in larger, more populated islands where the disease is endemic. There was also evidence of propagation of infection from larger islands to smaller neighbors. Unlike the initiation of epidemics, this transfer between islands appears to be independent of interannual climate variations, pointing to the importance of modulating factors in dengue transmission such as population density and travel. In the future, models of the impact of climate change must attempt to account for these factors. *Key words:* climate, dengue, disease vectors, El Niño, environment, epidemiology, southern oscillation. *Environ Health Perspect* 107:99–102 (1999). [Online 5 January 1999]

<http://ehpnet1.niehs.nih.gov/docs/1999/107p99-102hales/abstract.html>

Dengue is the most important viral vectorborne disease and an increasing problem globally (1,2). In the Pacific, there have been periodic epidemics of dengue fever over the past 30 years, most recently in 1998 (3). It has long been accepted that vectorborne disease incidence may be influenced by seasonal changes in the weather. In certain countries, the timing of epidemics of vectorborne disease has been shown to correlate with the El Niño southern oscillation (ENSO) climate cycle (4–8). ENSO is a semiperiodic climate cycle involving the interaction of ocean and atmospheric circulation in the tropical Pacific. ENSO has two extremes, El Niño and La Niña, which bring approximately opposite changes to global climate. Every 3–7 years the large pool of warm sea water normally situated off the northeast coast of Australia extends eastward toward the west coast of South America (El Niño). The southern oscillation refers to a “see-saw” of atmospheric pressure changes between the east and west Pacific that accompanies El Niño. The state of the ENSO cycle is summarized by the southern oscillation index (SOI), defined as the normalized difference in atmospheric pressure between Darwin (Australia) and Tahiti (French Polynesia) (Fig. 1). During El Niño conditions SOI is negative, but during La Niña SOI is positive. In the central Pacific region, much of the year-to-year variation in temperature and rainfall is related to ENSO (9). This makes the region ideal for the investigation of interannual relationships between dengue fever and climate.

There is current interest in the relationships between dengue and climate for two main reasons. First, there is hope that medium-term forecasts of the risk of dengue fever epidemics may be possible, based on ENSO. More broadly, it is hoped that improved understanding of interannual, regional scale relationships between environment and disease may help us to understand and anticipate more complex, indirect long-term processes such as global climate change (10). Current forecasts of the impact of global climate change on vectorborne disease transmission are based on models of local small-scale processes (for example, the effect of temperature on vector abundance) (11).

Methods

Monthly reports of dengue fever cases were obtained for 22 islands of the Pacific Community from the Secretariat of the Pacific Community (SPC, the former South Pacific Commission) for 1973–1994. Eight islands were excluded. Two islands had large gaps in their reporting of dengue fever. Six islands reported very few cases, probably for both social reasons (small populations, deficient reporting, public health interventions) and environmental reasons (e.g., climate unsuitable for vectors).

Climate data were obtained via the Internet: SOI data were obtained from the National Aeronautics and Space Administration's (NASA) Goddard Distributed Active Archive Center (12); rainfall and temperature data were obtained from the data library of the International Research Institute for

Climate Prediction (13). For rainfall and temperature estimates, the INGRID World Wide Web (WWW) interface (14) was used to access the gridded National Center for Atmospheric Research/National Centers for Environmental Prediction (NCAR/NCEP) reanalysis dataset (15). A rectangular geographical area was defined for each country by reading from a map the latitude and longitude ranges encompassing all islands within a given country. These coordinates were then entered (to the nearest degree) into the WWW interface. Data for resulting grid points were averaged to produce monthly estimates.

Data were examined for evidence of seasonal patterns by averaging within months over all years. The data were aggregated to produce January–December annual averages for each year of the study. Pearson correlations were calculated between SOI and temperature, SOI and rainfall, and SOI and dengue fever. Cross-correlations between monthly reports of dengue fever cases in each of the countries were calculated using SPSS software (16). We generated a series of bar charts showing correlations for all possible combinations of the islands at specified lag periods.

