Modeling dengue cases in Health Regions of Costa Rica using El Niño Southern Oscillation and local vegetation dynamics

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Abstract

Temporal behavior of dengue fever and dengue hemorrhagic fever (DH/DHF) has been associated with climate, which may modulate mosquito vector populations. El Niño Southern Oscillation (ENSO) fluctuations can be related to sea-surface temperatures in the Pacific that influence precipitation and temperature in Latin America. In addition, vegetation dynamics have been associated with DF/DHF at local scales. In this study, vegetation indices from the Moderate Resolution Imaging Spectrometer (MODIS) and Pacific sea-surface temperature anomalies were used to model weekly DF/DHF cases (2003 to 2007) in Costa Rica and its nine Health Regions (HR). Using cross correlation analyses, positive and negative lags were identified, where DF/DHF cases and each independent variable were better correlated. A sinusoid and non-linear least squares model was applied to fit case data for the county and HR using lagged variables. The countywide model, where variables were lagged according to their highest correlation coefficient, had an R^2 of 0.86. Models including either only the positive or only the negative lags of variables had R^2 values of 0.60 and 0.84, respectively. These models were all able to reproduce a major epidemic in 2005. Model performance differed between HR, with R^2 values from 0.41 (a region with few cases and slight wet/dry seasonality) to 0.85 (a region with marked seasonality and >20,000 cases). Results show that climate and vegetation dynamics are good predictors of DF/DHF cases in Costa Rica. The differences in model fits for HR may be due in part to local conditions that can affect transmission such as altitude, temperature, socioeconomic conditions, prevention and control actions, and human behavior. Moreover, these models may be improved further by using other variables like Atlantic sea surface temperatures. Considering that the HR of Costa Rica may represent conditions common to areas of Latin America and the Caribbean, these models may be applicable to various countries and function as an early warning system to predict epidemics in areas affected by dengue.

Climate modulates transmission of dengue fever and dengue hemorrhagic fever (DH/DHF) in various ways, including affecting the extrinsic incubation period, vector survival, vector densities, biting rate, and overall vector capacity. El Niño Southern Oscillation (ENSO) fluctuations, which influence temperature and rainfall in Latin America, and vegetation dynamics may be associated with spatial and temporal behavior of this mosquito-borne disease.[1,2,3,4]

Dengue is the most important vector-borne disease in Costa Rica,[5] especially in the Pacifico Central, Huetar Atlantica, and Chorotega Regions (Fig. 1). In this study, vegetation indices from the Moderate Resolution Imaging Spectrometer (MODIS) and Pacific sea-surface temperature anomalies were used to model weekly DF/DHF cases (2003 to 2007) in Costa Rica and its nine Health Regions.

Materials and Methods

A non-linear model was developed to fit weekly data of DF/DHF for Costa Rica and each Health Region (Fig. 1). The model uses weekly data from 5 NINO indices (sea surface temperature anomalies), and the weekly mean enhanced vegetation index (EVI) and normalized difference vegetation index (NDVI) extracted for each area from MODIS satellite imagery. Model form is:

$$c_t = a_0 + \sum_{n=1}^{\infty}(a_n \cos z_{tn} + b_n \sin z_{tn})$$

where c_t is number of cases at time t, z_{tn} are independent input variables, and a_n and b_n are parameters estimated using non-linear least squares.[6]

A cross correlation analysis was performed to determine lagged relationships between DF/DHF cases and each independent variable. Positive and negative lags (of up to 52 weeks) were evaluated and the lags with the maximum cross correlation coefficient were selected. Variables were lagged accordingly in the model. For the positive lags, consistent with a predictive model, lags of minimum +10 weeks were selected (Table 1).

Fig. 1. Health Regions of Costa Rica.

Table 1. Example of weekly lags of maximum cross correlation (in parentheses) chosen for the analyses of countrywide data.

Variable	Pos lag	Neg lag	Max. lag
Nino 1	10 (-0.26)	-3 (-0.42)	-3 (-0.42)
Nino 2	46 (0.24)	-52 (-0.42)	-52 (-0.42)
Nino 3	45 (0.21)	-11 (-0.45)	-11 (-0.45)
Nino 4	46 (0.28)	-17 (-0.47)	-17 (-0.47)
Nino 3.4	45 (0.24)	-13 (-0.50)	-13 (-0.50)
EVI	10 (0.38)	-24 (-0.46)	3 (0.54)
NDVI	39 (0.22)	-38 (-0.36)	-38 (-0.36)

Table 2. Model fit for each health region, according to the lags used for independent variables.

