ESTIMATING THE RISK OF VECTOR-BORNE INFECTIOUS DISEASE & ACUTE RESPIRATORY INFECTIONS USING SATELLITE DATA

Presented by Radina P. Soebiyanto$^{1,2}$

on behalf of Richard Kiang$^1$

$^1$NASA Goddard Space Flight Center, Code 610.2, Greenbelt, MD
$^2$Goddard Earth Sciences Technology & Research (GESTAR), Universities Space Research Association, Columbia, MD
AGENDA

- Malaria in Thailand, Afghanistan and Korea
- Dengue in Indonesia
- Avian Influenza in Indonesia
- Seasonal Influenza in New York, Arizona and Hong Kong
MALARIA

- **Cause:**
  - *Plasmodium* spp (protozoan)
  - Carried by *Anopheles* mosquito

- **Burden:**
  - 250 million cases each year
  - 1 million deaths annually
  - Every 30 seconds a child dies from malaria in Africa
  - Cost ~ 1.3% of annual economic growth in high prevalence countries

- **High Risk Group:** Pregnant women, children and HIV/AIDS co-infection

- **Treatment and Prevention:**
  - Indoor spraying
  - Bed nets
  - Vector Control
  - Artemisin-based Combination Therapy
MALARIA

Malaria Distribution

Malaria, countries or areas at risk of transmission, 2010

Role of climatic and environmental determinants

<table>
<thead>
<tr>
<th>Determinants</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>Parasite + Vector: development and survival</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Vector breeding habitat</td>
</tr>
<tr>
<td>Land-use, NDVI</td>
<td>Vector breeding habitat</td>
</tr>
<tr>
<td>Altitude</td>
<td>Vector survival</td>
</tr>
<tr>
<td>ENSO</td>
<td>Vector development, survival and breeding habitat</td>
</tr>
</tbody>
</table>
MALARIA IN THAILAND

- Leading cause of morbidity and mortality in Thailand
- ~50% of population live in malarious area
- Most endemic provinces are bordering Myanmar & Cambodia
  - Significant immigrant population
  - Mae La Camp
    - Largest refugee camp
    - >30,000 population
MALARIA IN THAILAND

- Satellite-observed meteorological & Environmental Parameters for 4 Thailand seasons

**Surface Temperature**
MODIS Measurements

**Vegetation Index**
AVHRR & MODIS Measurements

**Rainfall**
TRMM Measurements
### Neural Network training and validation accuracy

<table>
<thead>
<tr>
<th>Model</th>
<th>Input</th>
<th>Hidden Layer</th>
<th>Hidden Node</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td>( t, T, P, P \text{ (lag } 1)), H, V</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Model 2</td>
<td>( t, P, P \text{ (lag } 1)), H, V</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Model 3</td>
<td>( t, T, P, P \text{ (lag } 1)), H, V</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Model 4</td>
<td>( t, T, P, P \text{ (lag } 1)), H, V</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

\( t = \text{ time}, T = \text{ temperature}, P = \text{ precipitation}, H = \text{ humidity}, V = \text{ NDVI} \)
MALARIA IN THAILAND

Hindcast Incidence

Actual Malaria Incidence
MALARIA IN AFGHANISTAN

Provinces included in the study

TRMM

MODIS-LST

NDVI

Adimi et al. Malaria Journal 2010, 9: 125
MALARIA IN AFGHANISTAN

- NDVI and temperature were a strong indicator for malaria risk.
- Precipitation is not a significant factor → Malaria risk is mainly due to irrigation as implied from the significant contribution from NDVI.
- Average $R^2$ is 0.845.
- Short malaria time series (<2 years) pose a challenge for modeling and prediction.
Identification of potential larval habitat (irrigation and drainage ditches)

- US Army’s Camp Greaves in South Korea (N. Kyunggi Province)
- 43 sample sites with predominant habitats of rice fields (26 sites) and ditches (13 sites)
- Classification using pan-sharpened 1-m resolution IKONOS data on a 3.2 x 3.2 km test site
DENGUE

- Endemic in more than 110 countries
  - Tropical, subtropical, urban, peri-urban areas
- Annually infects 50 – 100 million people worldwide
- 12,500 – 25,000 deaths annually
- Symptoms: fever, headache, muscle and joint pains, and characteristic skin rash (similar to measles)
- Primarily transmitted by Aedes mosquitoes
  - Live between 35°N - 35°S latitude, >1000m elevation
- Four serotypes exist
  - Infection from one serotype may give lifelong immunity to that serotype, but only short-term to others
  - Secondary infection increases the severity risk

Source: CDC
DENGUE IN INDONESIA

- **Environmental variables used**
  - Temperature, dew point, wind speed, TRMM, NDVI

- **Modeling method**
  - ARIMA – Auto Regressive Integrated Moving Average
  - Classical time series regression
  - Accounts for seasonality

- **Result**
  - Best-fit model uses TRMM and Dew Point as inputs
  - Peak timing can be modeled accurately up to year 2004
  - Vector control effort by the local government started in the early 2005
The problem

First appeared in Hong Kong in 1996-1997, HPAI has spread to approximately 60 countries. More than 250 million poultry were lost.

35% of the human cases are in Indonesia. Worldwide the mortality rate is 53%, but 81% in Indonesia. In Indonesia, 80% of all fatal cases occurred in 3 adjacent provinces.

Co-infection of human and avian influenza in humans may produce deadly strains of viruses through genetic reassortment.

