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El Niño–Southern Oscillation and unusual severe acute respiratory infection in Colombia, 2011–2019: a national time-series analysis using distributed lag non-linear models

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Abstract

Background: The El Niño–Southern Oscillation (ENSO) is the main driver of inter-annual climate variability in Colombia, but its relationship with severe respiratory infections has not been quantified at national level. We estimated the association between ENSO intensity and the incidence of unusual severe acute respiratory infection (SARI), a sentinel surveillance event, and examined whether it varied by lag, region and departmental poverty.

Methods: We conducted an ecological time-series study of monthly unusual SARI cases notified to the national surveillance system (SIVIGILA, event 348) from 2011 to 2019. ENSO intensity was measured with the Oceanic Niño Index (ONI). We used quasi-Poisson distributed lag non-linear models with lags of 0 to 12 months, adjusting for seasonality and long-term trend, with population as offset. We fitted models nationally and by region and Multidimensional Poverty Index tertile, and ran prespecified sensitivity analyses.

Results: A total of 12,984 cases were notified (31.0 per million inhabitants per year). Nationally, ONI was not associated with cumulative incidence (relative risk [RR] per 1 °C 0.95, 95% CI 0.78–1.15). Higher ONI was followed by fewer cases at lags of 0 to 4 months and more cases at 8 to 12 months. In the Caribbean and Pacific regions, higher ONI was associated with lower incidence (RR 0.72, 0.56–0.93, and 0.65, 0.53–0.80), indicating higher incidence after La Niña conditions. The national estimate was sensitive to the flexibility of the long-term trend.

Conclusions: ENSO was not a national predictor of unusual SARI in Colombia, but La Niña was followed by higher incidence in the Caribbean and Pacific regions. Regional La Niña alerts could support respiratory preparedness, and future analyses should account for differences in surveillance capacity.

Introduction

Lower respiratory infections remain a leading cause of death worldwide, causing an estimated 2.18 million deaths and 344 million episodes in 2021, with the highest burden in children under five and in low- and middle-income countries [1]. Their incidence varies with season and climate: in tropical settings, where temperature and humidity remain high throughout the year, influenza activity tends to peak during the rainiest months [2], and in Colombia, humidity, rainfall and temperature have been associated with acute respiratory disease and respiratory syncytial virus hospitalisations [3–5]. Climate variability may therefore influence the burden of respiratory infection, particularly in countries exposed to large inter-annual climate swings.

The El Niño–Southern Oscillation (ENSO) is the dominant source of inter-annual climate variability in the tropics. Its warm phase, El Niño, and cold phase, La Niña, recur every two to seven years and alter rainfall, temperature and humidity across large regions [6]. Colombia is among the countries most affected. La Niña brings above-normal rainfall and flooding, particularly to the Andean, Caribbean and Pacific regions, while El Niño brings drought, higher temperatures and forest fires [7, 8]. The 2010–2011

La Niña rainy season alone affected more than 3.2 million people, about 7% of the national population, and caused 1,374 deaths [9]. These events change the conditions that favour respiratory transmission, including indoor crowding, displacement, humidity and exposure to smoke.

The evidence linking ENSO to respiratory infections is limited and inconsistent. Reviews describe robust associations between ENSO and vector-borne and diarrhoeal diseases, but weaker and more heterogeneous evidence for respiratory outcomes [6]. In China, El Niño years were associated with higher respiratory infectious disease morbidity across 31 provinces [10], and it has been proposed that La Niña conditions preceded past influenza pandemics [11]. Most of these studies used annual data or categorical ENSO phases, which cannot capture the delayed and possibly non-linear effects of climate on infection. Time-series methods developed in environmental epidemiology, such as distributed lag non-linear models, allow the exposure-response and lag-response relationships to be estimated jointly [12–14], but they have rarely been applied to ENSO and respiratory outcomes in Latin America.

In Colombia, the national public health surveillance system (SIVIGILA) monitors unusual severe acute respiratory infection (SARI) as a sentinel event: severe cases with features suggesting a novel or emerging pathogen, such as rapid deterioration in previously healthy young adults, clusters, or deaths of unknown aetiology [15]. This event is designed for early detection of respiratory threats and has been recorded with a consistent definition since 2011, which makes it suitable for examining whether climate variability changes the occurrence of severe respiratory infection at national scale. Because detection depends on hospital and laboratory capacity, any such analysis must also consider differences in surveillance between regions and socioeconomic contexts.

We therefore addressed three questions: (1) whether ENSO intensity, measured by the Oceanic Niño Index, is associated with the incidence of unusual SARI in Colombia; (2) over what lag period any association occurs; and (3) whether the association differs by geographic region and by departmental multidimensional poverty.

