Prediction of cholera dynamics in Haiti following the passage of Hurricane Matthew.

This work is presented as a collaboration between Epicentre Paris-Genève and the Laboratory of Ecohydrology of the Ecole Polytechnique Férédale de Lausanne[1].

This is a preliminary analysis; model predictions presented herein are subject to change when updated or as additional data become available.

Introduction

Following the landfall of Hurricane Matthew in Haiti on October 3, 2016, an increase of suspected cholera cases was reported in both the southern part of the island (with Grande-Anse and Le Sud departments reporting 1349 and 1533 cases respectively between 5 October and 6 November) and also in the capital, Port-au-Prince (438 cases reported over the same period) [1].
The hurricane caused the displacement of about 175,000 people [2], the vast majority of which remained in their department of origin; however, about 10% appear to have displaced to the capital Port-au-Prince [3].
In this context, a mass OCV vaccination campaign was planned, starting on November 8 and targeting 816,999 individuals in Grande-Anse and Le Sud.

Objectives of the study

The aim of this study is to provide additional information to health actors responding to the post-hurricane cholera outbreak in Haiti. To this end, we calibrated a mechanistic model of cholera transmission on currently available data for Haiti in order to forecast the spatio-temporal dynamics of the cholera epidemic at the departmental level from November 2016 to January 2017. Model outputs have been translated into operational recommendations, with a focus on the scheduled OCV campaign.

Results (please refer to the main figure below)

- Model forecasts suggest that the overall incidence is likely to reach a peak and start decreasing over the first two weeks of November. This is mainly

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[1] EPFL (Enrico Bertuzzo, Flavio Finger, Damiano Pasetto) designed the model and performed the analysis. Epicentre (Anton Camacho, Sandra Cohuet, Francesco Grandesso, Francisco Luquero, Emily Lynch) produced the report and recommendations. Both teams interpreted model results. Epicentre team is funded by MSF.

due to the falloff of the rainfall effect on cholera transmission one month after the passage of the hurricane.

- However, the model also suggests that a resurgence of cholera cases is likely to be observed at the beginning of December, since weather forecasts anticipate heavy rainfalls in Grande-Anse and Le Sud departments during the last week of November.
- Among the possible outcomes predicted by the model, we chose to highlight the two following scenarios:
    - The optimistic and currently most likely scenario (more than 75% chance according to model forecasts) is that the magnitude of the second epidemic wave will be similar to the first one in the southern part of Haiti (between 250 and 500 weekly new cases at peak time in Le Sud and Grande-Anse): in this case the propagation of this second wave to the central and northern part of the island should remain limited and no second wave will be observed in these areas.
    - The pessimistic and less likely scenario (less than 25% chance according to model forecasts) is that the magnitude of the second epidemic wave will be much bigger than the first one in the southern part of Haiti: in this case the second wave could propagate to the central and northern part of the country, generating an epidemic bigger than the one observed in 2015 (6,500 cases reported between September 2015 and January 2016 vs more than 35,000 cases predicted by the model for the same period this year).
- The model forecast does not yet account for the OCV campaign (see ongoing work section below). It is however expected the campaign will have a positive impact by mitigating the scale of the second wave in early December and thus preventing more substantial propagation to the central and northern parts of Haiti.
- The model also does not account for post-hurricane specific population movements (see below). However, it is expected that population movements between high/low cholera incidence areas will favour the widespread propagation of the epidemic at the country level.

Operational recommendation based on model predictions

- Preliminary estimates linked with the rainfall forecast indicate that the area at highest risk in the coming weeks remains the Southern part of Haiti. This suggests that completing the current planned campaign as quick as possible should be a priority.
- The vaccination planned for Le Sud and Grande-Anse should not be considered as a major step towards global cholera control in Haiti, but rather as a response to the current situation following the natural disaster.
- Other interventions that could reduce cholera spread like access to safe water (eg. chlorination of drinking water), access to improved sanitation

and hygiene promotion should be implemented in these areas to further reduce the risk.
- Ultimately, a locally-active and timely surveillance system is key to optimizing cholera control interventions in Haiti. Supporting high quality surveillance and data sharing among intervention partners is an important part of both short and long-term response.

Description of the model

The epidemiological model used for the real-time projections of the ongoing Haitian epidemic has been derived from the spatially-distributed SIRB model recently adopted in *Pasetto et al.* (2016) [4] and *Bertuzzo et al.* (2014) [5]: the Haitian population is subdivided into 365 communities, each of them represented by a node of the model. The individuals in each community are divided into three separate compartments, susceptible (S), symptomatic infected (I) and recovered (R). An additional compartment (B) accounts for the concentration of V. cholerae in the local environment and is fed by the shedding of infected (I). The communities are connected by a human mobility model, with the idea that the movement of susceptible individuals between communities is the main cause of the spatial spread of cholera . For more details on the model formulation, please refer to *Pasetto et al.* (2016) [4] and *Bertuzzo et al.* (2014) [5] and references therein.

