Improving Malaria Risk Monitoring with Flood Inundation Data from a SensorWeb

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Agenda

• Overview
• Malaria Vector
• Data
  ➢ Malaria
  ➢ Satellite Data and Physical Principal
  ➢ Flood Impact on Malaria and Vegetation health
• Methodology
• Results
• Conclusions
Overview

- Experiments conducted in Namibia on Flood and Disease Early Warning SensorWeb
- Created Flood Dashboard to provide relevant flood data and assist in early flood warning in Namibia with satellite data and ground sensors
- Preliminary results show as much as a 10 day early warning for floods downstream based on experiments
- These type of flood predictions can improve risk modeling for Malaria
- Bangladesh used as proxy for Namibia since we have not received all of the Namibia Malaria epidemiological data
SensorWeb Reference Architecture

[Diagram showing various services and nodes, including:
- Data Processing Node
- Data Distribution Service
- Web Processing Service (WPS)
- Data Aggregation Service
- Sensor Data Products
- Internet
- Workflows
- Workflow Chaining Services (WfCS)
- Web Coverage Processing Service (WCPS)
- Sensor Planning Service (SPS)
- Sensor Web Enablement (SWE)
- Identity Management Service (OpenID 2.0)
- Sensor Observation Service (SOS)
- Web Notification Service (WNS)
- UAV Sensor Data Node
- Satellite sensor data product
- EO-1 Satellite
- SWE Node]
In 2009, 2010 and 2011, record floods hit Namibia with as much as ¼ of the population of 2 million affected by the floods, along with hundreds of deaths and millions in property damage. SensorWeb technology is being integrated to help Department of Hydrology implement a Flood Early Warning system to save lives and property.

Detect: TRMM rainfall estimate monitored upstream, AMSR-E based Riverwatch used to monitor river widths, daily MODIS flood extent maps
Respond: Trigger EO-1 and Radarsat imagery based on detection of triggers
Product Generation: MODIS daily flood extent overlays, EO-1 flood extent overlays, river gauge plots
Delivery: Aggregated data layers on Flood Dashboard

“This is to reiterate and stress support and enthusiasm for ongoing efforts during the past two years to integrate SensorWeb components for use by us and other flood disaster response workers and institutions.”

— Guido Van Langenhove, Head of Namibia Department of Hydrology
Top Level Water Borne Disease SensorWeb
Functional Flow

Flood Predictions

Flood alerts

Flood conditions

Climate & vegetation conditions

Request for satellite imagery in area of interest

Statistical disease risk alerts

Campaign Manager

Customized plan of needed satellite images

Historical epidemiological data

Compare to history

*SPS – Sensor Planning Service
Strategy: WEATHER PROXY
AUGUST 26, 2008

Malaria risk map identify priority areas and additional resource needed to fight epidemics effectively.

INTENSIVE MALARIA

Felix Kogan/NOAA/NESDIS
Overview: Global situation

- **300 to 500 million** clinical cases of malaria each year
- Malaria kills more than 2,000,000 people per year
- **40% of the world's population** are at risk in about 90 countries and territories
- 80% to 90% of malaria deaths occur in Sub-Saharan Africa.
- Malaria and HIV have a wide geographic overlap
  - Malaria has substantial population-level implications

Geographic distribution of Malaria in Red
Overview: Goal of detection and monitoring of malaria

- Use satellite data for prediction of epidemics (generating malaria risk maps)
- Advise the government on appropriate siting of relocation camps to reduce the malaria risk
- Boosts economy

(a) explore sensitivity of regional ecosystems condition to malaria events for the period of available satellite records;
(b) identify some features in the impact of ecosystems in malaria transmission; and
(c) estimate the similarities and difference in the impacts weather on different malaria epidemic areas in the world.
(d) devise robust statistical model for forecasting malaria
Impact of Malaria

- Growth penalty 1.3%
- Reduce investment
- Poverty
- Loss of work

Factors affecting Malaria

- Climate
- Flood
- Availability of Health Care
- Population Density
- Use of DDT
- Urbanization
- Irrigation
- Life Style

Largest factors that affect rate and risk of Malaria is change of climate and flood condition. Other non-climatic factors have a lesser influence on risk and rate of Malaria.
Malaria Vector
Malaria

- Malaria is a vector-borne disease
- Malaria caused by genus Plasmodium.
- It needs an organism for transmission.
- Transmitted from person to person by the female mosquitoes of certain species.
Malaria Vector and Life Cycle

2,500 known species of mosquitoes

- Aedes
- Anopheles
- Culex
- Psorophora

larvae lie along the water-air interface
Malaria Parasite

- **Plasmodium falciparum**
- **Plasmodium vivax**
- **Plasmodium malariae**
- **Plasmodium ovale**

The gametocytes, male (microgametocytes) and female (macrogametocytes), are ingested by an *Anopheles* mosquito during a blood meal. is sporogonic cycle.

