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Seasonality of absolute humidity explains seasonality of influenza-like illness in Vietnam

Pham Quang Thai[a,b,*], Marc Choisy[b,c], Tran Nhu Duong[a], Vu Dinh Thiem[a], Nguyen Thu Yen[a], Nguyen Tran Hien[a], Daniel J. Weiss[d], Maciej F. Boni[e,f], Peter Horby[b,e]

[a] National Institute of Hygiene and Epidemiology, Hanoi, Viet Nam
[b] Wellcome Trust Major Overseas Programme, Oxford University Clinical Research Unit, Hanoi, Viet Nam
[c] MIVEGEC, University of Montpellier, CNRS 5290, IRD 224, Montpellier, France
[d] Spatial Ecology & Epidemiology Group, Department of Zoology, University of Oxford, Oxford, UK
[e] Centre for Tropical Medicine, Nuffield Department of Clinical Medicine, University of Oxford, Oxford, UK
[f] Wellcome Trust Major Overseas Programme, Oxford University Clinical Research Unit, Ho Chi Minh City, Viet Nam

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ABSTRACT

Background: Experimental and ecological studies have shown the role of climatic factors in driving the epidemiology of influenza. In particular, low absolute humidity (AH) has been shown to increase influenza virus transmissibility and has been identified to explain the onset of epidemics in temperate regions. Here, we aim to study the potential climatic drivers of influenza-like illness (ILI) epidemiology in Vietnam, a tropical country characterized by a high diversity of climates. We specifically focus on quantifying and explaining the seasonality of ILI.
Methods: We used 18 years (1993–2010) of monthly ILI notifications aggregated by province (52) and monthly climatic variables (minimum, mean, maximum temperatures, absolute and relative humidities, rainfall and hours of sunshine) from 67 weather stations across Vietnam. Seasonalities were quantified from global wavelet spectra, using the value of the power at the period of 1 year as a measure of the intensity of seasonality. The 7 climatic time series were characterized by 534 summary statistics which were entered into a regression tree to identify factors associated with the seasonality of AH. Results were extrapolated to the global scale using simulated climatic times series from the NCEP/NCAR project.
Results: The intensity of ILI seasonality in Vietnam is best explained by the intensity of AH seasonality. We find that ILI seasonality is weak in provinces experiencing weak seasonal fluctuations in AH (annual power <17.6), whereas ILI seasonality is strongest in provinces with pronounced AH seasonality (power >17.6). In Vietnam, AH and ILI are positively correlated.
Conclusions: Our results identify a role for AH in driving the epidemiology of ILI in a tropical setting. However, in contrast to temperate regions, high rather than low AH is associated with increased ILI activity. Fluctuation in AH may be the climate factor that underlies and unifies the seasonality of ILI in both temperate and tropical regions. Alternatively, the mechanism of action of AH on disease transmission may be different in cold-dry versus hot-humid settings.

1. Introduction

Influenza remains a globally important illness which results in high mortality, morbidity and economic burden (Stephenson and Zambon, 2002). The epidemiology of influenza is diverse, with a stronger seasonality in the temperate regions than in the tropical ones, and differences in epidemic timing between different parts of the world (the two hemispheres being notably out of phase) (Viboud et al., 2006a). Characterizing and understanding the seasonality of influenza is critical for optimizing vaccination and other control policies (Bolker and Grenfell, 1996; Grenfell and Harwood, 1997; Grenfell et al., 2001) as well as sampling of viruses in order to update the vaccine from year to year (Ampofo et al., 2013).

A number of hypotheses have been explored to explain the seasonality of influenza, among which climatic factors appear to

* Corresponding author at: National Institute of Hygiene and Epidemiology, Hanoi, Viet Nam. Tel.: +84 9 13 09 27 77; fax: +84 4 38 21 04 87.
E-mail addresses: phamquangthai@gmail.com, phamthaidt@yahoo.com (P.Q. Thai).

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be most important (Tamerius et al., 2011). Experimental studies on guinea pig models have shown an increase in influenza virus transmissibility as the absolute humidity (AH) decreases (Lowen et al., 2007; Shaman and Kohn, 2009). An epidemiological study of influenza in the United States has shown that a drop in AH is a good predictor of epidemic onset (Shaman et al., 2010). Other climatic factors have been proposed as drivers of influenza epidemiology, such as the number of hours of sunshine (Hope-Simpson, 1981), mediated through the effect of Vitamin D synthesis on individuals' innate immune response to infection (Cannell et al., 2006; Liu et al., 2006; Yamshchikov et al., 2009). However, this hypothesis remains unproven (Shaman et al., 2011).

