AN EARLY WARNING SYSTEM FOR VECTOR-BORNE DISEASE RISK IN THE AMAZON

NASA PROJECT NNX15AP74G
William Pan, Duke University

Health & Air Quality Applications Program Review, Sept 15 & 21, 2020, Virtualtown, USA
Project Team

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# Project Summary
**NNH13ZDA001N-Health**

## Objective
Develop an **early warning system for malaria** in the Peruvian Amazon and evaluate the expansion of the system to other diseases and Amazon regions.

## Geographic Scope
- **Primary:** Peru (Loreto), Ecuador (Napo, Orellana, Succumbios)
- **Secondary locations:** Colombia, Western Brazil (Acre)

## Societal Benefit
Improved / targeted interventions; Application of components to other diseases and climate events

## Earth Observations / Models / Technology
- Land Data Assimilation System (LDAS) – MODIS, LandSAT, GRACE, TRMM, GPM, SMAP, GOES
Summary of Accomplishments (overall)

• We forecast malaria outbreaks in small, administrative districts 12 weeks in advance with ~90% sensitivity
  - Two modeling levels: Ecoregion and District

• We have strong government & academic partnerships in Peru & Ecuador that are ready to adopt and implement the system
  - LDAS implementation in Ecuador in the Institute of Geography at USFQ in partnership with the Ministry of Public Health
  - Forecasting capacities to be adopted by CDC-Peru and CLIMA (Climate and Infectious Disease Laboratory at UPCH, Lima)

• Additional Funding:
  - Bi-weekly team telecons to prepare application to EU “Early Warning for Epidemics” prize for vector-borne disease forecasting ($5 million euros)
  - 10% score from NIAID to support technical improvements to MEWS for understanding cross-border malaria risk

• Publications: 3 articles published, 6 in review (4 are COVID-related)

• ARL7 (goal ARL 8)
Accomplishments & Challenges 2019-20

- Implementation & Training program (March – June 2020)

Carlos Culquichicon
CDC Peru & CLIMA

Andrea Chace Campos
USFQ & MinSALUD

Alonso Bussalleu
CLIMA

USFQ Institute for Geography

CLIMA (USFQ) and CDC-Peru (Ecuador)
- Forecast model application
- Risk Visualization
- Outbreak reporting

USFQ Institute for Geography

CDC-Peru & MinSALUD (Ecuador)
- Daily / Weekly Malaria Surveillance & Population Data

Supported by Duke
Accomplishments & Challenges 2019-20

- Training was postponed to Fall 2020, then cancelled

Carlos Culquichicon
CDC Peru & CLIMA
- Began MSPH Program at Emory

Andree Valle Campos
CDC Peru

Manuel Benjamin Narvaez
USFQ & MinSALUD
- Repurposed to COVID-19

Alonso Bussalleu
CLIMA
- Began PhD at Swiss-TPH
The rest of this presentation ...

- How do we achieve 90% sensitivity in detecting malaria outbreaks?
  - LDAS
  - Ecoregion analysis & District level forecast models

- Recent Publications on PAMAFRO and International Migration using our model
LAND DATA ASSIMILATION SYSTEM
- Temperature
- Precipitation
- Soil Moisture
- Solar Radiation
- Stream Flow

LANDSCAPE ECOLOGY
- Districts (n=51)
- Bodies of Water
- Humid Amazon Forest
- Humid Andean Forest
- Forest Flooded by Clear-water Rivers
- Forest Flooded by Black-water Rivers
- Anthropic Areas
- Amazonian azonal vegetation (edaphically conditioned)
- Upper Amazon alluvial plains marsh

Government Malaria Surveillance, Interventions & Population at Risk

12-week forecast in Ecoregions

12-week forecast in Districts

Intervention & Control Scenarios

ECO-REGION FORECAST MODEL

DISTRICT FORECAST MODEL

AGENT-BASED MODELS
EcoRegion Forecast

- LDAS & Ecosystem data are combined to identify EcoRegions
- Malaria & Population data are aggregated to the EcoRegion level
- Unobserved Component Model (UCM) used to conduct forecasts

\[ y_t = \mu_t + \gamma_t + \phi_t + \tau_t + \sum_{i=1}^{p} \phi_i y_{t-i} + \sum_{j=1}^{m} \beta_j x_{jt} + \varepsilon_t \]