Results

The expected seasonal pattern of dengue fever cases, with a peak in the warmer months, was evident in many islands. The seasonal pattern was most clear-cut in islands with an endemic pattern; Figure 2 shows monthly average data for French Polynesia. Table 1 shows correlations between annual estimates of local rainfall and temperature, reports of dengue fever, and the SOI.

Countries with positive correlations between SOI and dengue fever cases. There were positive correlations between SOI and dengue fever in 10 countries. In five of these

Address correspondence to S. Hales, Department of Public Health, Wellington School of Medicine, Mein St., Wellington, New Zealand.

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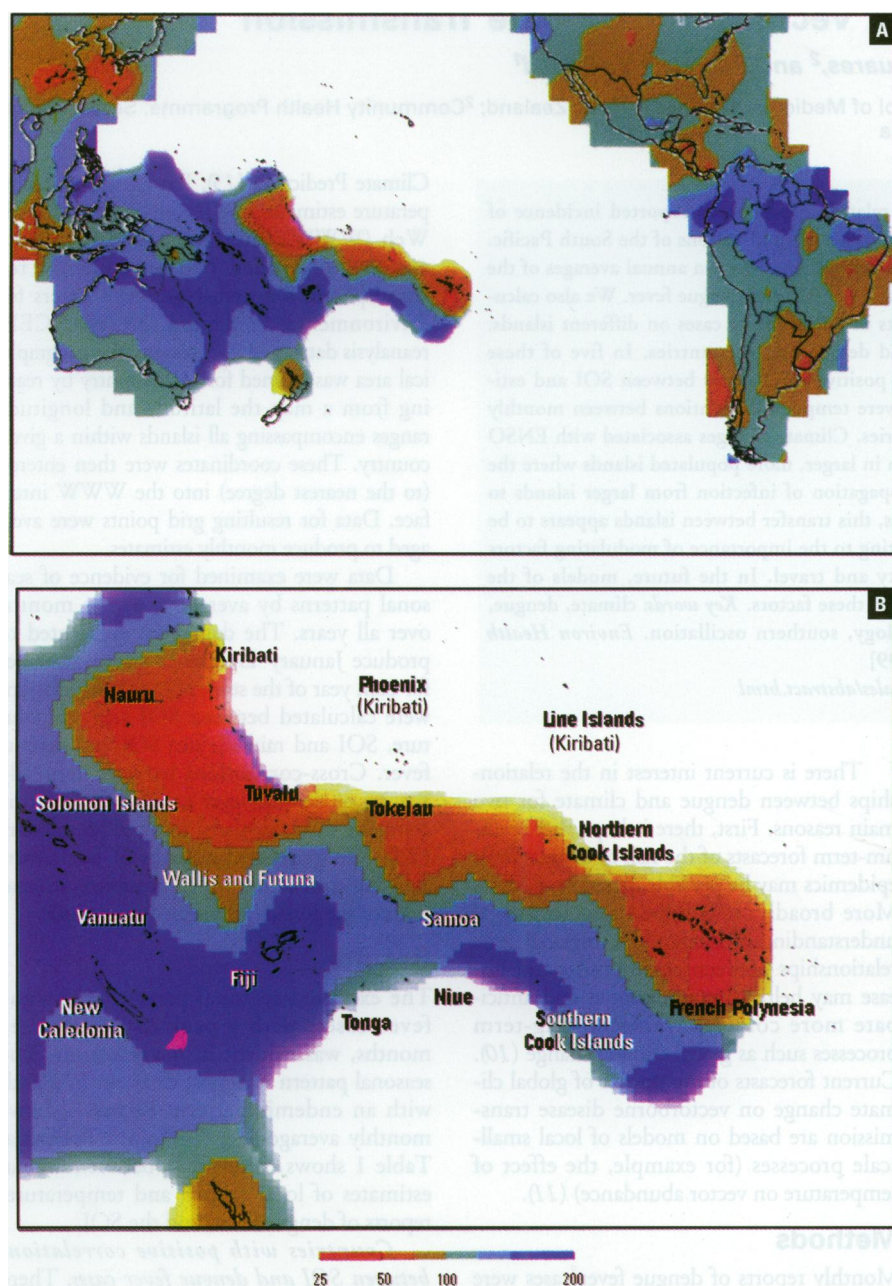