Methods

Study design and setting

We conducted an ecological time-series study of monthly counts of unusual severe acute respiratory infection (SARI) in Colombia between January 2011 and December 2019. Colombia is divided into 32 departments (first-level administrative units, comparable to provinces) and the capital district of Bogotá, which together contain 1,122 municipalities. The national population grew from 44.6 million in 2011 to 49.4 million in 2019 [16]. The country spans Andean highlands, Caribbean and Pacific lowlands, and the Orinoquía and Amazon basins, and ENSO affects these regions differently: La Niña phases are associated with above-normal rainfall and flooding, particularly in the Andean, Caribbean and Pacific regions, and El Niño phases with drought, higher temperatures and forest fires [7,8]. The study period

ends in December 2019 because the COVID-19 pandemic changed case definitions and notification for respiratory events from 2020 onwards.

Outcome

The outcome was the monthly number of cases notified to the national public health surveillance system (SIVIGILA) under event code 348, unusual SARI (*infección respiratoria aguda grave inusitada*). A case is defined as a patient with fever and cough requiring hospital management who meets at least one additional condition: (a) an exposure criterion, namely being a health care worker with recent contact with SARI patients, working in the poultry or swine sector or having contact with birds or pigs, or having travelled in the previous 14 days to areas where avian influenza or other novel respiratory agents circulate; (b) being a previously healthy person aged 5 to 65 years with rapid clinical deterioration within 72 hours of symptom onset requiring vasopressors or ventilatory support; (c) belonging to a cluster of two or more SARI cases; or (d) dying from SARI of unknown aetiology [15]. Unusual SARI is a sentinel event designed to detect novel or emerging respiratory pathogens and differs from routine acute respiratory infection morbidity, which is monitored through aggregate collective notification (event 995).

We obtained weekly case counts by municipality of occurrence from the open-data portal of the Colombian government (datos.gov.co, SIVIGILA public dataset) [17]. Data for 2010 covered only epidemiological weeks 45 to 52 and were excluded. We assigned each epidemiological week (Sunday to Saturday) to the calendar month containing its midpoint and summed counts by month. Annual totals matched those reported in the official event reports of the National Institute of Health (INS) [18].

Exposure

ENSO intensity was measured with the Oceanic Niño Index (ONI), the three-month running mean of sea surface temperature anomalies in the Niño 3.4 region (5°N to 5°S, 120°W to 170°W) based on the ERSSTv5 dataset [19,20], published by the NOAA Climate Prediction Center. Each month was assigned the ONI value of the three-month season centred on it. ONI values of +0.5 °C or higher define El Niño conditions and −0.5 °C or lower define La Niña conditions. We modelled ONI as a continuous variable to use the full range of ENSO intensity rather than categorical phases.

Covariates and stratification variables

Annual population estimates by department came from the National Administrative Department of Statistics (DANE) [16] and were linearly interpolated to mid-month values to use as an offset. Departments were grouped into four regions according to the natural regions coded in the IDEAM climate change vulnerability dataset [21]: Andean, Caribbean, Pacific, and Orinoquía-Amazonía (which also includes the insular department of San Andrés). Socioeconomic deprivation was measured with the

departmental Multidimensional Poverty Index (MPI) from DANE, which captures deprivation in household education, childhood and youth conditions, health, employment, and housing and public services [22]; departments were grouped into tertiles. Table 1 summarises all data sources.

Table 1. Data sources.

Variable	Source	Spatial unit	Temporal resolution	Period used	Unit
Unusual SARI cases (event 348)	SIVIGILA, INS, via datos.gov.co [17]	Municipality of occurrence	Epidemiological week, aggregated to month	2011–2019	Count
Oceanic Niño Index	NOAA Climate Prediction Center, ERSSTv5 [19,20]	Niño 3.4 region	Month (3-month running mean)	2010–2019 (including lags)	°C anomaly
Population	DANE projections [16]	Department	Year, interpolated to month	2011–2019	Persons
Region	IDEAM [21]	Department	Fixed	—	4 categories
Multidimensional Poverty Index	DANE, 2023 [22]	Department	Fixed	—	% of population; tertiles

Causal assumptions

We represented our assumptions in a directed acyclic graph (Supplementary Figure S1). ENSO is driven by ocean-atmosphere dynamics in the tropical Pacific and is not influenced by Colombian population characteristics, so no variable measured in Colombia can confound its effect on unusual SARI. Precipitation, temperature, humidity and air pollution from forest fires lie on the causal pathway between ENSO and respiratory infection and are therefore mediators; adjusting for them would block part of the effect we aim to estimate, so we did not include them in the main model. The main threat to validity is instead non-causal temporal variation in case counts: seasonal circulation of respiratory viruses, and long-term changes in surveillance capacity, notification practices and population size. We controlled these with seasonal terms, a smooth function of time and a population offset. Because notification of a sentinel event depends on local surveillance capacity, which varies by department and correlates with deprivation, we treat region and MPI as effect modifiers rather than confounders.

