Mapping, Monitoring and Forecasting Climate-sensitive Diseases: CHIKUNGUNYA (CHIKRisk)

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CHIKUNGUNYA VIRUS (CHIKV)

• Mosquito-borne, viral infection
• First described in Tanzania in 1952 – derived from Makonde word **kungunyala** meaning "that which bends up"
• Known to circulate in a sylvatic cycle between forest-dwelling mosquitoes and nonhuman primates in Central/East Africa
• Symptoms include fever, rash and severe joint pains that may cause stoop posture
• Rarely causes death, but can be debilitating
• Neither vaccine nor specific medicine are available for Chikungunya
• Loss of Duty Days due to sickness
• Economic impacts – especially tourism during epidemic periods
• Episodic epidemics and outbreaks across the tropics
• Transmitted by *Aedes aegypti* and *Aedes albopictus* mosquito vectors
BACKGROUND AND MOTIVATION

- Chikungunya outbreaks in East Africa and Indian Ocean Islands – drought-associated [Chretien JP et al., 2007]
- ENSO teleconnections – opposing anomaly conditions between Rift Valley fever (wet and cool) and chikungunya (hot and dry) in Africa and SE Asia [Anyamba et al., 2012]
- Chikungunya spread – mutation of East/Central Africa genotype enhance transmission by *Aedes Albopictus* to Asia and other areas [Zeller et al., 2016]
- Global spread – Italy (2007), Americas (2013 – to present)
- Effect of drought / temperature induced dehydration on blood feeding frequency [Hagan et al., 2007]
CLIMATE ANOMALIES

- Chikungunya activity in eastern Africa and southeast Asia, 2004 – 2007
- Hot and dry conditions persist in locations reporting chikungunya activity

Land Surface Temperature, Jun 2004 - Aug 2004

Rainfall Anomaly, Dec 2006 - Feb 2007
PROJECT OVERVIEW

CHIKRisk App addresses
- Where has chikungunya activity occurred
- Where is it occurring now
- Which regions are currently at risk for chikungunya
- Which regions are at risk in the future

Products
- Monthly chikungunya risk map
- Forecast risk map (up to 6 months lead time)
- Locations of reported chikungunya occurrence

Customers
- Defense Health Agency – Armed Forces Health Surveillance Center
- Pan-America Health Organization

Science + Technology Activity

TRL 7 – We have demonstrated the technology
TRL 8 – Field testing with field application this year
CHIKUNGUNYA HISTORICAL OCCURRENCE DATA

Main Resource

- Reported outbreaks catalogued and georeferenced based on closest “named” location

Central America
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Costa Rica. 4 Mar 2016. 
(reported) 1167 cases; Localities most affected: Central Pacific coast 555 cases; Guanacaste province 372 cases

Honduras. 29 Feb 2016. 
(reported) 4000 cases; Deaths 18.8
CHIKUNGUNYA HISTORICAL OCCURRENCE DATA

Other Sources:

Armed Forces Health Surveillance Branch (AFHSB) Health Surveillance Update (AHSU) reports – for confirmation (2014 – Present)

Pan American Health Organization

Literature – searched through PubMed for outbreaks prior to 2000; Local Ministry of Health publications, including CDC MMWR

ProMED, 1999 to present

Historical chikungunya locations from literature
### CLIMATE AND ANCILLARY DATA

<table>
<thead>
<tr>
<th>Geophysical Variable</th>
<th>Dataset</th>
<th>Coverage Spatial</th>
<th>Period</th>
<th>Resolution Spatial</th>
<th>Temporal</th>
<th>Processing Status</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rainfall</strong></td>
<td>Global Precipitation Climatology Project (GPCP)</td>
<td>Global</td>
<td>1979-Current</td>
<td>1° (100 km)</td>
<td>Monthly</td>
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<td>GPM - 3IMERGHH</td>
<td>Global</td>
<td>2015-Current</td>
<td>0.1° (11 km)</td>
<td>30 minutes</td>
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<tr>
<td></td>
<td>Climate Prediction Center Unified (CPC-UNI)*</td>
<td>Global</td>
<td>1979-Current</td>
<td>0.5° (50 km)</td>
<td>Daily</td>
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<td>CPC-UNI Morphing Technique (CMORPH)</td>
<td>Global</td>
<td>1998-Current</td>
<td>8 km</td>
<td>30 min</td>
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<tr>
<td><strong>Land Surface Temperature</strong></td>
<td>Moderate Resolution Imaging Spectroradiometer (MODIS)*</td>
<td>Global</td>
<td>2000-Current</td>
<td>0.05° (5 km)</td>
<td>Daily</td>
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<tr>
<td><strong>Near Surface Temperature</strong></td>
<td>Global Land Data Assimilation (GLDAS)</td>
<td>Global</td>
<td>2000-Current</td>
<td>0.25° (25 km)</td>
<td>3-Hourly, Monthly</td>
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<tr>
<td><strong>Specific Humidity</strong></td>
<td>Global Land Data Assimilation (GLDAS)</td>
<td>Global</td>
<td>2000-Current</td>
<td>0.25° (25 km)</td>
<td>3-Hourly, Monthly</td>
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<td><strong>Vegetation Index</strong></td>
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<td>Global</td>
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<td><strong>Soil Moisture</strong></td>
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<td>3-Hourly, Monthly</td>
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<td><strong>Elevation</strong></td>
<td>Shuttle Radar Topography Mission (SRTM)</td>
<td>Global</td>
<td>2000-Current</td>
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<td><strong>Population</strong></td>
<td>NASA Socioeconomic &amp; Social Data Center</td>
<td>Global</td>
<td>2000-Current</td>
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<td><strong>Rainfall &amp; Temperature Forecasts</strong></td>
<td>The North American Multi-Model Ensemble*</td>
<td>Global</td>
<td>1° (~100 km)</td>
<td>Monthly, 3-Monthly</td>
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<td>✓</td>
</tr>
</tbody>
</table>