Health Region	DF/DHF cases	R^2 Neg lags	R^2 Pos lags	R^2 Max lags
Huetar Norte	1,000	0.411	0.294	0.411
Chorotega	29,020	0.611	0.578	0.553
Occidente	226	0.591	0.389	0.591
Brunca	4,939	0.673	0.415	0.668
Central Este	1,566	0.651	0.432	0.699
Huetar Atlantica	27,520	0.793	**0.669**	0.804
Central Norte	9,387	0.792	0.615	0.807
Central Sur	8,851	0.837	0.470	0.837
Pacifico Central	20,748	0.849	0.577	**0.849**
Countrywide	**103,257**	**0.839**	**0.601**	**0.857**

Results

Model performance differed between HR. R^2 values ranged from 0.41 in a region with few cases and slight seasonality to 0.85 in a region with marked seasonality and >20,000 cases (Table 2). In the countrywide model, the outbreaks in 2005 and 2007 were evident with both positive and negatively lagged variables (Fig. 2). Most HR models were able to reproduce the epidemic of 2005, and models of the Huetar Atlantica and Pacifico Central Regions with positive lags were able to predict an increase in cases for 2005 (Fig. 3).

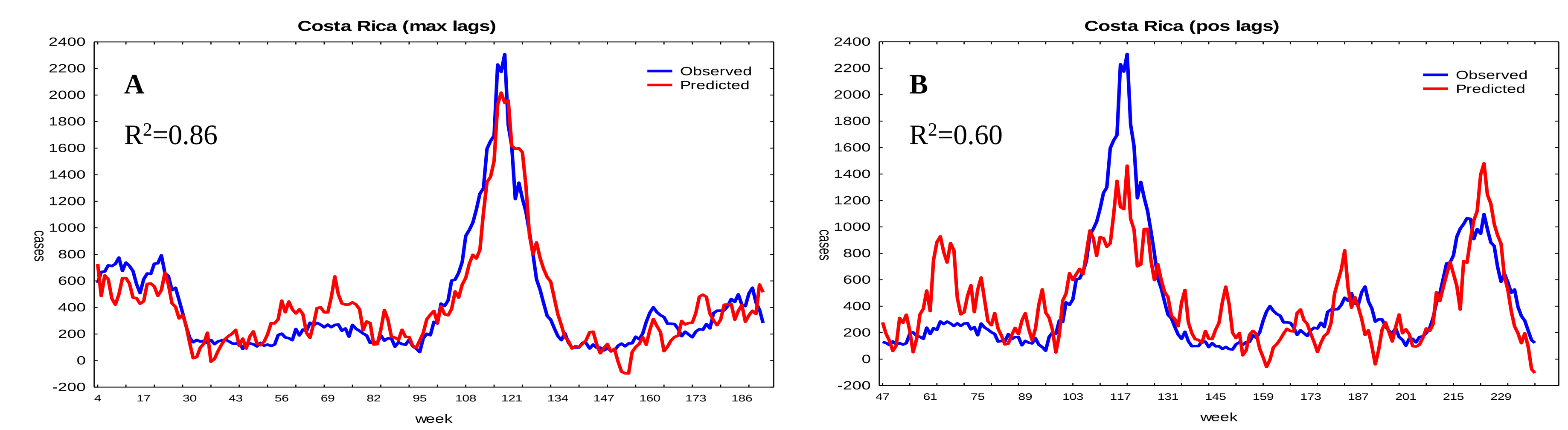

Fig. 2. Observed and predicted dengue cases for Costa Rica. A: Model using variables lagged according to maximum cross correlations. B: Model using only positively lagged variables (predictive).

