Monitoring Malaria from Operational Satellites

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OUTLINE

• Background
• Malaria and Environment
• AVHRR Sensor & Data
• Vegetation Health (VH) System
• Data Applications & Interpretation
• Challenges
### Global Burden of Infectious Diseases Caused by Anthropod Vector

<table>
<thead>
<tr>
<th>Diseases</th>
<th>Disease Burden (% from total)</th>
<th>Mortality (% from total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malaria</td>
<td>78</td>
<td>89</td>
</tr>
<tr>
<td>African trypanosomiasis</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Lymphatic filariasis</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Dengue fever</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Leishmamiasis</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Chaga disease</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Onchocerciasis</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

Based on Disability Adjusted Life Years (DAILY) – the number of healthy years of life lost due to premature death and disability (World Health Organization 2002, The World Health Report, Geneva).
WORLD Malaria Facts

- 107 world countries are affected
- 3.2 billion people (48% of the world) are at risk
- 300–500 million annual malaria cases
- 1.5-3 million people die annually (4-5% of global fatalities)
- Children (C) & Pregnant women (PW) vulnerable
  - (C): One million dies annually; (PW): 10% maternal death
- *P. falciparum* and *P. vivax* cause of death (*one million deaths caused by P. falciparum only*)
- Area: Africa, Asia, Latin America, the Middle East & part of Europe
- Expenditure: 40% of Africa’s health
- Sub-SAHARA Africa contributes: 60% of global, 75% of *P. falciparum* & 80% of deaths cases; Every 30 sec a child dies
• CLIMATE & LANDSCAPE determine distribution of mosquito-borne diseases

• WEATHER affects timing, duration, area and intensity of outbreaks

• WARM & WET surface stimulates mosquito’s activities to carrying the disease to people
Correlation between malaria cases & weather data, **TANZANIA, Hai District**

<table>
<thead>
<tr>
<th>MONTH</th>
<th>Rains</th>
<th>Tmax</th>
<th>Tmin</th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>0.24</td>
<td>0.45</td>
<td>0.45</td>
</tr>
<tr>
<td>Jun</td>
<td>0.38</td>
<td>0.36</td>
<td>0.29</td>
</tr>
<tr>
<td>Jul</td>
<td>0.41</td>
<td>0.29</td>
<td>0.30</td>
</tr>
<tr>
<td>Aug</td>
<td>0.29</td>
<td>0.42</td>
<td></td>
</tr>
</tbody>
</table>

AFRICA: GTS weather station network

GTS Weather Stations
THEORY

Typical Vegetation Reflectance

VIS reflectance depends on CHLOROPHYLL CAROTENOID

NIR reflectance depends on WATER CONTENT CELL STRUCTURE

NDVI = (NIR-VIS)/(NIR+VIS)
### NDVI & Reflectance

<table>
<thead>
<tr>
<th>Cover Type</th>
<th>Ch1</th>
<th>Ch2</th>
<th>NDVI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetation:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dense</td>
<td>.050</td>
<td>.150</td>
<td>0.500</td>
</tr>
<tr>
<td>Medium</td>
<td>.080</td>
<td>.110</td>
<td>0.140</td>
</tr>
<tr>
<td>Light</td>
<td>.100</td>
<td>.120</td>
<td>0.090</td>
</tr>
<tr>
<td>Bare Soil</td>
<td>.269</td>
<td>.283</td>
<td>0.025</td>
</tr>
<tr>
<td>Clouds</td>
<td>.227</td>
<td>.228</td>
<td>0.002</td>
</tr>
<tr>
<td>Water</td>
<td>.022</td>
<td>.013</td>
<td>-0.26</td>
</tr>
</tbody>
</table>

NDVI = (Ch2 - Ch1) / (Ch2 + Ch1)
NDVI from MSG-2 SEVIRI
June 2007
NDVI & Rainfall (% mean), SUDAN (1984-1987)
NDVI in **Dry & Wet** Ecosystems

**NDVI_{max}** indicates **HEALTHY** vegetation

**NDVI_{min}** indicates **UNHEALTHY** vegetation
AVHRR-based VH Indices

Vegetation condition index (VCI), values 0 - 100

\[ VCI = \frac{NDVI - NDVI_{\text{min}}}{NDVI_{\text{max}} - NDVI_{\text{min}}} \]