Statistical analysis

We used quasi-Poisson regression with distributed lag non-linear models (DLNM) [12,13], the standard approach for time-series studies of environmental exposures and health [14]. The model was:

$$\log E(Y_t) = \alpha + cb(ONI_t, \text{lag } 0–12) + ns(t, df = 3) + \Sigma_{k=1,2} [\beta_k \sin(2\pi k m_t/12) + \gamma_k \cos(2\pi k m_t/12)] + \log(P_t)$$

where Y_t is the number of unusual SARI cases in month t, cb() is the cross-basis for ONI, ns(t) is a natural cubic spline of time with three degrees of freedom to control long-term trends, the two pairs of Fourier terms control seasonality (m_t is the calendar month), and P_t is the population offset. The cross-basis assumed a linear exposure-response relationship and modelled the lag-response with a natural cubic spline with one internal knot at an equally spaced position on the log scale over lags 0 to 12 months. We chose a maximum lag of 12 months because ENSO affects Colombian rainfall and temperature with delays of several months and its phases typically last 9 to 12 months [7,8]. We used a quasi-Poisson family to account for overdispersion.

We chose three degrees of freedom for the long-term trend a priori. ENSO varies on time scales of two to seven years [6], so over a nine-year series a more flexible trend would absorb part of the variation we aim to attribute to ENSO, and would treat changes in surveillance and ENSO-driven changes in incidence as indistinguishable. Three degrees of freedom allow for gradual changes in notification practices and population size while leaving inter-annual ENSO variation to the cross-basis. We report results with 2, 5 and 9 degrees of freedom as sensitivity analyses.

We report the cumulative relative risk (RR) over lags 0 to 12 per 1 °C increase in ONI, and lag-specific RRs, with 95% confidence intervals. ONI = 0 is the reference. We fitted the same model separately in each region and in each MPI tertile. We assessed residual autocorrelation with the autocorrelation function of deviance residuals.

Sensitivity analyses

We assessed the robustness of the main results by (1) changing the maximum lag to 6 and 18 months; (2) changing the degrees of freedom for long-term trend to 2, 5 and 9 (one per year); (3) replacing Fourier terms with calendar-month indicators; (4) adding an autoregressive term (log of the previous month's count plus one) to account for residual autocorrelation [23]; (5) allowing a non-linear exposure-response relationship with a natural cubic spline with knots at the tertiles of ONI; and (6) excluding the department of Antioquia, which contributed 19.5% of all cases and has the most active sentinel surveillance. We compared models with the quasi-Akaike information criterion (QAIC) [24].

All analyses were performed in R version 4.3.3 using the dlnm framework [13]. Code and aggregated data are available at https://github.com/carlosreina-epi/enso-unusual-sari-colombia (archived version: doi:10.5281/zenodo.23924392).

Results

Descriptive analysis

Between January 2011 and December 2019, 12,984 cases of unusual SARI were notified in Colombia, a mean of 120 cases per month (median 105; range 32 to 499) and an average annual incidence of 31.0 cases per million inhabitants (Table 2). Annual incidence rose from 18.3 per million in 2011 to a peak of 51.2 per million in 2013 and then declined to 17.4 per million in 2019. Notifications followed a clear seasonal pattern, with the highest monthly means in May (174 cases) and June (184 cases) and the lowest in September (88 cases). The three largest monthly peaks occurred in mid-2013 (May to July, up to 499 cases), June 2016 (322 cases) and June 2018 (243 cases); all three fell in ENSO-neutral months (ONI between − 0.45 and 0.13°C) (Fig. 1).

The Andean region accounted for 59.4% of cases (7,716) and the department of Antioquia alone for 19.5% (2,535). Incidence was highest in Orinoquía-Amazonía (46.8 per million per year) and Antioquia (45.7 per million) and lowest in the Caribbean region (20.3 per million). Departments in the least deprived MPI tertile had higher incidence (35.8 per million) than those in the middle (23.8) and most deprived (25.1) tertiles.

During the study period, ONI ranged from − 1.29 to 2.59°C. Thirty-three months met El Niño conditions, including the very strong 2015–2016 event (peak ONI 2.59°C in November 2015 to January 2016), 18 months met La Niña conditions (mainly 2011–2012 and late 2017 to early 2018), and 57 months were neutral.

Table 2
Unusual SARI cases notified to SIVIGILA by region and departmental MPI tertile, Colombia, 2011–2019. *Includes San Andrés and cases without an assigned department of occurrence.

