Improving Malaria Risk Monitoring with Flood Inundation Data from a SensorWeb

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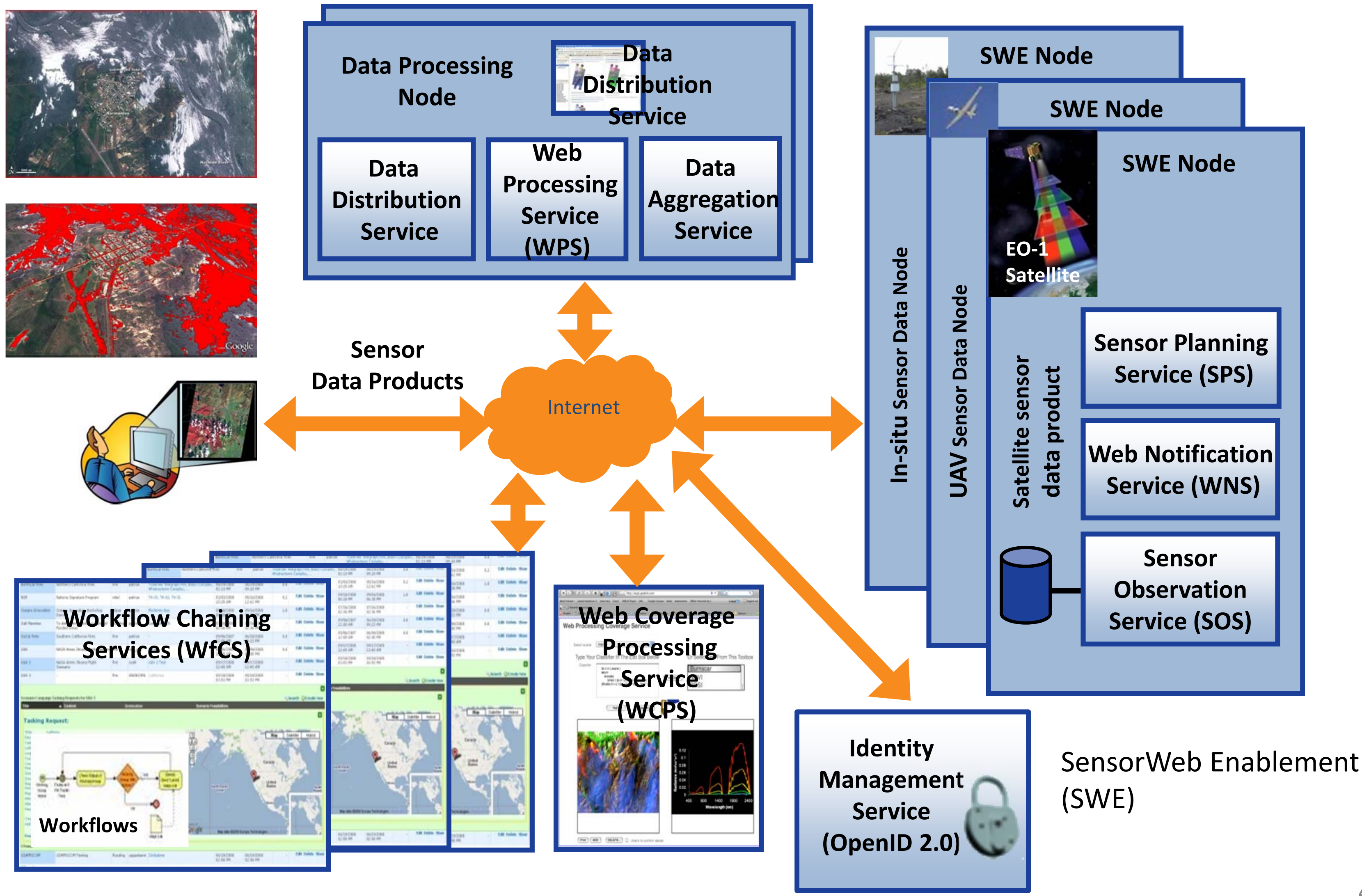
Agenda