For the application to the ongoing epidemic, the model has been calibrated using the Ensemble Kalman filter (EnKF) with the augmented state technique (see *Pasetto et al.*, 2016, [5]) on the infected cases in each department reported by the Haitian ministry of health since August 2015. The presented results are obtained using an ensemble of 1000 model runs. The initial values of the model parameters associated to the ensemble are collected in the following way: 20000 parameters set are sampled from a wide uniform prior parameter distribution. Then, the 1000 parameters associated to the lowest root mean squared errors are selected to initialize the EnKF, which further adapts the parameter sets.

For each model run, the initial number of infected and recovered individuals is estimated by downscaling to the community level the number of infected and recovered computed at the departmental level estimated from a previous modelling study based on historical data from 2010 to 2016 [6].

Daily rainfall measurement are estimated from the data collected by the NASA-JAXA's Tropical Rainfall Measuring Mission [7], while future projections of daily rainfall are obtained from the operational climate forecast produced by the Climate Forecast System (CFS) of the National Centers for Environmental Prediction (NCEP) [8].

Why model forecasts might not be so accurate?

- The forecast reliability of the model is dependent on the validity and quality of the data used, which is limited to what is currently available in the post-hurricane context. The cholera surveillance network of Haiti has been affected by the hurricane, with many areas remaining inaccessible and many health facilities having sustained significant damage that is affecting their operations. Moreover, cholera cases, particularly at the community level, may be underreported in some areas. The data may therefore not represent the true dynamics of the ongoing epidemic.
- The model disregards several known mechanisms of cholera transmission, for which empirical data is lacking:
    - Variations in local water and sanitation risk factors related to both chronic and post-hurricane conditions.
    - Specific population displacements following the hurricane, which may not be properly accounted for by the human mobility network algorithm used in the model.
- Rainfall forecasts of up to a month in advance might not be reliable.
- The model outputs might be highly sensitive to the prior parameter distribution used to initialize the ensemble. A sensitivity analysis has not been performed yet to prove the robustness of the forecast.

As more data becomes available, the model will be updated and re-calibrated, thus increasing its forecast reliability.

Ongoing modelling work

- The model is currently modified to account for the mass vaccination campaign and should be able to provide some benchmarks for its expected impact. In other words, the model should be able to quantify to what extent the OCV campaign can prevent a major epidemic across the country later this year. We will explore different strategies to allocate the available vaccine doses.
- As a sensitivity analysis, the model is currently being re-run using historic rainfall data instead of the rainfall forecast for the period November 2016 to January 2017. The intent of this analysis is to assess whether model predictions are robust given historic rainfall levels recorded in previous years over the same period of time.

References

[1] http://ais.paho.org/phip/viz/ed_haiticoleracases.asp
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[4] D. Pasetto, F. Finger, A. Rinaldo and E. Bertuzzo. *Real-time projections of cholera outbreaks through data assimilation and rainfall forecasting*, in Advances in Water Resources, 2016.