Figure 1. Spatial pattern of rainfall anomalies associated with El Niño southern oscillation (ENSO). (A) The whole Pacific region. (B) Enlargement showing the islands of the South Pacific. Blue shaded areas tend to be wetter than usual during the La Niña phase of the ENSO cycle, and red areas tend to be drier. The spatial pattern of temperature anomalies is similar. The color scale indicates the percentage change from long-term average rainfall. Based on composite data from the National Oceanic and Atmospheric Administration Cooperative Institute for Research in Environmental Sciences Climate Diagnostics Center (17).

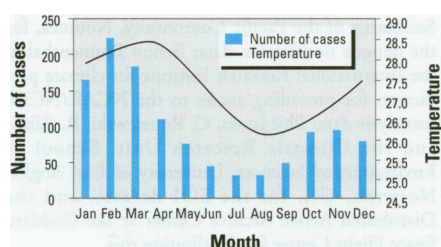


Figure 2. Seasonal pattern of dengue fever in French Polynesia.

(Fiji, New Caledonia, French Polynesia, Tonga, Vanuatu) there were also positive correlations between SOI and estimates of local temperature and/or rainfall. In the other five countries (American Samoa, Nauru, Tokelau, Wallis, Western Samoa) there were weak or negative correlations between SOI and local temperature and rainfall.

Remaining countries. There were weak or negative correlations between SOI and dengue fever in four countries: Kiribati,

Niue, Tuvalu, and Cook Islands. Correlations between SOI and local temperature and rainfall were negative in two of these.

Cross-correlations between monthly reports of dengue fever cases in different islands. Dengue fever cases in American Samoa, Western Samoa, Tokelau, and Tonga were correlated with case numbers in nearby Fiji 1–6 months previously (Fig. 3). There was a similar relationship between case numbers in another group (French Polynesia, New Caledonia, Vanuatu, Wallis, Futuna), but epidemics were less clearly initiated in any one of these islands (Fig. 4).

We reran all of the analyses, this time including data from the previously excluded islands. This did not alter the pattern of the results.

Discussion

The quality and completeness of the dengue fever data is difficult to assess. However, we can think of no reason to suspect that the accuracy of the reports might be related to climate. The results are therefore likely to have been biased toward the null by random misclassification in the dengue fever data. Serial correlation of the data tends to increase the apparent statistical significance of the findings; thus, some of the apparently significant findings may in fact have been due to chance. However, serial correlation should not have had a major effect on the magnitude of the correlation coefficients.

It is difficult to make estimates of biologically relevant exposure to temperature and rainfall where island subgroups within a country are spread out over a large area. This was a particular problem in the case of French Polynesia and Cook Islands, as in these countries the climate anomalies associated with ENSO are not uniform over the geographical area covered by the subgroups. For these countries, increases in rainfall, for example, in one subgroup are likely to be confounded by decreases in another, making it difficult to detect correlations at the country level.

Despite these difficulties, in the majority of islands there were positive correlations between SOI and dengue fever. When SOI is positive (La Niña conditions) much of the Central Pacific tends to be both wetter and warmer than usual (blue areas in Fig. 1). Correlations between SOI and dengue fever were absent or negative in Niue, Kiribati, Tuvalu, and Cook Islands. With the exception of Niue, these islands tend to be wetter and/or warmer when SOI is negative (El Niño conditions, red areas of Fig. 1). Thus, for the majority of islands, the findings are consistent with an effect of interannual climate variation on dengue fever transmission. This is biologically plausible because

warmer and/or wetter conditions are generally favorable for mosquito development.