HPAI H5N1 was found in Delaware in 2004.

The risk of an H5, H7 or H9 pandemic is not reduced or replaced by the 2009 H1N1 pandemic.
Indonesia has 35% of the world’s human cases with 81% mortality. For the rest of the world, mortality is 53%
H5N1 Transmission Pathways

POULTRY TRADE
- poultry, products, feed, waste, personnel, equipment

BIRD TRADE
- LPAI spill over
- wild birds, domestic birds, ducks & geese

MIGRATORY BIRDS
- HPAI spill back

POULTRY
- Sectors 1&2, Sectors 3&4
- ?

HUMANS
- human flu virus
- reassortment
- pandemic strain
AVIAN INFLUENZA

- **NAMRU-2 Bird surveillance sites on Java**

- **Buffer zones can be established to limit the spread of H5N1 around wetlands and nearby farmlands**

- **EU’s & UK’s Practice:**
  - 3 km protection zone
  - 10 km surveillance zone
  - Larger restricted zone

ASTER image showing NAMRU-2 bird surveillance site around *Muara Cimanuk* estuary
AVIAN INFLUENZA

- **Poultry and human outbreaks in Greater Jakarta**

- **Distance from outbreaks**
  - Primary road
  - Secondary road
  - Wet market
  - Distribution center
  - River
  - Water body

- **Cases vs Meteorological factors**
SEASONAL INFLUENZA

- Worldwide annual epidemic
  - Infects 5 – 20% of population with 500,000 deaths
- Economic burden in the US
  ~US$87.1 billion
- Spatio-temporal pattern of epidemics vary with latitude
  - Role of environmental and climatic factors
- Temperate regions: distinct annual oscillation with winter peak
- Tropics: less distinct seasonality and often peak more than once a year

Source: Viboud et al., 2006
### Factors implicated in influenza

<table>
<thead>
<tr>
<th>Influenza Process</th>
<th>Factors</th>
<th>Relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Virus Survivorship</strong></td>
<td>Temperature</td>
<td>Inverse</td>
</tr>
<tr>
<td></td>
<td>Humidity</td>
<td>Inverse</td>
</tr>
<tr>
<td></td>
<td>Solar irradiance</td>
<td>Inverse</td>
</tr>
<tr>
<td><strong>Transmission Efficiency</strong></td>
<td>Temperature</td>
<td>Inverse</td>
</tr>
<tr>
<td></td>
<td>Humidity</td>
<td>Inverse</td>
</tr>
<tr>
<td></td>
<td>Vapor pressure</td>
<td>Inverse</td>
</tr>
<tr>
<td></td>
<td>Rainfall</td>
<td>Proportional</td>
</tr>
<tr>
<td></td>
<td>ENSO</td>
<td>Proportional</td>
</tr>
<tr>
<td></td>
<td>Air travels and holidays</td>
<td>Proportional</td>
</tr>
<tr>
<td><strong>Host susceptibility</strong></td>
<td>Sunlight</td>
<td>Inverse</td>
</tr>
<tr>
<td></td>
<td>Nutrition</td>
<td>Varies</td>
</tr>
</tbody>
</table>

**Ex Vivo study showing efficient transmission at dry and cold condition** [Lowens et al., 2007]

- High temperature (30°C) blocks aerosol transmission *but not contact transmission*
# Seasonal Influenza

<table>
<thead>
<tr>
<th></th>
<th>Hong Kong, China</th>
<th>Maricopa County, AZ</th>
<th>New York City, NY</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Center Lat.</strong></td>
<td>22° N</td>
<td>33° N</td>
<td>40° N</td>
</tr>
<tr>
<td><strong>Climate</strong></td>
<td>Sub-Tropical</td>
<td>Sub-Tropical</td>
<td>Temperate</td>
</tr>
<tr>
<td><strong>General Condition</strong></td>
<td>Hot &amp; humid during summer. Mild winter, average low of 6°C</td>
<td>Dry condition. Mean winter low is 5°C, and summer high is 41°C</td>
<td>Cold winter, average low of -2°C. Mean summer high is 29°C</td>
</tr>
</tbody>
</table>

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[Maps showing locations of Hong Kong, China, Maricopa County, AZ, and New York City, NY]
SEASONAL INFLUENZA

DATA

- Weekly lab-confirmed influenza positive
- Daily environmental data were aggregated into weekly
- Satellite-derived data
  - TRMM 3B42
  - LST - MODIS
- Ground station data

![Graphs showing data trends over time for different locations.](image-url)
Several techniques were employed, including:

**ARIMA (AutoRegressive Integrated Moving Average)**
- Classical time series regression
 Accounts for autocorrelation and seasonality properties
- Climatic variables as covariates
- Previous week(s) count of influenza is included in the inputs
- Results published in PLoS ONE 5(3): 9450, 2010

**Neural Network (NN)**
- Artificial intelligence technique
- Widely applied for
  - approximating functions,
  - Classification, and
  - pattern recognition
- Takes into account nonlinear relationship
- Radial Basis Function NN with 3 nodes in the hidden layer
- Only climatic variables and their lags as inputs/predictors
NN models show that ~60% of influenza variability in the US regions can be accounted by meteorological factors.

ARIMA model performs better for Hong Kong and Maricopa:
- Previous cases are needed
- Suggests the role of contact transmission

Temperature seems to be the common determinants for influenza in all regions.
ACKNOWLEDGMENT

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THANK YOU