Sporozoites infect liver cells and mature into schizonts, which rupture and release merozoites.

Merozoites infect red blood cells. The ring stage trophozoites mature into schizonts, which rupture releasing merozoites. Some parasites differentiate into sexual erythrocytic stages (gametocytes).
Relationship of Temp. & Relative Humidity with Malaria Parasite and Mosquito Development

<table>
<thead>
<tr>
<th>Minimum temp. for parasite development</th>
<th>Maximum temp. for mosquito survival</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 11 12 13</td>
<td>40 °C</td>
</tr>
<tr>
<td>14 15 16 17 18 19</td>
<td></td>
</tr>
<tr>
<td>Optimum temp.</td>
<td></td>
</tr>
<tr>
<td>25 26 27</td>
<td></td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>40 60 70 80</td>
</tr>
</tbody>
</table>

Effect of Rise in Temperature on mosquitoes Vectors

- Rate of development (from egg to adults) will be faster
- Rate of digestion of blood meal will be faster.
- Frequency of feeding will be faster
- Survival affected by RH.
- Death of mosquitoes at 40°C
Data

- Malaria Statistics
- Satellite Data and Physical Principal
- Flood level
Malaria Data

Malaria Statistics (Ministry of health)

Performance Indicator

Annual parasite Incidence (API) = \( \frac{\text{Number of blood smears positive for malaria Parasite in a year}}{\text{Total population}} \times 1000 \)

Slide Positive rate (SPR) = \( \frac{\text{Number of blood smears positive for malaria Parasite in a year}}{\text{Number of Blood smears examined}} \times 100 \)

Number of positive cases of malaria from all patient with fever visited hospital
NOAA Operational Environmental Satellites

- **Polar orbiting satellites**
  - 860 km altitude
  - North-south orbit
  - Sun synchronous
  - 1:40 p.m pass equator
  - Longer term forecasting

- **Geostationary satellites**
  - Orbit around the Earth at an altitude of about 35800 km above the equator
  - Temporal resolution 30 minutes
  - Limited spatial resolution
DATA from NOAA operational polar orbiting satellites

**Sensor:** Advanced Very High Resolution Radiometer (AVHRR)

**Satellites:** NOAA-7, 9, 11, 14, 16, 18 (afternoon.), 17

**Data Resolution:**
- **Spatial** - 4 km GVI, sampled to 16 km;
- **Temporal** - Daily sample 7-day composite

**Period:** 1981-2009

**Coverage:** World (75 N to 55 S)

**Channels:** VIS (ch1), NIR (ch2), Thermal (ch4, ch5)
AVHRR Reflectance

Chlorophyll controls much of spectra response in visible part of spectrum

DATA PROCESSING:
- Pre-launch calibration of VIS and NIR
- Post-launch calibration of VIS and NIR
- Non-linear correction of IR4
- Calculation of NDVI
- Calculation of brightness temperature (BT)
- High frequency noise removal from NDVI & BT time series
- Derivation of 24-year climatology
- Derivation of indices
  - Vegetation Condition (VCI)
  - Temperature Condition (TCI)
  - Vegetation Health (VHI)

\[ \text{NDVI} = \frac{(\text{NIR-VIS})}{(\text{NIR + VIS})} \]
AVHRR Reflectance

Chlorophyll controls much of spectra response in visible part of spectrum

Weather and Ecosystem components in NDVI & BT

• Blue Part mainly controls weather components (like temperature, humidity and rainfall)
• Ecosystem component (green part) controls by slow changing environmental factor

\[ \text{NDVI} = \frac{\text{NIR} - \text{VIS}}{\text{NIR} + \text{VIS}} \]
Vegetation Health Indices and Algorithm

- Normalized Difference Vegetation Index
  \[ \text{NDVI} = \frac{(CH2 - CH1)}{(CH2 + CH1)} \]
- Vegetation Condition Index (VCI)
  \[ \text{VCI} = 100 \times \left( \frac{\text{NDVI} - \text{NDVI min}}{\text{NDVI max} - \text{NDVI min}} \right) \]
- Temperature Condition Index (TCI)
  \[ \text{TCI} = 100 \times \left( \frac{\text{BTmax} - \text{BT}}{\text{BTmax} - \text{BTmin}} \right) \]

Use Vegetation Health Indices to Assess

- Moisture Condition (VCI)
- Thermal Condition (TCI)
- Vegetation Health (VHI)
Methodology
Tools and Methods

- Trend Analysis
- Correlation Analysis
- Regression Analysis
- Principal Component Analysis
- Mat Lab, SAS
Trend Analysis