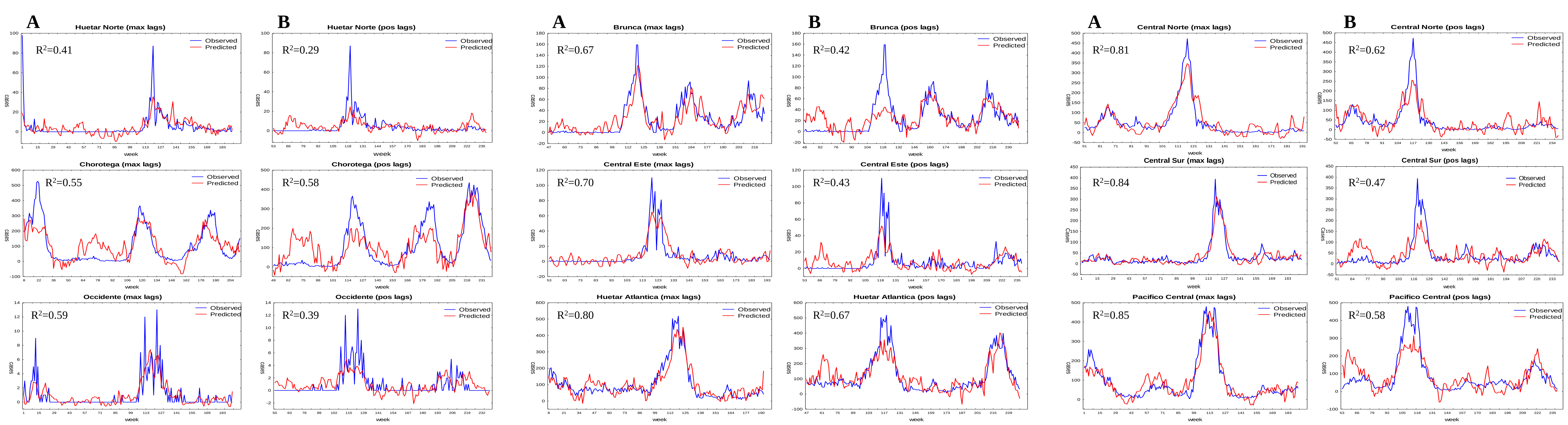

Fig. 3. Observed and predicted dengue cases for Health Regions of Costa Rica. Column A: Model using variables lagged according to maximum cross correlations. Column B: Model using only positively lagged variables. (predictive).

Conclusions

Results show that climate and vegetation dynamics can be good predictors of DF/DHF in Costa Rica and that the limited parameters used reliably explain and predict DF/DHF incidence. In this new approach, the model fit for the country was improved compared to previous studies.[6] In addition, this is the first study to show that the model performs well and may be used at the level of Health Regions. Next steps will include determining how these simple models may be improved further by incorporating other sea surface temperature indices (such as Atlantic sea surface temperatures) and by assessing how local conditions that affect dengue transmission (such as altitude, temperature and rainfall patterns, local mosquito control actions, human behavior, and herd immunity) may be responsible for model differences between Health Regions. This model may be applicable to other countries and areas in Latin America and serve to develop an early warning system for DF/DHF epidemics in the region.

References:

1. Cazales B, Chavez M, McMichael A J, Hales S. 2005. Nonstationary influence of El Niño on the synchronous dengue epidemics in Thailand. *PLoS Medicine* 2:313-318.
2. Chadee DD, Shivnauth B, Rawlins SC, Chen AA. 2007. Climate, mosquito indices and the epidemiology of dengue fever in Trinidad (2002-2004). *Ann. Trop. Med. Parasitol.* 101:69-77.
3. Peterson AT, Martinez-Campos C, Nakazawa Y, Martinez-Meyer E. 2005. Time-specific ecological niche modeling predicts spatial dynamics of vector insects and human dengue cases. *Trans. Roy. Soc. Trop. Med. Hyg.* 99:647-655.
4. Troyo A, Fuller DO, Calderón-Arguedas O, Solano ME, Beier JC. 2009 Urban structure and dengue incidence in Puntarenas, Costa Rica. *Sing. J. Trop. Geogr.* 30:265-282.
5. Troyo A, Porcelain SL, Calderon-Arguedas O, Chadee DD, Beier JC. 2006. Dengue in Costa Rica: The gap in local scientific research. *Rev. Panam. Salud. Publ.* 20:350-360.
6. Fuller DO, Troyo A, Beier JC. 2009. El Niño Southern Oscillation and vegetation dynamics as predictors of dengue fever cases in Costa Rica. *Environ. Res. Lett.* 4:014011.

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