Stratum	Cases, n	Mean cases per month	Months with zero cases	Annual incidence per million
National	12,984	120.2	0	31.0
Andean	7,716	71.4	0	33.5
Caribbean	1,877	17.4	0	20.3
Pacific	2,232	20.7	0	31.2
Orinoquía-Amazonía*	1,159	10.7	2	46.8
MPI tertile 1 (least deprived)	8,803	81.5	0	35.8
MPI tertile 2	2,876	26.6	0	23.8
MPI tertile 3 (most deprived)*	1,305	12.1	1	25.1
Antioquia	2,535	23.5	4	45.7
National excluding Antioquia	10,449	96.8	0	28.7

Association between ENSO and unusual SARI

At the national level, ONI was not associated with unusual SARI over lags 0 to 12 months: the cumulative RR per 1°C increase in ONI was 0.95 (95% CI 0.78 to 1.15) (Table 3, Fig. 2). The lag-response curve showed a change in direction over time (Fig. 3). Higher ONI was associated with slightly fewer cases at short lags (RR per 1°C 0.92, 95% CI 0.86 to 0.99, at lag 0; 0.96, 0.94 to 0.98, at lag 3) and with slightly more cases at longer lags (1.04, 1.02 to 1.05, at lag 9; 1.08, 1.02 to 1.14, at lag 12). These opposing short- and long-lag associations largely cancelled out in the cumulative estimate. Figure 4 shows the full exposure-lag-response surface.

Regional and socioeconomic differences

Associations differed by region (Table 3). In the Caribbean and Pacific regions, higher ONI was associated with lower incidence, with cumulative RRs per 1°C of 0.72 (0.56 to 0.93) and 0.65 (0.53 to 0.80). Equivalently, La Niña conditions were associated with higher incidence in these regions: for ONI = − 1.5°C compared with 0, the cumulative RR was 1.63 in the Caribbean and 1.91 in the Pacific. No association was observed in the Andean region (1.03, 0.82 to 1.31) or in Antioquia (1.09, 0.82 to 1.45). Estimates for Orinoquía-Amazonía were imprecise (1.23, 0.85 to 1.76). Across MPI tertiles, point estimates decreased from the least to the most deprived tertile (0.97, 0.88 and 0.80), but confidence intervals overlapped and all included the null.

Table 3
Cumulative relative risk of unusual SARI over lags 0 to 12 months per 1°C increase in ONI. RR, relative risk; CI, confidence interval; MPI, Multidimensional Poverty Index. Reference: ONI = 0°C. †RR for ONI = 1°C compared with 0°C.

Analysis	RR (95% CI)	Dispersion (φ)
Main model, national	**0.95 (0.78–1.15)**	19.3
By region		
Andean	1.03 (0.82–1.31)	17.2
Caribbean	0.72 (0.56–0.93)	4.1
Pacific	0.65 (0.53–0.80)	4.0
Orinoquía-Amazonía	1.23 (0.85–1.76)	5.1
By departmental MPI tertile		
Tertile 1 (least deprived)	0.97 (0.79–1.20)	16.3
Tertile 2	0.88 (0.70–1.12)	5.4
Tertile 3 (most deprived)	0.80 (0.60–1.06)	3.9
Sensitivity analyses (national)		
Excluding Antioquia	0.91 (0.75–1.11)	15.9
Maximum lag 6 months	0.78 (0.66–0.92)	22.0
Maximum lag 18 months	0.86 (0.69–1.07)	19.5
Trend, 2 df	0.89 (0.73–1.09)	21.7
Trend, 5 df	1.53 (1.01–2.30)	17.6
Trend, 9 df (1 per year)	2.04 (0.81–5.17)	18.1
Calendar-month indicators for seasonality	0.95 (0.78–1.16)	20.1
Autoregressive term	0.96 (0.81–1.15)	15.9
Non-linear exposure-response†	2.85 (0.13–62.81)	15.9

Sensitivity analyses

The national null result was robust to excluding Antioquia, to replacing Fourier terms with month indicators, to adding an autoregressive term, and to extending the maximum lag to 18 months (Table 3; Supplementary Figure S2). Restricting the lag window to 6 months produced an inverse association (0.78, 0.66 to 0.92), consistent with the short-lag reduction seen in the main model. Results were sensitive to the flexibility of the long-term trend: with 5 degrees of freedom the cumulative RR was 1.53 (1.01 to 2.30), and with 9 degrees of freedom it was 2.04 (0.81 to 5.17). The QAIC favoured the 5-df trend

model (2,785) over the main model (2,948). The non-linear exposure-response model produced very imprecise estimates, indicating that the data could not support a non-linear specification. Deviance residuals of the main model showed autocorrelation at lag 1 (0.46). Adding an autoregressive term reduced overdispersion (φ from 19.3 to 15.9) without changing the estimate.

Discussion

In this nine-year national time series, ENSO intensity was not associated with the cumulative incidence of unusual SARI in Colombia. This null result hid two patterns. First, the association changed direction with lag: warmer ONI values were followed by fewer cases in the first months and by more cases 8 to 12 months later. Second, the association varied by region: in the Caribbean and Pacific regions, La Niña conditions were followed by higher incidence, with roughly 60% to 90% more cases at an ONI of − 1.5°C than in neutral conditions, whereas no association was observed in the Andean region. The largest epidemic peaks of the period, in mid-2013, 2016 and 2018, occurred in ENSO-neutral months and coincided with the usual mid-year respiratory season.