The investigation of the links between influenza epidemiology and climatic factors has followed two paths. The first one has looked at predictors of epidemic onset, for example in the United States (Shaman et al., 2010). More recent studies conducted at the global scale by Bloom-Feshbach et al. (2013) and Tamerius et al. (2013) have shown that epidemics tend to start in "cold-dry" and "humid-rainy" conditions in temperate and tropical regions respectively. However, this approach of working on epidemic onset is relevant only when the epidemiology is seasonal enough for epidemic onset to be characterized. Since the intensity of the seasonality itself varies latitudinally, both at the between-country (Viboud et al., 2006a) and at the within-country (Alonso et al., 2007) levels, the second path of investigation has examined predictors of the intensity of seasonality. A recent study carried out in different localities of China quantified the seasonality of influenza from the Fourier value around the period of 1 year and related it to a number of potential climatic drivers (Yu et al., 2013). The results of this study found temperature and hours of sunshine to be good predictors of influenza seasonality. However, AH was not tested in this analysis, making comparisons with previously published results on the topic difficult (see Lowen et al., 2007; Shaman and Kohn, 2009; Shaman et al., 2010 cited above).

In this article we investigated the climatic factors that explain the intensity of the seasonality of influenza-like illness (ILI) in Vietnam. Vietnam is a tropical country characterized by a high population density (90 million inhabitants on 330,000 km^2), and a high diversity of climates resulting from Vietnam's wide latitudinal (8–24° N) and elevational (0–3200 m) ranges. These characteristics make Vietnam an ideal country to test the effects of climatic factors on ILI epidemiology. The climatic variables tested in the present study include minimum, mean, and maximum temperatures, relative and absolute humidities, rainfall, and hours of sunshine. Our results are then tentatively extrapolated to the global scale and compared with previously published reports.

2. Materials and methods

2.1. ILI data

ILI is one of 26 notifiable communicable diseases in Vietnam. Monthly data have been aggregated by province by the Ministry of Health of Vietnam since 1979. Given quality issues in the data before 1993, we focused our analysis on the 1993–2010 time period. A number of provinces split since 1993 and, for consistency, we used the province administrative borders of 1993 (i.e. 52 provinces instead of 63 as of today).

2.2. Climatic data

Meteorological data from January 1993 to December 2010 were obtained from the Vietnamese Institute of Meteorology, Hydrology and Environment in 67 climatic stations spanning all of Vietnam. The data include the monthly means of the minimum, mean, and maximum temperatures (°C), the monthly means of absolute (g/L) and relative (%) humidities, and the monthly cumulative sums of rainfall (mm) and hours of sunshine. Each province was assigned the climatic station that is closest to its population centroid. Province population centroids were calculated from commune population sizes and commune geographic centroid coordinates (≈200 communes per province).

2.3. Outlier identification

The identification of outliers was performed on stationarized and normalized versions of the time series obtained by simple differencing. On these normalized time series, we computed the 1st and 99th expected percentile values from the mean and standard deviation. Outliers were identified as data points either below the 1st percentile or above the 99th percentile. The identified points were quite far below and far above the 1st and 99th percentiles. They are likely errors created at the time of reporting and appear at a very low rate (≈1%) but with extremely high values, hence our willingness to discard them.

2.4. ILI data transformations

Outliers in the ILI time series were removed and missing data were linearly interpolated. ILI time series were then square-root transformed for variance stabilization, and then detrended, centered and reduced. The trends were estimated by lowess regressions (Crawley, 2007) with smoother spans of 0.1, which captured the trends neatly for all the provinces.

2.5. Intensity of seasonality

Wavelet decompositions using the Morlet wavelet (Torrence and Compo, 1998; Cazelles et al., 2008) were carried out on the ILI time series of all the provinces to check for stationarities. The intensities of seasonality of ILI and climatic time series were quantified by the power value at the period of 1 year in the global wavelet power spectrum (equivalent to a Fourier spectrum). Wavelet decompositions were performed using the `biwavelet` R package (Gouhier, 2013).

2.6. Regression tree

Relationships between climatic variables and the intensity of ILI seasonality were explored by a regression tree, using the `tree` R package (Ripley, 2012). In order to explore as many climatic characteristics as possible, we computed, for each climatic variable, a number of summary statistics. These statistics include the minimum, mean, and maximum values, the amplitude (difference between minimum and maximum values), the intensity of seasonality as defined by wavelet analysis, and the number of months during which the value of the variable is below a given threshold (varying this threshold over 50 values regularly spaced between the minimum and the maximum values). In total, these summary statistics for all the climatic variables generated 534 potential explanatory variables that were entered into the regression tree analysis to identify climate factors that best explained the observed intensity of ILI seasonality.

2.7. Extrapolation to the global scale

In order to extrapolate the result of the regression tree to the global scale we used monthly climatic data simulated from the NCEP/NCAR project (Kalnay et al., 1996) by pixels of 2.5° × 2.5°, over the 1993–2010 time period. Since AH was not included in