- 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



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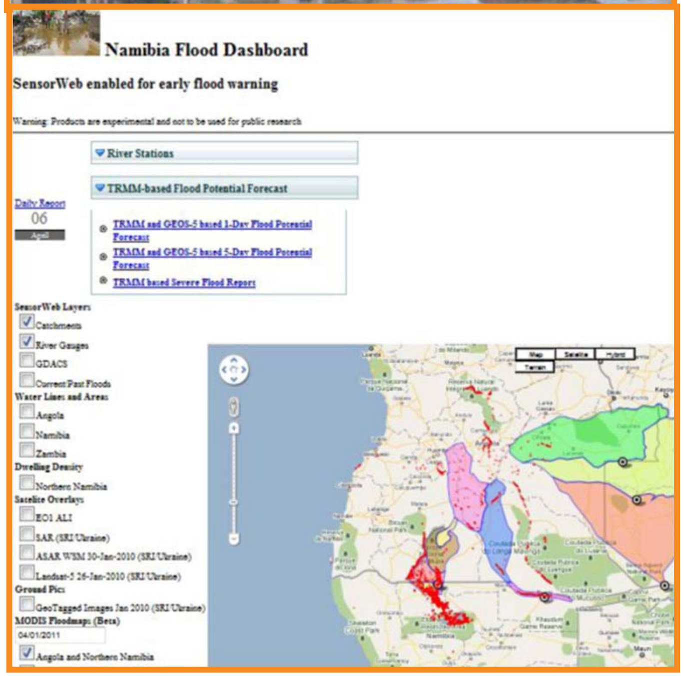
Namibia Flood Early Warning SensorWeb

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.

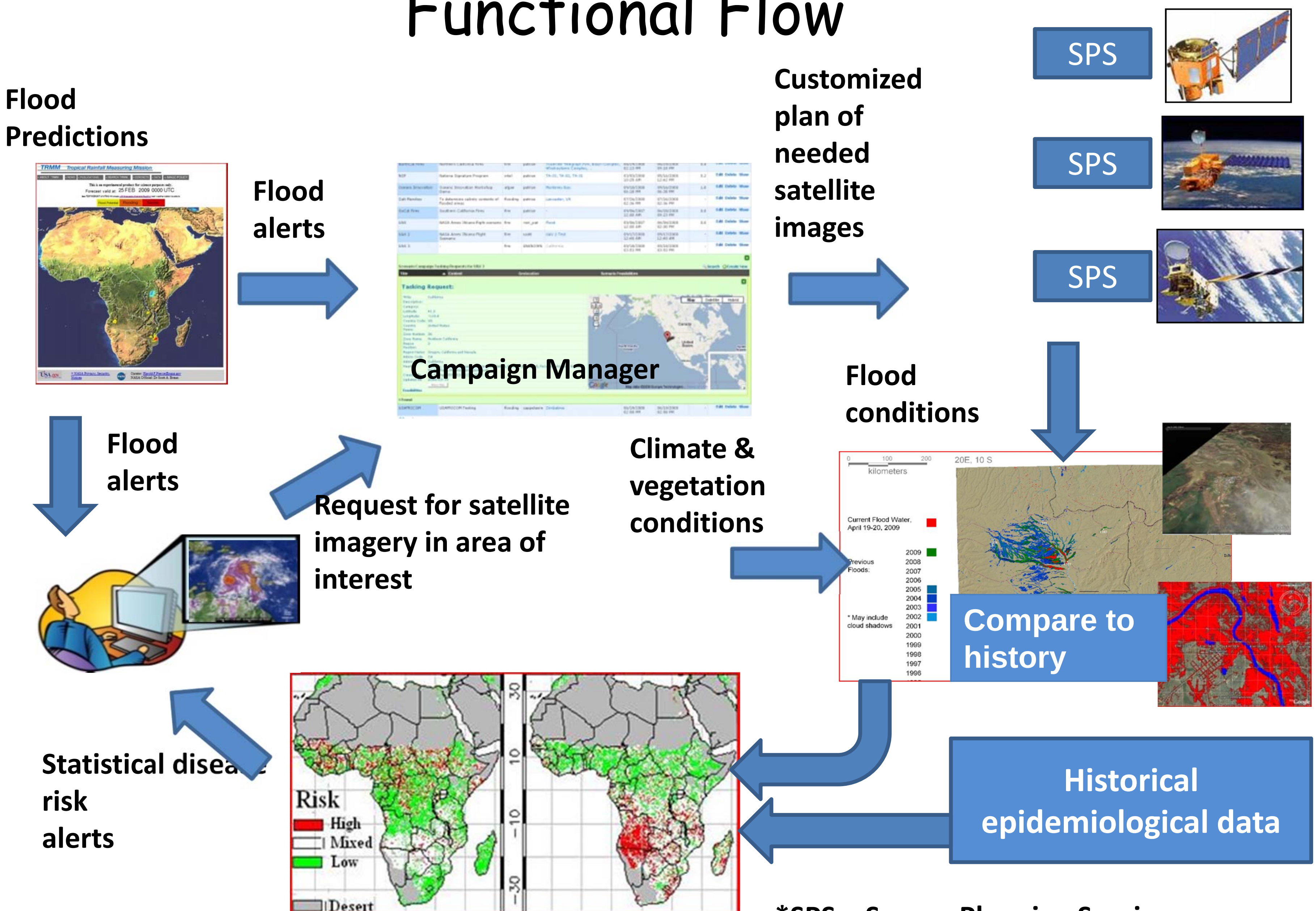
Detect: TRMM rainfall estimate monitored upstream, AMSR-E based Riverwatch used to monitor river widths, daily MODIS flood extent maps
Respond: Trigger EO-1 and Radarsat imagery based on detection of triggers
Product Generation: MODIS daily flood extent overlays, EO-1 flood extent overlays, river gauge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