Comparison with previous studies

Evidence on ENSO and respiratory infections is limited and inconsistent. Reviews of ENSO and health describe robust links with vector-borne diseases, diarrhoeal disease and malnutrition, but weaker and more heterogeneous evidence for respiratory infections [6]. In China, El Niño years were associated with about 6% higher respiratory infectious disease morbidity across 31 provinces between 2007 and 2018 [10]. However, that study used annual provincial data, and the climatic expression of El Niño in East Asia differs from that in northern South America. Shaman and Lipsitch noted that the four influenza pandemics of the past century were preceded by La Niña conditions, and proposed that La Niña alters bird migration and virus reassortment [11]. Our finding that La Niña was followed by more unusual SARI in two regions is consistent with this direction, although our outcome mostly reflects seasonal rather than pandemic activity.

In Colombia, previous studies have related respiratory infections to local meteorological variables rather than to ENSO directly. In Bogotá, relative humidity was the variable most strongly associated with acute respiratory disease during the 2011–2012 La Niña period, with effects lasting 8 to 10 weeks [3]. Respiratory syncytial virus hospitalisations in children were associated with temperature and rainfall [5]. In a national survey, children with acute malnutrition living in high-rainfall municipalities had a higher risk of acute respiratory infection [4]. These findings support the pathway we assumed in our causal diagram, in which ENSO acts through rainfall, humidity and temperature, which we treated as mediators.

Interpretation of the regional and lag patterns

The regional pattern is consistent with how ENSO affects Colombian climate. La Niña brings above-normal rainfall, flooding and lower temperatures to the Caribbean and Pacific lowlands [7, 8]. In tropical settings where temperature and humidity remain high throughout the year, influenza activity tends to

peak in the rainiest months [2], and heavy rainfall and flooding can increase crowding indoors and displacement, two conditions that favour respiratory transmission. In the Andean region, where altitude buffers temperature extremes and incidence is dominated by large urban centres with intensive sentinel surveillance (Bogotá, Medellín, Cali), the signal from seasonal virus circulation and surveillance activity may outweigh any ENSO effect.

The change in direction across lags should be interpreted with caution. One explanation is that ENSO alters the timing of the respiratory season rather than its overall size, so that a reduction in the months after a warm anomaly is followed by a delayed rebound. A second explanation is that, with only one strong El Niño (2015–2016) and two moderate La Niña periods in the series, lag-specific estimates partly reflect the timing of a few individual events. The cumulative estimate, which summarises the overall effect and is the more stable quantity, was null.

The lower point estimates in more deprived departments, and the higher incidence in less deprived ones, most likely reflect surveillance capacity rather than true risk. Unusual SARI is detected and notified mainly through hospitals with sentinel or reference capacity, which are concentrated in wealthier departments; Antioquia alone notified one in five cases. Departmental poverty therefore modifies both the probability that a case is detected and the population's vulnerability, and our data cannot separate the two.

Strengths and limitations

This study has several strengths. We used the complete national series of a single, consistently defined surveillance event over nine years, validated against official reports. We modelled ENSO as a continuous exposure with a distributed lag model, the standard approach for time-varying environmental exposures [12–14], rather than as annual categories. We specified the causal structure explicitly, avoided adjusting for mediators, and examined the robustness of the results in prespecified sensitivity analyses.

The study also has important limitations. First, the outcome is a sentinel event whose notification depends on hospital capacity, clinical suspicion and laboratory access, which vary between departments and over time; changes in surveillance intensity could mask or mimic an ENSO effect. Second, the series covers only nine years and few ENSO events, which limits statistical power and makes the estimates sensitive to how long-term trend is modelled: with a more flexible trend the cumulative association became positive. We chose the trend specification a priori for the reasons given in the Methods, but this sensitivity means that our national result should be read as inconclusive rather than as evidence of no effect. Third, residual autocorrelation and large overdispersion remained, although adding an autoregressive term did not change the results. Fourth, this is an ecological analysis at national and regional level; it cannot be interpreted at the individual level, and aggregation may hide heterogeneity within regions. Fifth, we did not have virological data and could not separate influenza, respiratory syncytial virus and other pathogens, which may respond differently to climate. Sixth, departmental poverty was measured with the 2023 Multidimensional Poverty Index, after the study period; although the relative ranking of departments changes slowly, misclassification of some departments between

tertiles is possible. Finally, assigning epidemiological weeks to months introduces small misalignments with the monthly ONI series, which are unlikely to affect estimates with lags measured in months.

Implications

For surveillance, our results suggest that ENSO forecasts alone are not a useful national predictor of unusual SARI in Colombia, but that La Niña alerts could inform preparedness for respiratory services in the Caribbean and Pacific regions, together with existing flood and rainfall early warning systems. For research, the strong dependence of this sentinel event on surveillance capacity argues for analyses that combine notification data with measures of testing and hospital coverage, for longer series that include more ENSO events, and for pathogen-specific outcomes linked to meteorological data at finer spatial and temporal resolution.

