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

William Pan, Duke University

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Ben Zaitchik, Johns Hopkins Univ

Carlos Mena, Francesco Pizzitutti, Universidad San Francisco de Quito, Ecuador

Andres Lescano, Gabriela Salmon-Mulanovich, Universidad Peruana Cayetano-Heredia

Beth Feingold, SUNY-Albany

Cesar Munayco, CDC-Peru, Ministry of Health
# 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

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**Duke GLOBAL HEALTH INSTITUTE**
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

Andres Andree Valle Campos
CDC Peru

Hamin Narvaez
MinSALUD

Alonso Bussalleu
CLIMA

USFQ Institute for Geography

CDC-Peru & MinSALUD
(Ecuador)

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

Supported by Duke

Daily / Weekly Malaria Surveillance & Population Data
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
### Project Budget, Obligations & Cost Status

#### Project to Date (FY16- August 2019)

<table>
<thead>
<tr>
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<th>Duke</th>
<th>JHU</th>
<th>SUNY-Alb</th>
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<td>896,526</td>
<td>314,502</td>
<td>22,705</td>
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<td>896,526</td>
<td>314,502</td>
<td>22,705</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Costed</td>
<td>794,621</td>
<td>314,501</td>
<td>22,705</td>
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<td>Uncosted</td>
<td>101,905</td>
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#### Year 5 (FY2020) through September 1, 2020

<table>
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<td>Budget</td>
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<td>26,865</td>
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<td>Uncosted</td>
<td>101,689</td>
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</table>
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**

- ECO-REGION FORECAST MODEL
  - 12-week forecast in Ecoregions

- DISTRICT FORECAST MODEL
  - 12-week forecast in Districts

- AGENT-BASED MODELS
  - Intervention & Control Scenarios
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

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

- \( y_t \sim \) malaria cases/1000 during week \( t \)
- \( \mu_t, \gamma_t, \varphi_t, \) and \( r_t \) 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
- \( \epsilon_t \) 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>
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</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>
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<tr>
<td>5-8</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>9</td>
<td>100%</td>
<td>90%</td>
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<tr>
<td>9-12</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>7</td>
<td>100%</td>
<td>70%</td>
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<tr>
<td>Eco-Region 3</td>
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<td></td>
<td></td>
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<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>
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<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>
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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

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

- 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>
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<tr>
<td><strong>EcoRegion 1</strong></td>
<td></td>
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<tr>
<td>Iquitos</td>
<td>88%</td>
<td>84%</td>
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<tr>
<td>Fernando Lores</td>
<td>51%</td>
<td>84%</td>
</tr>
<tr>
<td>Punchana</td>
<td>89%</td>
<td>74%</td>
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<tr>
<td>Belen</td>
<td>79%</td>
<td>70%</td>
</tr>
<tr>
<td>San Juan Bautista</td>
<td>97%</td>
<td>67%</td>
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<tr>
<td>Jenaro Herrera</td>
<td>94%</td>
<td>98%</td>
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<tr>
<td><strong>EcoRegion 3</strong></td>
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<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>
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<tr>
<td>San Pablo</td>
<td>60%</td>
<td>76%</td>
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Publications / Manuscripts in Review 2019-20


Janko, MM, C Recalde-Colonel, AG Lescano, G Salmón-Mulanovich, BF Zaitchik, WK Pan “Sustained malaria control and its withdrawal in the Loreto region of Peru: A retrospective, observational study of the potential impact of the PAMAFRO program”, LANCET, in-review

(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

THANK YOU!

They say the best way to manage the coronavirus is to spread it to people you dislike.

The happiness you get from that will boost your immune system.

Maybe I'll get my medical advice from an actual doctor.

They leave out the good stuff.