ACHIEVING >90% SENSITIVITY IN FORECASTING MALARIA RISK 12 WEEKS IN ADVANCE IN THE AMAZON

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GEOHealth Community of Practice, February 16, 2021
Outline

Malaria Situation in South America
  ▪ Current Surveillance System

Malaria Early Warning System
  - Objectives & Methods
    ▪ Land Data Assimilation System
    ▪ Ecosystem & District Forecast Model
  - Examples of Impact
Situation in Peru

PAMAFRO Program 2006-2011

Flood

Mega El Nino

Dengue & Zika Outbreaks
The Amazon has experienced the largest increase in malaria cases compared to any region in the world since 2010 – over 700% increase in cases.

Malaria cases reported in 2020 are significantly lower than 2019, but there is widespread undercount.

Almost complete closure of primary health care units are shuttered due to COVID (Peru, Brazil, Colombia, Ecuador).

2021 Malaria Burden
Malaria en el departamento de Loreto

Número de casos de malaria, 2016 - 2021*

<table>
<thead>
<tr>
<th>Semanas Epidemiológicas</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
<th>2021*</th>
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<tbody>
<tr>
<td></td>
<td>222</td>
<td>334</td>
<td>451</td>
<td>552</td>
<td>453</td>
<td>424</td>
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</tbody>
</table>

Número de casos de malaria reportados en el 2020* - 2021*

<table>
<thead>
<tr>
<th>Distritos</th>
<th>2020*</th>
<th>2021*</th>
<th>Casos en la SE 04</th>
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<tbody>
<tr>
<td>ANDOAS</td>
<td>202</td>
<td>112</td>
<td>15</td>
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<td>NAPO</td>
<td>144</td>
<td>23</td>
<td>4</td>
</tr>
<tr>
<td>TIGRE</td>
<td>68</td>
<td>44</td>
<td>0</td>
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<tr>
<td>SAN JUAN BAUTISTA</td>
<td>59</td>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td>PASTAZA</td>
<td>51</td>
<td>95</td>
<td>6</td>
</tr>
<tr>
<td>BALSAPUERTO</td>
<td>45</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>YAQUERANA</td>
<td>44</td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td>TROMPETEROS</td>
<td>42</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>MANSERICHE</td>
<td>39</td>
<td>31</td>
<td>3</td>
</tr>
<tr>
<td>ALTO NANAY</td>
<td>36</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>DEMAS DISTRITOS</td>
<td>296</td>
<td>188</td>
<td>40</td>
</tr>
<tr>
<td>Dpto Loreto</td>
<td>1026</td>
<td>548</td>
<td>72</td>
</tr>
</tbody>
</table>
Limitations of the Current Surveillance System

• **4-week lag in reporting** ➔ response is *Reactive* and not *Proactive*

![Graph showing % Malaria Reporting vs Time / Epidemiological Week (0=today)](image)

• **MIGRATION---**Many cases are migrants
  - Where do they live?
  - Where infected?
  - Where diagnosed?

• Surveillance is disconnected from (environmental) risk factors
# OUR APPROACH

## Observations, Parameters & Products

### Earth Observations

- **Land Cover and Vegetation Index**: MODIS, Landsat
- **Surface Temperature**: MODIS, Landsat
- **Terrestrial Water Storage (TWS) Anomalies**: GRACE
- **Precipitation**: TRMM, GPM
- **Surface Soil Moisture**: SMAP
- **Root Zone Soil Moisture**: GOES, MODIS

### Human Data

- **Malaria Surveillance**: Weekly case counts from all government health posts on confirmed cases of each disease
- **Human Population**: Census population and estimates from INEI (Peru), INEC (Ecuador), INE (Colombia), IBGE (Brazil)
- **Concessions**: Land concessions for logging, mining, oil/gas exploration, and agriculture
- **Interventions**: IRS, aerial spraying, bednet distribution, education campaigns

## Predictions / Forecasts

### Earth System Models

**NASA Land Data Assimilation System (LDAS)**: optimal estimates of land surface states and fluxes at 1km resolution, produced through integration of physically-based land surface models and Earth Observations using advanced data assimilation techniques