\( y_t \sim \text{malaria cases/1000 during week } t \)

\( \mu_t, \gamma_t, \phi_t, \text{ and } \tau_t \) represent the trend, seasonal, cyclical and autoregressive components
\( \phi_i \) is an autoregressive term capturing the momentum of infections
\( \beta_j \) is the unknown effect for explanatory factors
\( \varepsilon_t \) is the error term

- MINSA-defined outbreak level
EcoRegion Forecast

Real-time data reporting (top) and forecast (bottom) for EcoRegion 1 from May-July 2018 in Loreto, Peru

Forecast Performance, 2016

<table>
<thead>
<tr>
<th>Forecast weeks</th>
<th>TP</th>
<th>FN</th>
<th>FP</th>
<th>TN</th>
<th>Se</th>
<th>Sp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eco-Region 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-4</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>5-8</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>9</td>
<td>100%</td>
<td>90%</td>
</tr>
<tr>
<td>9-12</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>7</td>
<td>100%</td>
<td>70%</td>
</tr>
<tr>
<td>Eco-Region 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-4</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>10</td>
<td>50%</td>
<td>91%</td>
</tr>
<tr>
<td>5-8</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>10</td>
<td>50%</td>
<td>91%</td>
</tr>
<tr>
<td>9-12</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>8</td>
<td>100%</td>
<td>73%</td>
</tr>
</tbody>
</table>

TP= True Pos; FN= False Neg; FP= False Pos.; TN= True Neg.
## District Level Forecast

- **Probability of District outbreak** = (Ecoregion Outbreak Prob) * (District Outbreak Prob)
- **Hierarchical Bayesian spatio-temporal logistic model**

$$
y(s, t) = x^T(s, t)\beta + \theta(s, t)
$$

- $y(s, t)$ ~ # malaria cases in district $s$ during week $t$
- $x(s, t)$ ~ vector of covariates & lagged predictors
- $\theta(s, t)$ ~ spatio-temporally correlated random effects

  - The Model estimates Malaria incidence rate during week $t$ in district $s$

- **MINSA thresholds used to define an outbreak**
District Level Forecast

Root-mean square prediction error, Fernando Lores and Ramon Castilla districts, 2016-19

Sensitivity & Specificity of 8-week district forecasts, 2007-2019

<table>
<thead>
<tr>
<th>District</th>
<th>Se</th>
<th>Sp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iquitos</td>
<td>88%</td>
<td>84%</td>
</tr>
<tr>
<td>Fernando Lores</td>
<td>51%</td>
<td>84%</td>
</tr>
<tr>
<td>Punchana</td>
<td>89%</td>
<td>74%</td>
</tr>
<tr>
<td>Belen</td>
<td>79%</td>
<td>70%</td>
</tr>
<tr>
<td>San Juan Bautista</td>
<td>97%</td>
<td>67%</td>
</tr>
<tr>
<td>Jenaro Herrera</td>
<td>94%</td>
<td>98%</td>
</tr>
<tr>
<td>Ramon Castilla</td>
<td>57%</td>
<td>79%</td>
</tr>
<tr>
<td>Pebas</td>
<td>54%</td>
<td>68%</td>
</tr>
<tr>
<td>Yavari</td>
<td>55%</td>
<td>63%</td>
</tr>
<tr>
<td>San Pablo</td>
<td>60%</td>
<td>76%</td>
</tr>
</tbody>
</table>


(COVID-19 related)

Pan, WK, S Tyrovolas, GV Iago, RR Dasgupta, D Fernandez, B Zaitchik, P Lantos, CW Woods “Heterogeneity of non-pharmaceutical intervention effectiveness in the US before phased reopening” [https://www.medrxiv.org/content/10.1101/2020.08.18.20177600v1](https://www.medrxiv.org/content/10.1101/2020.08.18.20177600v1)

THANK YOU!

1. They say the best way to manage the coronavirus is to spread it to people you dislike.
2. The happiness you get from that will boost your immune system.
3. Maybe I'll get my medical advice from an actual doctor.
   They leave out the good stuff.