Conclusions

In this national time-series analysis, ENSO intensity was not associated with the overall incidence of unusual SARI in Colombia between 2011 and 2019, although the national estimate depended on how long-term trend was modelled. In the Caribbean and Pacific regions, La Niña conditions were followed by higher incidence. These findings suggest that ENSO forecasts are not useful as a national predictor of severe respiratory infection, but that La Niña alerts could support regional preparedness of respiratory services alongside existing rainfall and flood warning systems. Because the detection of unusual SARI depends on surveillance capacity, which is concentrated in wealthier departments, future studies should combine notification data with measures of testing and hospital coverage, use longer series that include more ENSO events, and examine pathogen-specific outcomes.

Declarations

Disclaimer: The views expressed in this article are those of the authors and do not necessarily represent the official position of the Ministerio de Salud y Protección Social of Colombia.

Conflicts of interest: The authors declare no conflicts of interest.

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Data and code availability: Weekly case counts are publicly available from the Colombian open-data portal (datos.gov.co, dataset 4hyg-wa9d) and the Oceanic Niño Index from the NOAA Climate Prediction Center. The aggregated analysis dataset and R code are available at https://github.com/carlosreina-epi/enso-unusual-sari-colombia and archived in Zenodo (v1.0.0, doi:10.5281/zenodo.23924392).

Ethics: The study used publicly available, anonymised, aggregated surveillance data and was classified as research without risk under Colombian Resolution 8430 of 1993; ethical review was not required.

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Figures

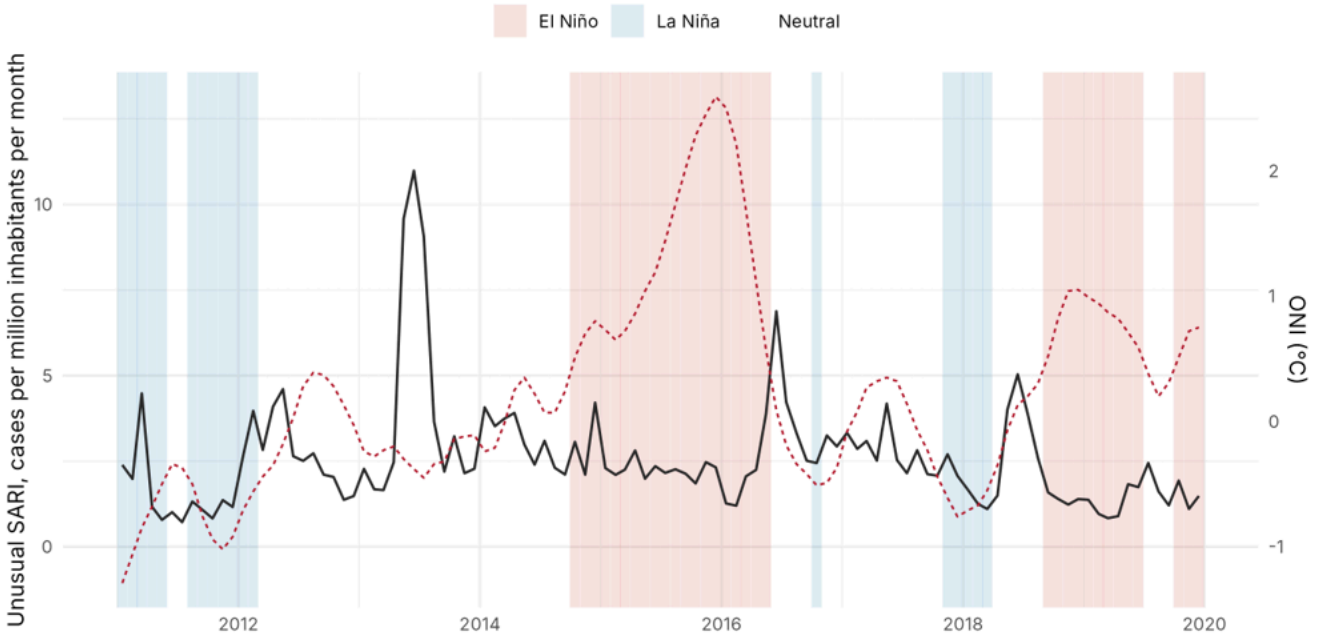


Figure 1

Monthly incidence of unusual SARI notified to SIVIGILA (solid line, cases per million inhabitants) and Oceanic Niño Index (dashed line), Colombia, 2011–2019. Shaded bands indicate El Niño (ONI ≥ 0.5 °C) and La Niña (ONI ≤ −0.5 °C) months.