We do not suggest that climate is the only factor affecting dengue fever transmission in the region. Local climate changes associated with ENSO may trigger an increase in transmission in larger, more populated islands where the disease is endemic (French Polynesia, New Caledonia, Fiji, and possibly Vanuatu). Subsequently, dengue fever may spread to smaller neighboring islands (such as Samoa, Tonga, Tokelau, Wallis) via major travel routes. In support of this, we found time-series correlations between monthly reports of dengue fever in two groups of islands. In one group, the islands are geographically close (Fiji, Tonga, Samoa, Tokelau), whereas the other group includes the four Francophone countries of the South Pacific.

Table 1. Population, climate, and dengue fever in the South Pacific

Country	Population (thousands)	Pearson correlations		
		SOI and temperature	SOI and rainfall	SOI and dengue
Tokelau	1.5	-0.71	-0.02	0.57*
Western Samoa	170	-0.28	-0.01	0.49*
Fiji	773	0.78	0.70	0.45*
American Samoa	61	-0.31	-0.20	0.45*
Tonga	98	0.62	0.46	0.41*
Nauru	11	-0.71	-0.65	0.34
Vanuatu	177	0.86	0.84	0.34
Wallis	14	0.04	-0.03	0.24
French Polynesia	220	-0.62	0.35	0.23
New Caledonia	197	0.85	0.86	0.22
Kiribati	78	-0.81	-0.46	0.02
Niue	2	0.66	0.74	0.0
Tuvalu	11	-0.62	-0.47	-0.13
Cook Islands	10	-0.36	0.29	-0.18

Population data from the demography program of the Secretariat of the Pacific Community, of the various years 1994–1997.
* $p < 0.05$.

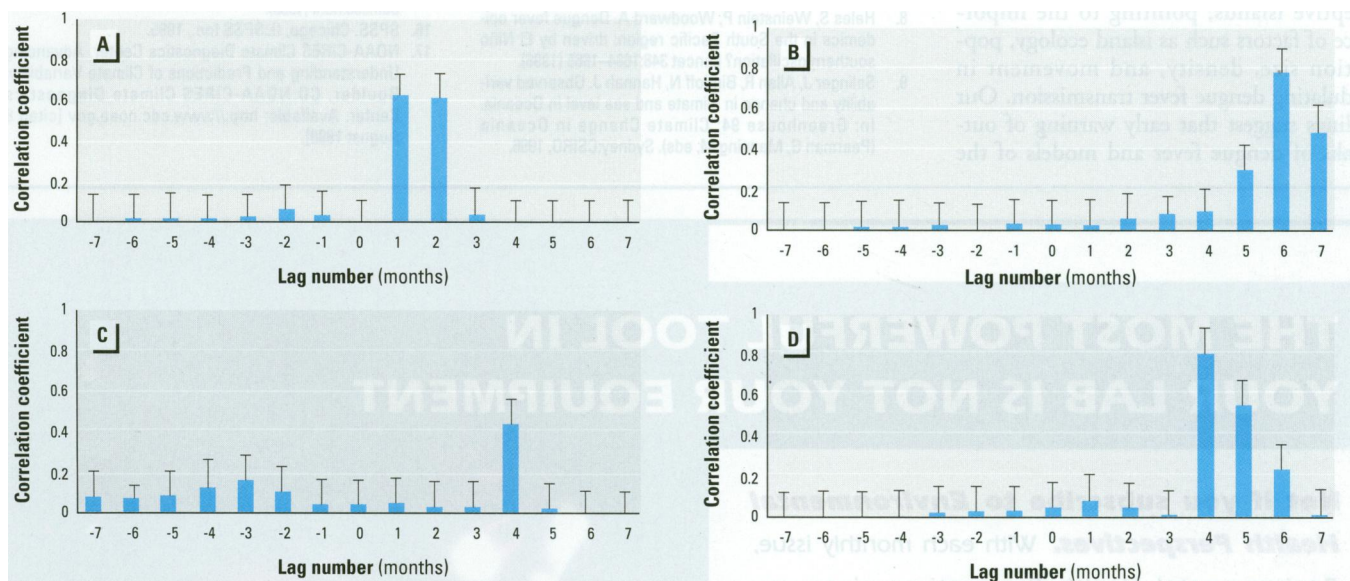


Figure 3. Cross-correlations between monthly reports of dengue fever in Fiji and reports in (A) Tonga, (B) Western Samoa, (C) Tokelau, and (D) American Samoa.