Extract weather related variations from malaria time series

\[ T_t = a_0 + a_1 t_{\text{year}} \]

slowly changing function representing the deterministic component (trend) (ecosystem and non climatic factors)

\[ \sum_{i=1}^{i=n} (Y_i - T_i)^2 \]

a_0 (intercept) and a_1 (slope) by minimizing the sum of squares

\[ \text{DY} = (Y_{\text{actual}} / T_t) \times 100 \]

random component regulated by weather fluctuations (Deviation around trend line)

Correlation Dynamics

Correlation of 13 years (depends on Malarial data) of Deviation from Trend Line (DY) with 13 years of thermal and moisture condition indices (TCI and VCI) for all 52 weeks are calculated, Level of inundation has been correlated with Malaria for 365 days all 13 years

To explain the trend analysis, Correlation dynamics and Regression analysis, the malaria of Bangladesh dataset (1992-2004) has been presented here
Distribution of Positive Malaria Cases and Malaria Deaths in Bangladesh, 2006

Total Confirmed Malaria Cases = 51,705
Total Malaria Deaths = 513

Bandarban, Khagrachari, Cox’s Bazar, Rangamati and Chittagong contribution 85.5% of the confirmed malaria cases and 87% of the malaria deaths.

Confirmed Malaria Cases, 2006
- < 250
- 251 - 1500
- 1501 - 10000
- 10001 - 15000

1 Dot = 1 Malaria Death

Source: Directorate General of Health Services, Government of Bangladesh, Dhaka
Prepared by: Department of Communicable Diseases, Malaria Unit, WHO SEARO
Malaria endemic districts of Bangladesh

- Malaria Parasite
  - Plasmodium falciparum (95%)
  - Plasmodium vivax (5%)
- Female Anopheles Vectors
  - An Dirus
  - An minimus

**Climate of Bangladesh**

- Wet hot (flooding season) - April to October
- Cool dry – November to February
- Hot dry – February to April
Bangladesh Situation

• Out of 64 districts, 13 bordering districts in the east and north-east region belongs to the high-risk malaria zone.

• Plasmodium falciparum is the predominant parasite (61%-71%).

• 14.7 million people are at high-risk of malaria in the country.

• 1.0 million clinical cases are treated every year.

• In 2002 - a total of 598 deaths were reported in Bangladesh.
Annual malaria cases, and Trend line 1992-2004 in Bangladesh
Correlation dynamics of DY versus TCI and VCI in Bangladesh

Pre monsoon
Not correlated

Post monsoon
Correlated

Malaria season
Correlation dynamics of DY versus Water Level at Sunamgong

Pre monsoon Correlated
Too much Flood
Wash away malaria Larva Negatives correlation

Post monsoon Correlated

Malaria season
Correlation dynamics of Water Level at Sunamgong versus TCI and VCI in Bangladesh

Because of inter-Correlation multicolinearity exists in OLS Regression method
Regression Analysis

Variation inflation and tolerance

\[ \text{DY} = b_0 + \]

| Variable | Estimate | Error  | t value | Pr>|t| | Tolerance | Inflation |
|----------|----------|--------|---------|-------|-----------|------------|
| Intercept | 53.61238 | 35.35812 | 1.52 | 0.1638 | . | 0 |
| TCI34 | 0.6971 | 0.4354 | 1.6 | 0.1438 | 0.95011 | 1.05251 |
| day120 | 5.64404 | 4.33054 | 1.3 | 0.2248 | 0.67609 | 1.47909 |
| VCI34 | -0.05714 | 0.38583 | -0.15 | 0.9855 | 0.65767 | 1.52262 |

Small Tolerance
High variance inflation
P>10%

Correlation matrix

Predictor variables are highly correlated
Predictor variables are not independent
This is collinearity
Violation of assumption of OLS method

Principal Component Regression

Transforms another set of variables
They are orthogonal to each other
These are Principal components

| Parameter | Standard | Variable | Estimate | Error  | t Value | Pr>|t| |
|-----------|---------|----------|----------|--------|---------|-------|
| Intercept | 99.87334 | 4.62302 | 21.6 | <.0001 |
| Prin1 | 8.64547 | 3.72325 | 2.32 | 0.0404 |

P<5%
Simulated and observed malaria

$R^2 = 0.74$
Conclusion

- TCI and VCI identify climatic features that have impact on malaria transmission
- TCI and VCI can be used for malaria prediction
- Model for Malaria prediction that relies on (Vegetation health indices /VCI&TCI) will allow for reliable prediction of epidemics 1-2 months in advance. It’s shown here that addition of flood level parameter as the third input vector (in addition to VCI&TCI) for the Malaria Model improves the capability to as much as 4-6 months of advanced warning
- This increased lead time will allow for improved government response to deploy assets to fight epidemics
- Presented Malaria model allows for comparison of malaria epidemics in different ecosystems
- PCR allows for model improvement
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