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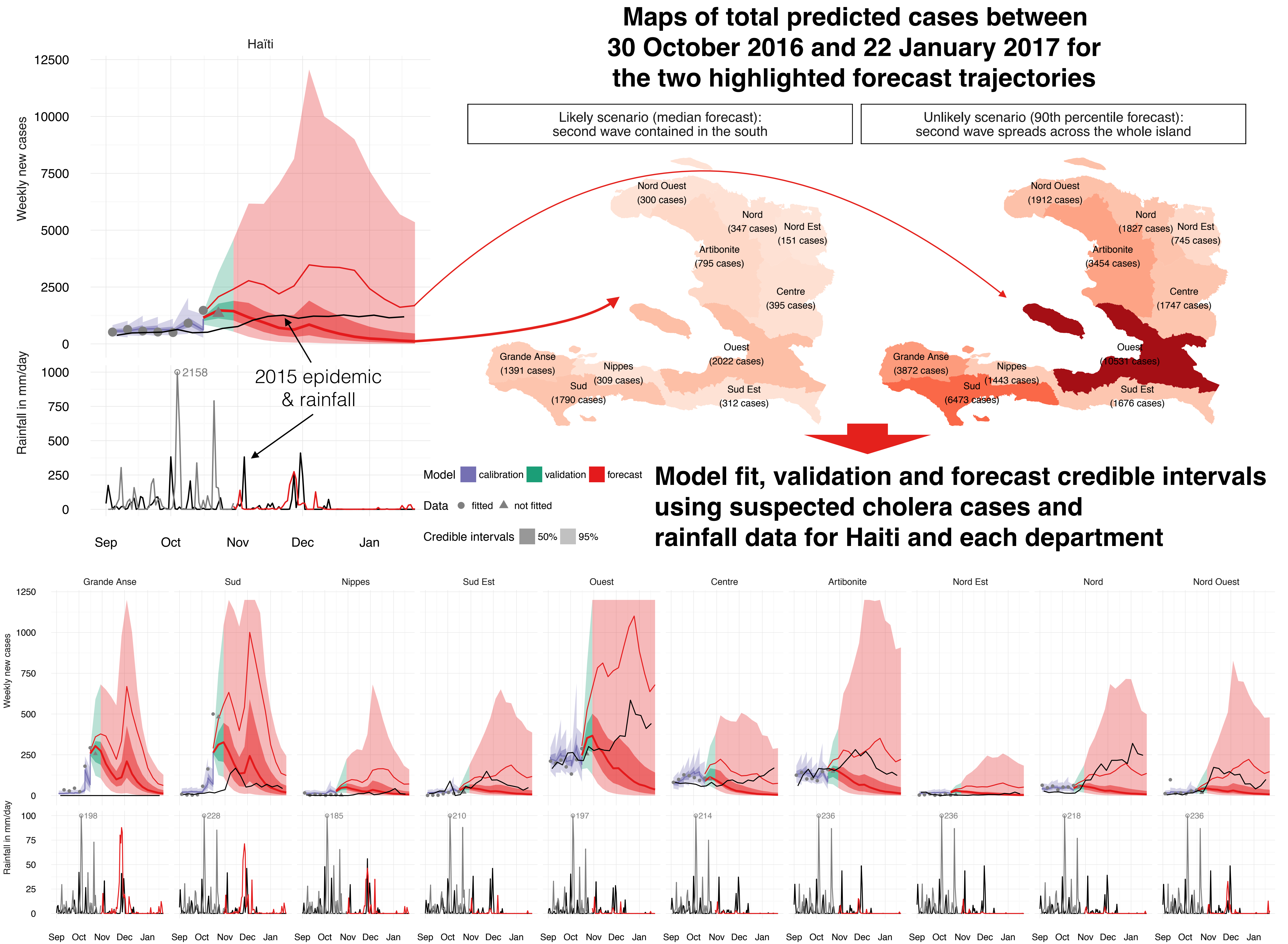
[7] http://iridl.ldeo.columbia.edu/SOURCES/.NASA/.GES-DAAC/.TRMM_L3/.TRMM_3B42RT/.v7/.daily/.precipitation/[8] https://www.ncdc.noaa.gov/data-access/model-data/model-datasets/climate-forecast-system-version2-cfsv2


Maps of total predicted cases between 30 October 2016 and 22 January 2017 for the two highlighted forecast trajectories
Haïti
Weekly new cases
12500
10000
7500
5000
2500
0
Rainfall in mm/day
1000
750
500
250
0
2158
2015 epidemic & rainfall
Sep
Oct
Nov
Dec
Jan
Likely scenario (median forecast): second wave contained in the south
Unlikely scenario (90th percentile forecast): second wave spreads across the whole island
Nord Ouest (300 cases)
Nord (347 cases)
Nord Est (151 cases)
Artibonite (795 cases)
Centre (395 cases)
Ouest (2022 cases)
Grande Anse (1391 cases)
Nippes (309 cases)
Sud (1790 cases)
Sud Est (312 cases)
Nord Ouest (1912 cases)
Nord (1827 cases)
Nord Est (745 cases)
Artibonite (3454 cases)
Centre (1747 cases)
Ouest (10531 cases)
Grande Anse (3872 cases)
Nippes (1443 cases)
Sud (6473 cases)
Sud Est (1676 cases)
Model calibration validation forecast
Data fitted not fitted
Credible intervals 50% 95%
Model fit, validation and forecast credible intervals using suspected cholera cases and rainfall data for Haiti and each department
Grande Anse
Sud
Nippes
Sud Est
Ouest
Centre
Artibonite
Nord Est
Nord
Nord Ouest
Weekly new cases
1250
1000
750
500
250
0
Rainfall in mm/day
100
75
50
25
0
198
228
185
210
197
214
236
236
218
236
Sep Oct Nov Dec Jan