* Available in CHIKRisk App
ANALYTICS: STATIC/ BASELINE INPUTS

Mosquito vector locations

- VectorMap (Walter Reed Biosystematic Unit)
- VectorBase (National Institute of Allergy and Infectious Diseases (NIAID) Bioinformatics Resource Center (BRC))

Population Density, 2015
Potential epidemic area

Derived from climate envelope and chikungunya locations
CURRENT CHIKUNGUNYA RISK MAPPING

Based on observed climate and historical chikungunya locations

90 Climate Variables
- Land Surface Temperature
- Precipitation
- Air Temperature
- Specific Humidity
- Soil Moisture

Accuracy
(calculated based on data not used in training the model)
- Partial Least Square: 0.808 (0.605, 0.775)
- Neural Network: 0.816 (0.783, 0.846)
- Random Forest: 0.889 (0.861, 0.912)
- Support Vector Machine: 0.815 (0.782, 0.844)

Machine Learning-Based Models
- Repeated 10-fold cross validations
- Final model is selected based on classification accuracy for data that had not been used in training the model

2514 point locations chikungunya presence and pseudo-absence (2000 – 2017)

Population Density

Mosquito vector locations

Chikungunya suitibility map

Mosquito vector locations

Population density

Potential epidemic area
CHIKUNGUNYA FORECAST

Substituted observed/assembled climate data with climate forecast

**Machine Learning-Based Models**
- Repeated 10-fold cross validations
- Final model is selected based on classification accuracy for data that had not been used in training the model

**Random forest** had highest performance with accuracy of: 0.859 (95% CI: 0.829, 0.886)

**Forecast Generation**
- Substitute air temperature and precipitation anomalies with forecasts data

**Risk Map Model**

**Chikungunya suitabiltiy map**

**Mosquito vector locations**

**Chikungunya Forecast Risk Map**
VALIDATION

~80% of reported locations with chikungunya activity were predicted to be at risk by the current risk maps

~70% of reported locations with chikungunya activity were predicted to be at risk by the forecast risk maps
CHIKRISK APP

https://vbd.usra.edu
Defense Health Agency/ Armed Forces Health Surveillance Branch - Global Emerging Infections Surveillance (GEIS)

Provide surveillance and risk forecast products to support Combatant Command Force Health Protection (FHP) Decisions (pre and post-deployment)
BUDGET AND COSTING DATA

- TOTAL: $175K
- OBLIGATED TO CONTRACTS: $175
- EXPENDITURE: NO DATA YET
PROGRESS

• Upgrades: App and Functionality – deployment early October 2020
  • New look map graphics
  • Time Series
  • Light weight – user oriented data
HIGHLIGHTS

• Featured Earth Observatory story to showcase the application of NASA Earth Science Data and Models: Of Mosquitoes and Models: Tracking Disease by Satellite
  https://earthobservatory.nasa.gov/features/disease-vector.
HIGHLIGHTS-2

- Featured on *Netflix Connected* series - *The Hidden Science of Everything* documentary with Latif Nasser *Episode 5: Clouds* showcasing how NASA satellite derived climate data, disease data from a variety of sources, in situ mosquito vector data is used to map and forecast areas at potential risk for disease outbreaks globally.

[Link to YouTube video](https://www.youtube.com/watch?v=B-aZrftUPIk)
HIGHLIGHTS-3

17 Rooms Flagship (virtual) Summit, September 20, 2020
- Structured based on Sustainable Development Goals (SDG’s)
- Organized by The Brookings Institution & The Rockefeller Foundation
- Contributed to Room 3 Initiative on Transforming National and Global Epidemic Intelligence Systems aimed at determining systems, methodologies and infrastructure that will better prepare us for future outbreaks and pandemics
- Recognized the importance of the One Health Approach
- Reported to Amina Mohammed, Deputy Secretary-General, The United Nations.
- Implementation will be through UN Country Teams
CHALLENGES

• Budgetary Challenges – look to continue in FY2021
• Computational Resources
• Fieldwork