Project Summary

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.

TEAM

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Summary of Accomplishments

• We forecast malaria outbreaks in small, administrative districts 12 weeks in advance with ~90% sensitivity

• IMPLEMENTATION:
  - 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)
  - Partnership with the InterAmerican Institute for Global Change Research

• Additional Funding:
  - Finalist for EU “Early Warning for Epidemics” prize ($5 million euros)
  - Newly funded R01 from NIAID ($2.5 million) for expansion & cross-border malaria

• Publications: >10 (2 more in review/resubmit)
• Fully costed or encumbered
Summary of Methods
• How do we achieve 90% sensitivity in detecting malaria outbreaks?
  - LDAS
  - Ecoregion analysis & District level forecast models

Project Plans after NASA (R01, EC Prize)
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

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

\[ y_t \sim \text{malaria cases}/1000 \text{ during week } t \]

\( \mu_t, \gamma_t, \varphi_t, \) and \( \eta_t \) 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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<tbody>
<tr>
<td>Eco-Region 1</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</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>
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<tr>
<td>9-12</td>
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<td>3</td>
<td>7</td>
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<td>70%</td>
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<tr>
<td>Eco-Region 3</td>
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<tr>
<td>1-4</td>
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<td>1</td>
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<td>10</td>
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<td>91%</td>
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<tr>
<td>5-8</td>
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<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>
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<td>73%</td>
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TP= True Pos; FN= False Neg; FP=False Pos.; TN=True Neg.
District Level Forecast

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

<table>
<thead>
<tr>
<th>District</th>
<th>Se</th>
<th>Sp</th>
</tr>
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<tbody>
<tr>
<td>Ecoregion 1</td>
<td></td>
<td></td>
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<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>Ecoregion 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ramon Castilla</td>
<td>57%</td>
<td>79%</td>
</tr>
<tr>
<td>Pebas</td>
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<tr>
<td>Yavari</td>
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<td>63%</td>
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<tr>
<td>San Pablo</td>
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<td>76%</td>
</tr>
</tbody>
</table>

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

Hierarchical Bayesian spatio-temporal logistic model

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

\( y(s,t) \sim \# \) malaria cases in district \( s \) during week \( t \)

\( x(s,t) \sim \) vector of covariates & lagged predictors

\( \theta(s,t) \sim \) spatio-temporally correlated random effects
Life After NASA—R01 Malaria EWS

• NIAID R01: Improving Response to Malaria Outbreaks in Amazon-Basin Countries
  - 5 years (Sept 1, 2021-Aug 31, 2026), $2.5 million direct costs

Aim 1. To evaluate (i) MEWS expansion to the Brazilian and Ecuadorian Amazon and (ii) downscaling of forecasts to sub-district levels

Aim 2. To evaluate the relationship between infrastructure, socio-economic networks and migration across international border (Brazil-Peru, Ecuador-Peru) with malaria incidence rates

Aim 3. Evaluate scenarios of potential malaria interventions along borders to jointly reduce malaria rates
A Consortium to Effectively Respond to Climate-Attributable Risks-Malaria Elimination (ACERCAR-ME)

- Creation of CoP & build Governance Structure around climate-health through STeP Fellow Program led by IAI
- Technology Implementation through partnerships (USFQ and UPCH as model)
- Seeking support from IADB, World Bank, Gates Foundation (& NASA?)

Implementation Timeline:
- Years 1-4: Ecuador, Peru, Brazil, Fr. Guiana
- Years 5-7: Colombia, Suriname
- Years 8-10: Bolivia, Guyana
- Years 11+: Mesoamerica
THANK YOU!