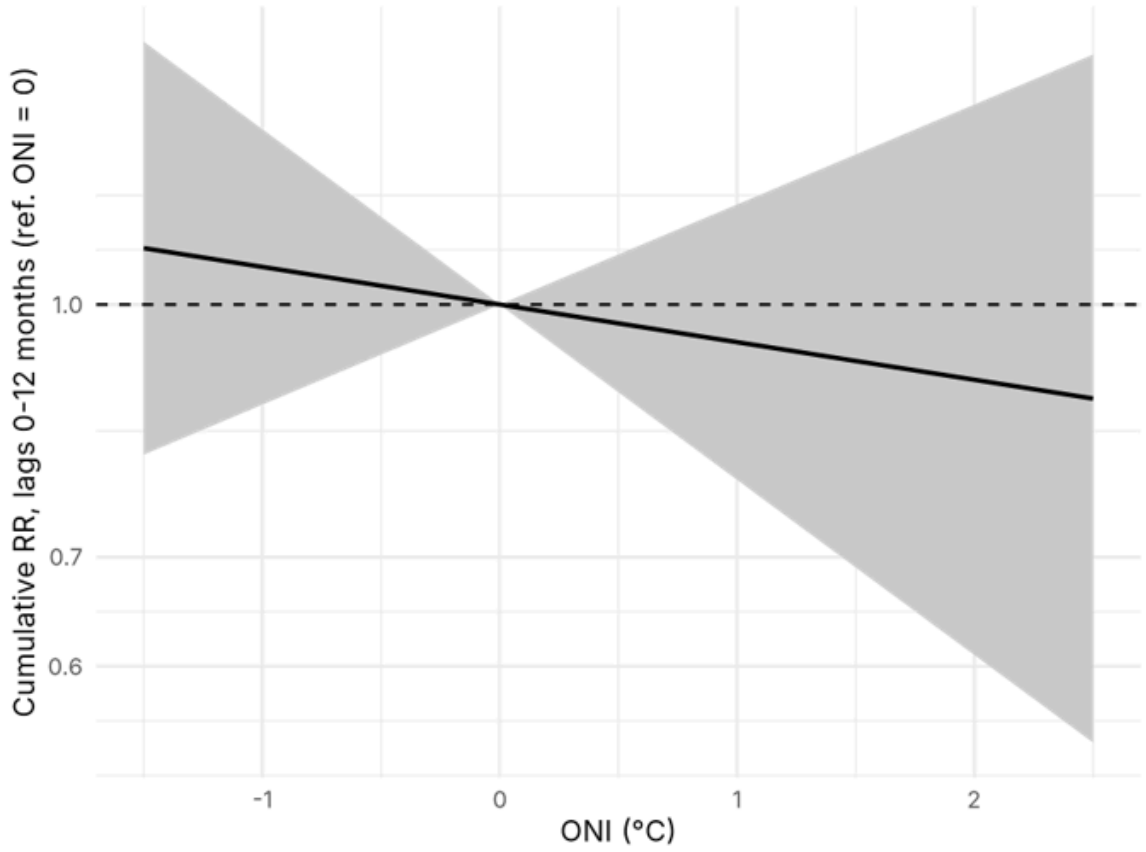


Figure 2

Cumulative exposure-response association between ONI and unusual SARI over lags 0 to 12 months, national model. Relative risk relative to ONI = 0 °C, with 95% confidence interval.