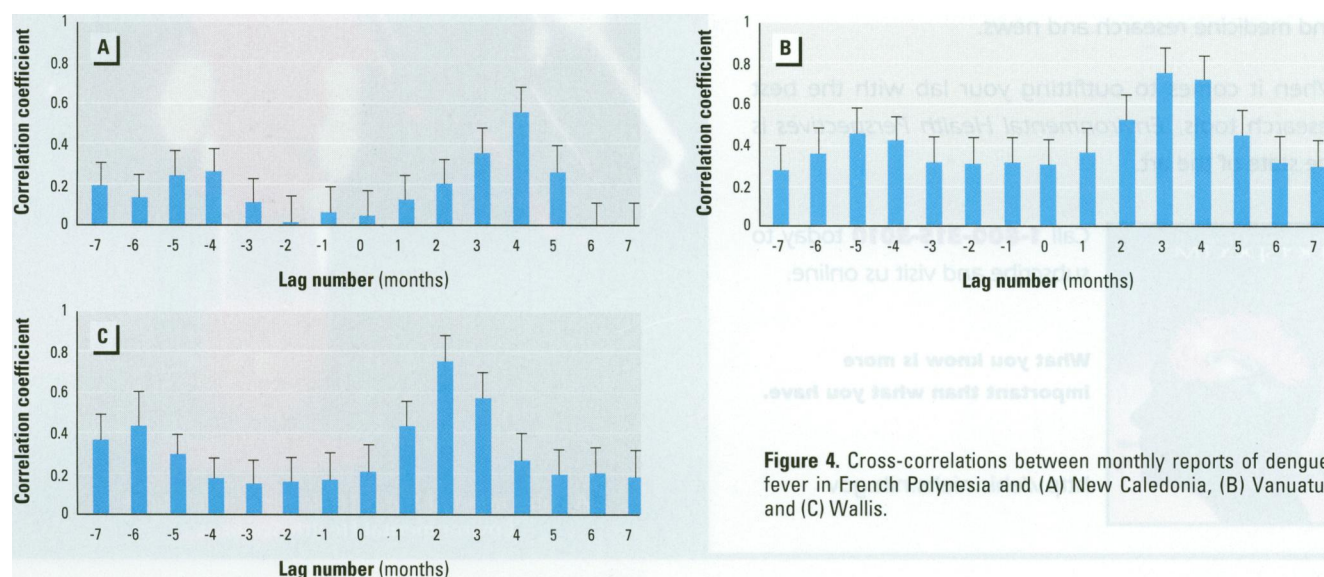


Figure 4. Cross-correlations between monthly reports of dengue fever in French Polynesia and (A) New Caledonia, (B) Vanuatu, and (C) Wallis.

In larger islands, forested and agricultural ecosystems offer a great variety of rain-dependent larval mosquito habitats; on smaller islands and atolls, rapid drainage and evaporation are more likely to mask the rain-driven availability of larval sites (hence, a clear correlation between mosquito numbers and climate may be lacking). On smaller islands, population densities of both mosquitoes and human reservoirs of the virus are likely to be low. In these islands, initiation of an epidemic is dependent on importation of the virus from larger islands. This is consistent with the observed lag period of several weeks or months between dengue fever cases on larger islands and the outbreaks on their smaller neighbors (Figs. 3, 4). Propagation of infection from large to small islands appears to be independent of local interannual climate variations in the receptive islands, pointing to the importance of factors such as island ecology, population size, density, and movement in modulating dengue fever transmission. Our findings suggest that early warning of outbreaks of dengue fever and models of the

potential impacts of climate change will need to account for these regional factors if accurate forecasts are to be made.

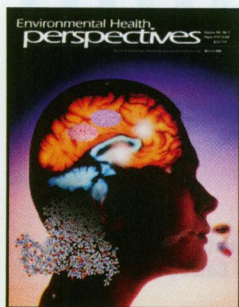
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