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

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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:**
  - Vector Control
  - *Artemisinin*-based Combination Therapy
  - Indoor spraying
  - Bed nets

- Transmission through female *Anopheles* bite

Images: Nat’l Geographic, Nature, WHO
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>

This map is intended as a visual aid only and not as a definitive source of information about malaria endemicity.
- 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
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>Input</th>
<th>Hidden Layer</th>
<th>Hidden Node</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model 1</strong></td>
<td>t, T, P, P (lag 1), H, V</td>
<td>1</td>
</tr>
<tr>
<td><strong>Model 2</strong></td>
<td>t, P, P (lag 1), H, V</td>
<td>1</td>
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<tr>
<td><strong>Model 3</strong></td>
<td>t, T, P, P (lag 1), H, V</td>
<td>1</td>
</tr>
<tr>
<td><strong>Model 4</strong></td>
<td>t, T, P, P (lag 1), H, V</td>
<td>1</td>
</tr>
</tbody>
</table>

\[ t = \text{time}, \ T = \text{temperature}, \ P = \text{precipitation}, \ H = \text{humidity}, \ V = \text{NDVI} \]
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%.
AVIAN INFLUENZA

- **H5N1 Transmission Pathways**

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

- **BIRD TRADE**
  - wild birds
domestic birds
ducks & geese

- **MIGRATORY BIRDS**
  - LPAI spill over
  - HPAI spill back

- **POULTRY**
  - Sectors 1&2
  - Sectors 3&4

- **HUMANS**
  - human flu virus
  - reassortment
  - pandemic strain

- Human flu virus can spill over from poultry, leading to reassortment, and eventually to a 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
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>
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
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