NDVI_{\text{max}}, and NDVI_{\text{min}} – climatology (1981-2000 maximum and minimum NDVI for a pixel;

Temperature condition index (TCI), values 0 - 100

\[ TCI = \frac{BT_{\text{max}} - BT_{\text{min}}}{BT_{\text{max}} - BT_{\text{min}}} \]

NDVI_{\text{max}}, and NDVI_{\text{min}} – climatology (1981-2000 maximum and minimum NDVI for a pixel

Vegetation Health Index (VHI), values 0 – 100

\[ VHI = a \times VCI + (1-a) \times TCI \]

0 – indicates extreme stress

100 – indicates favorable conditions
Vegetation Health (VH) System

- **Satellites:** NOAA
- **Sensor:** AVHRR
- **Records:** 30-year
- **Characterize:** LAND SURFACE
  - GEENNESS (Chlorophyll)
  - MOISURE (Vigor)
  - THERMAL (Temperature)
- **Assess:** VEGETATION HEALTH
  - CUMULATIVE impact “have memory”
  - from EXTREME STRESS to FAVOURABLE
- **Issued**
  - WEEKLY
  - 4 km PIXEL
  - ALL LANDSCAPE
- **Products:** VEGETATION HEALTH, MOISTURE (VCI), THERMAL (TCI) CONDITION
Vegetation Health Interpretation

Central USA
Healthy vegetation
Impact: **Good crops**

Kazakhstan
Vegetation stress
Impact: **Bad crops**

Western USA
Vegetation stress
Impact: **Fire**

Argentina
Vegetation Stress
Impact: **Drought**

Southern Africa
Healthy Vegetation
Impact: **Malaria**

Significance: Vegetation Health estimates vegetation condition – a proxy for drought, crop & pasture production, fire, malaria;  http://www.star.nesdis.noaa.gov/smcd/emb/vci/VH

Project Lead: Felix Kogan

Sponsor: NOAA/NESDIS
Healthy condition
- Started in May
- Expands in July & August

VH products
- Detect
- Diagnose
- Forecast
Malaria risk maps identify priority areas to fight epidemics.
Malaria risk maps identify priority areas & additional resource distribution to fight epidemics effectively
Malaria risk maps identify priority areas and additional resource needed to fight epidemics effectively.

Strategy: WEATHER PROXY
AUGUST 26, 2008

INTENSIVE MALARIA
VALIDATION: VH & Malaria
SENегал

Healthy Vegetation
(1993, 1995)
4-5 times more malaria cases than stressed vegetation

NO Malaria if dry condition in semi-arid climate

Malaria Cases in a month of their MAXIMUM

Climate controls selection of VH strategy
Plasmodium vivax & P. falciparum in village studies, INDIA

Month wise, year wise cases of Plasmodium vivax and P. falciparum recorded in study villages between 1989-2000.

Breeding Sites
Labour Camp
Treated Bed Nets Evaluation
Validation: VH & Malaria in INDIA
Karnataka, Raichur

(Correlation of Malaria Cases (Annual Malaria Incident (AMI)/Trend of AMI) with Moisture Index (VCI))

VCI < 40 (dry) – Lower AMI
VII > 60 (wet) – Larger AMI

Rainfall 600 mm/year

VH is a good proxy for estimation of vegetation health & malaria epidemic
VALIDATION: Malaria (%) Observed vs. VH-Simulated Gujarat INDIA
VALIDATION: Malaria observed vs. VH (TCI)-simulated Caprivi NAMIBIA

Malaria Simulation for Caprivi, NAMIBIA

Lat 17.5-18.0 S; Long 21.5-22.10 E
dY = 60.26 - 0.34TCI49 + 0.34TCI50 + 0.65TCI51 + 0.08TCI52
Malaria Cases (%)

Choco COLOMBIA

Malaria cases, 1982-1997

% Malaria

15 20 25 30 35 40 45 50 55 60

Year
Correlation: Malaria Cases (%) with VCI & TCI

Choco COLOMBIA

![Graph showing correlation between Malaria Cases and VCI & TCI over weeks from January to November in Choco, Colombia.](image-url)
Strategy: PREDICTION