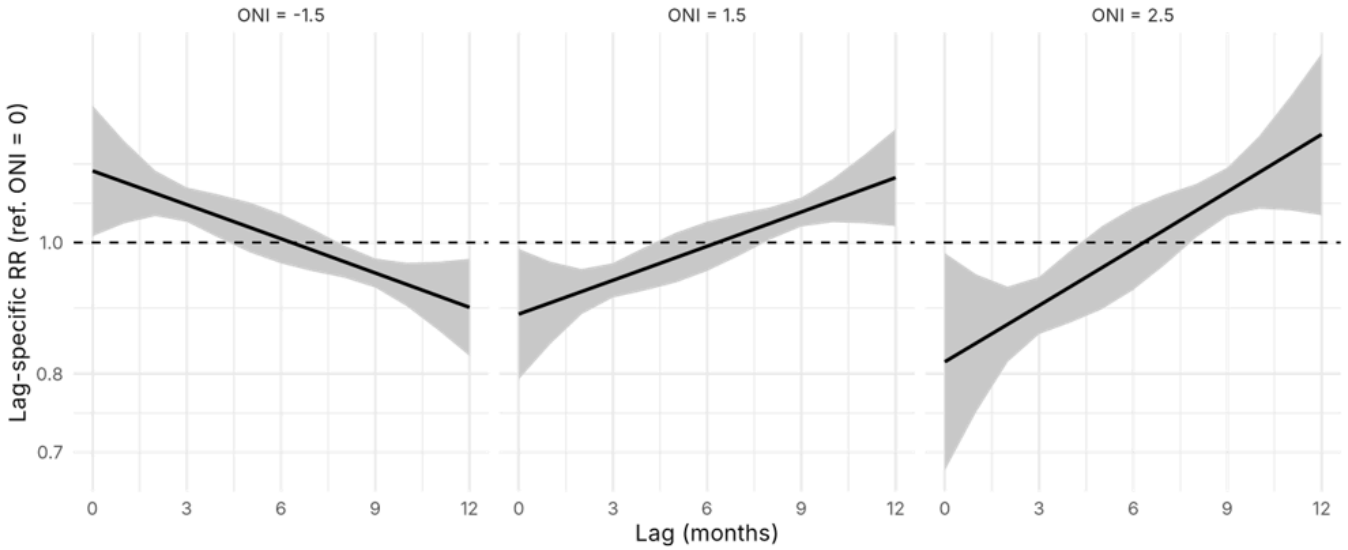


Figure 3

Lag-response association at ONI values of −1.5, 1.5 and 2.5 °C relative to ONI = 0 °C, national model, with 95% confidence intervals.

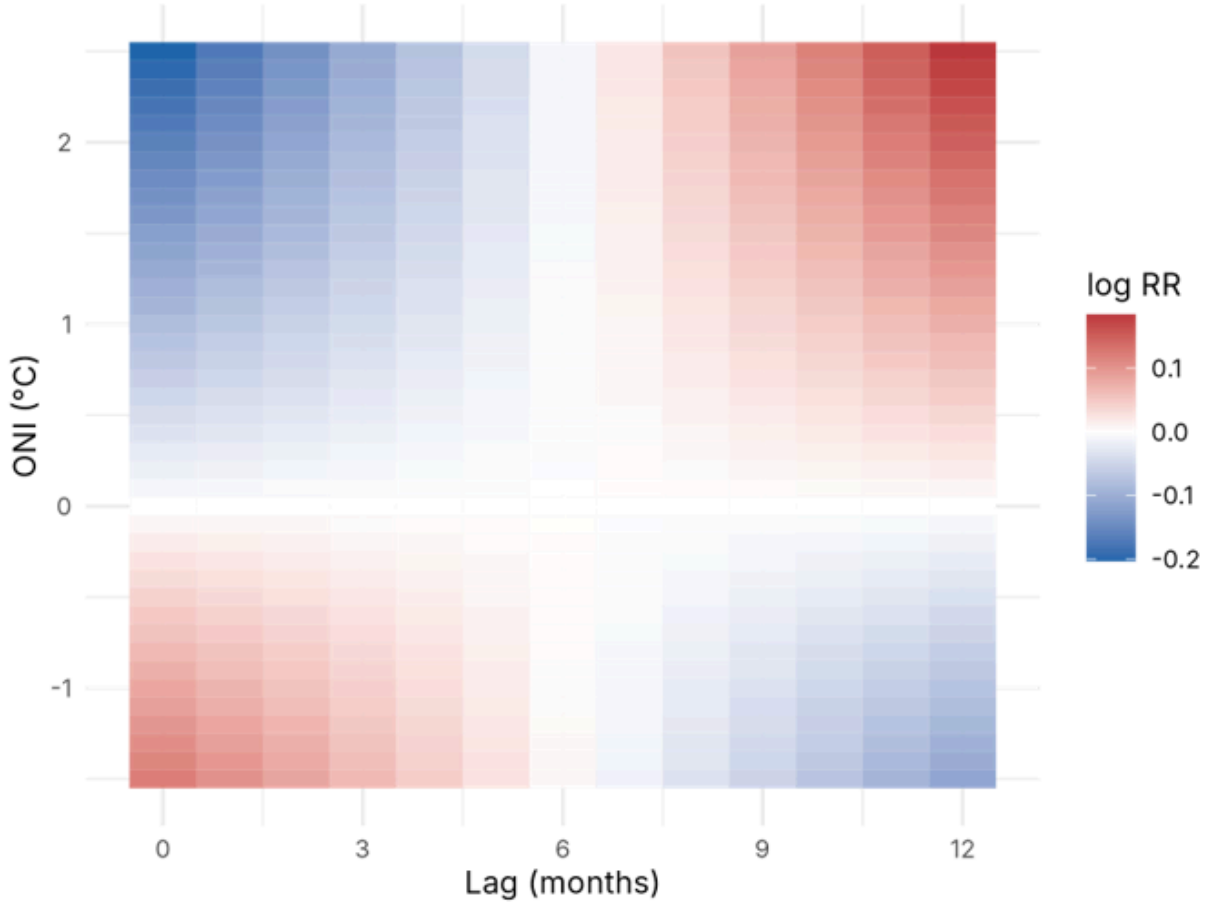


Figure 4

Exposure-lag-response surface for the association between ONI and unusual SARI (log relative risk), national model.

Supplementary Files

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- ENSOunusualSARIColombiasupplementary.docx