**Land Cover Analysis**: Improved estimation of land cover change over time

### District and Catchment Area

**STATISTICAL Models**

- Space-time Bayesian CAR Model
- Polynomial Distributed Lag Model

## Decision Support & Application Readiness

### Management Actions

**End-Users**: Ministries of Health: Peru, Ecuador, Brazil, Colombia Regional Health Directorates in Peru

**End-User Decision Support**

- Training primary and secondary end-users in system components and prediction products
- Real-time predictions of malaria risk
- Seasonal malaria forecast
- Alert notices and identification of focal areas of disease risk
- Improved space-time mapping of disease

**Specific Decisions / Actions / Benefits**

- Targeted interventions and efficient deployment of resources
- Potential reduction and control of disease
- Scientific basis for government requirements on private industry to improve health prevention strategies (particularly in logging and mining)
LAND DATA ASSIMILATION SYSTEM
- Temperature
- Precipitation
- Soil Moisture
- Solar Radiation
- Stream Flow

LANDSCAPE ECOLOGY
- Districts (n=51)
- Bodies of Water
- Ecoregions:
  - 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
2 Forecasts at different Spatial Scales

EcoRegion Forecast Model

- EcoRegions are aggregated areas with similar climate, land cover, population, and ecosystems
- Malaria data are aggregated to EcoRegion to reduce statistical noise
- Unobserved Components Model

District Level Forecast Model

- Administrative Districts
- Smallest unit of aggregation other than community
- Spatial Bayesian Model estimates incidence rate
Examples of Impact

1. Quantifying the Impact of the PAMAFRO Program withdrawal from Peru

2. Demonstration of MEWS output with Vice Minister of Peru, Feb 2019

3. Prioritization in restarting malaria control following COVID-19
MEWS-estimated Impact of PAMAFRO: **153,025 cases averted**
MEWS-estimated impact of PAMAFRO: **151,523 cases not averted**
Feb 2019 Demo with Peru’s Vice Minister of Health
### Outbreak probabilities

<table>
<thead>
<tr>
<th>District</th>
<th><em>P. vivax</em></th>
<th><em>P. falciparum</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Morona</td>
<td><strong>0.82</strong></td>
<td><strong>0.70</strong></td>
</tr>
<tr>
<td>Napo</td>
<td>0.48</td>
<td>0.48</td>
</tr>
<tr>
<td>Nauta</td>
<td>0.47</td>
<td>0.46</td>
</tr>
<tr>
<td>Padre Marquez</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Pampa Hermosa</td>
<td>0.63</td>
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<tr>
<td>Parinari</td>
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</tr>
<tr>
<td>Pastaza</td>
<td>0.40</td>
<td>0.40</td>
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<tr>
<td>Pebas</td>
<td>0.61</td>
<td>0.54</td>
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<tr>
<td>Puinahua</td>
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<td>0.46</td>
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<tr>
<td>Punchana</td>
<td>0.56</td>
<td>0.51</td>
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<tr>
<td>Putumayo</td>
<td>0.46</td>
<td>0.45</td>
</tr>
<tr>
<td>Ramon Castilla</td>
<td>0.62</td>
<td>0.56</td>
</tr>
<tr>
<td>Requena</td>
<td>0.55</td>
<td>0.50</td>
</tr>
</tbody>
</table>
Prioritizing malaria control following COVID-19

2020 Surveillance: 9,653 cases of *P. vivax*; 2,789 cases of *P. falciparum*
MEWS estimates: 26,903 cases of *P. vivax*; 7,544 cases of *P. falciparum*
In Sum....

- We have developed a Malaria Early Warning System that can produce 12-week forecasts of outbreaks with >90% sensitivity
- We have strong government & academic partnerships in Peru, Ecuador and Brazil
  - LDAS implementation in Ecuador at USFQ
  - Forecasting capacity at CDC-Peru and the CLIMA Lab at UPCH
- There are major challenges regarding implementation, especially due to COVID-19
- Formed a new partnership with the InterAmerican Institute for Global Change Research (IAI) to transfer technology. We have a detailed plan and are currently shopping for funding
THANK YOU!

Project Team

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