Kisii District Hospital KENYA

Malaria & VH

1. High VH (green circle) occurs 1-4 months prior to the malaria peak (red circle).

2. VH correlates with malaria cases & can be used as an epidemic predictor.

3. In 1998, the malaria peak shifted to spring - similarly, VH.

- VH provides up to 4 months advance malaria warnings.
- The warnings must be area specific.
VH-based Malaria Risk

2010

2009

http://www.star.nesdis.noaa.gov/smcd/emb/vci/VH/vh_browse.php
Combat Malaria Programs

• UN Malaria Envoy
• Roll Back Malaria Partnership
• Global Fund to Fight Aids, TB & Malaria
• Presidential Malaria Initiative
• Melinda & Bill Gates Foundation
• US Congress (2009-2013)
PMI Program

- Indoor Residual Spraying (IRS)
- Insecticide Treated Nets (ITN) incl. LLITN
- Artemisinin-based combination therapy (ATC)
- Intermittent preventive treatment for pregnant women (IPTp)
- Improving infrastructure and technology

Interview to RBM by Rear Admiral T.Ziemer (7/24.2008)
PMI: Goals & Countries

June 2005, President G.W. Bush announced a $1.2 billion aid package for AFRICA: Reduce 50% malaria death in 15 countries

SENEGAL
MALI
LIBERIA
GHANA
BENIN
ETHIOPIA
KENYA
UGANDA
RWANDA
MALAWI
TANZANIA
MOZAMBIQUE
ZAMBIA
ANGOLA
MADAGASCAR

Area – 3,243,000 sq. mi.   People – 343,000,000
POPULATION AFFECTED
- Rwanda 1.5 mil. (9% pop.)
- Uganda 13.0 mil. (41% pop.)

MALARIA CASES are SPECIFIC to
- Country
- Affected area
- Population
- Weather
- Climate
- Malaria Intensity

VH PROVIDES COMBINE ESTIMATION OF THESE CONDITIONS in ENDEMIC AREAS

VH diagnoses malaria risk over a country & an area advising on cost-effective resource distribution

2003 Malaria PMI Countries
Endemic Area

http://www.who.int
**VH-Malaria Risk Area as a predictor, 2003**

**Endemic Area**

**TANZANIA**
- 25-30% malaria risk area, Sep-Jan
- April-June provided 3-4 months advance malaria indication

**RWANDA**
- <5% malaria risk area, Sep-May
- Pre-season malaria risk area was low indicating no malaria risk

* VH provides malaria risk area for an entire country
* Pre-season VH forecasts malaria epidemics
VH Malaria Risk Area (%) by Intensity UGANDA

AREA - 94,000 sq mi. PEOPLE – 30,900,000

VH
(a) Provides risk area & epidemic intensity
(b) Validates effectiveness of fighting measures
GOALS

• Early detection of environmental conditions conducive for mosquito development & spread of malaria using operational satellites

• Monitoring Malaria Start/End, Area, Intensity & Impacts
1987 & 1988 Dengue Fever & VH
Vietnam, Thailand, Malaysia

Vegetation Health and Dengue Fever Disease

No Stress

NUMBER of CASES

Vegetation Stress

Vegetation Health & Dengue Hemorrhagic Fever Cases

Source: NOAA-9 & WHO
NOAA Capabilities (Examples)

KENYA: RVF (Rift Valley Fever) & Vegetation Health (VH)

1996-97
VH<20 - Severe DROUGHT – NO RVF epidemics

1997-98
VH>80 - FAVORABLE condition – Intensive RVF epidemics

VEGETATION HEALTH, Kenya

1996-1997 NO Epidemics

NOAA has capability to identify & monitor other mosquito-born diseases
Challenges in Monitoring Malaria

COLOMBIA

Satellite data are proxy requiring calibration & validation
CHALLENGES in treatment

- Increasing mosquitoes resistance to insecticides
- Parasite resistance (undermine malaria control)
- Changes in mosquitoes behavior due to treatments
- Changes in ecology due to human activities
- Diminishing number of effective insecticides
- No alternatives for DDT and pyrethroids
- Limited evidence of the treatment impact
Web

Thank You