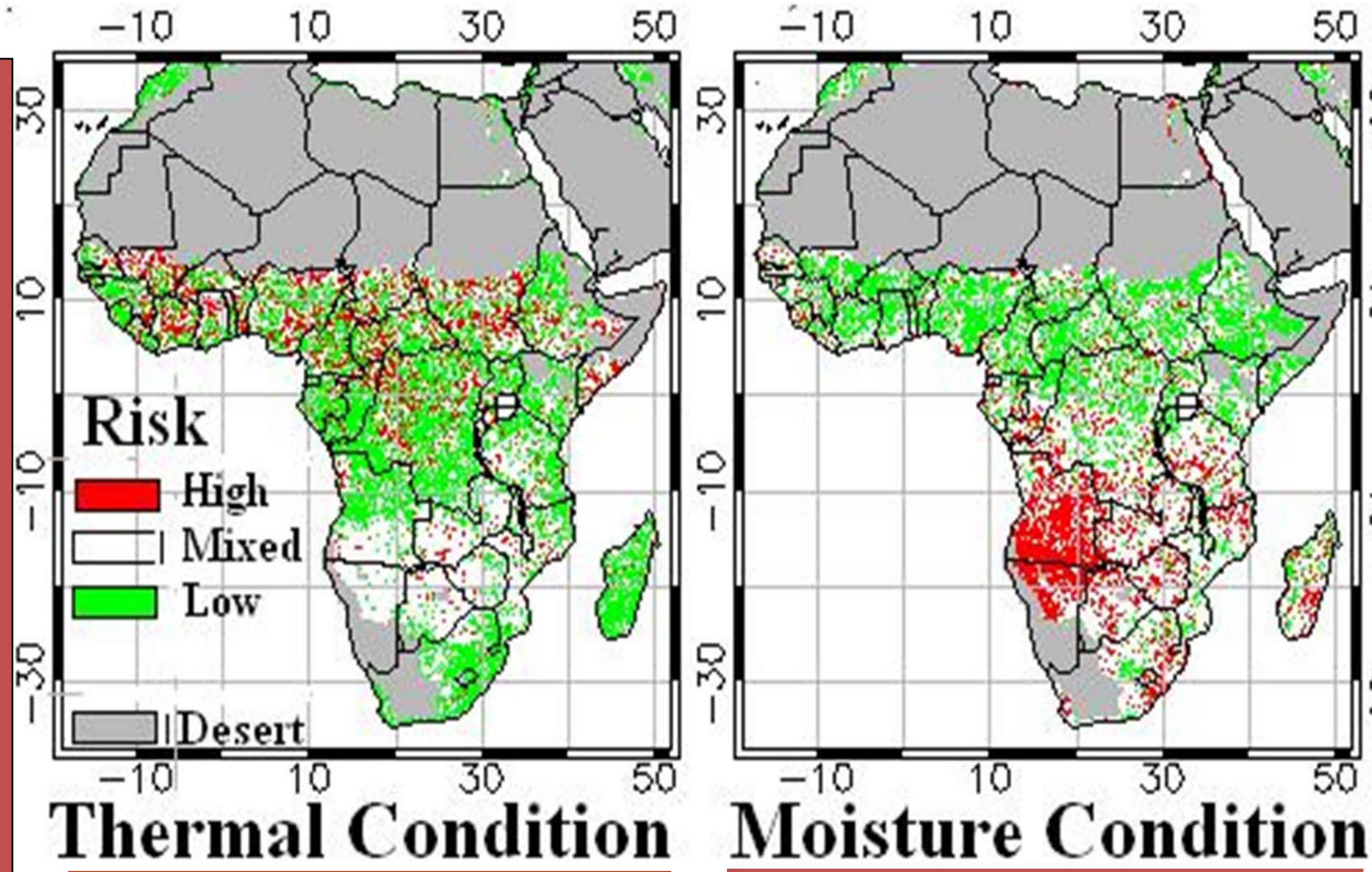
Top Level Water Borne Disease SensorWeb Functional Flow



*SPS – Sensor Planning Service

Strategy: WEATHER PROXY
AUGUST 26, 2008

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

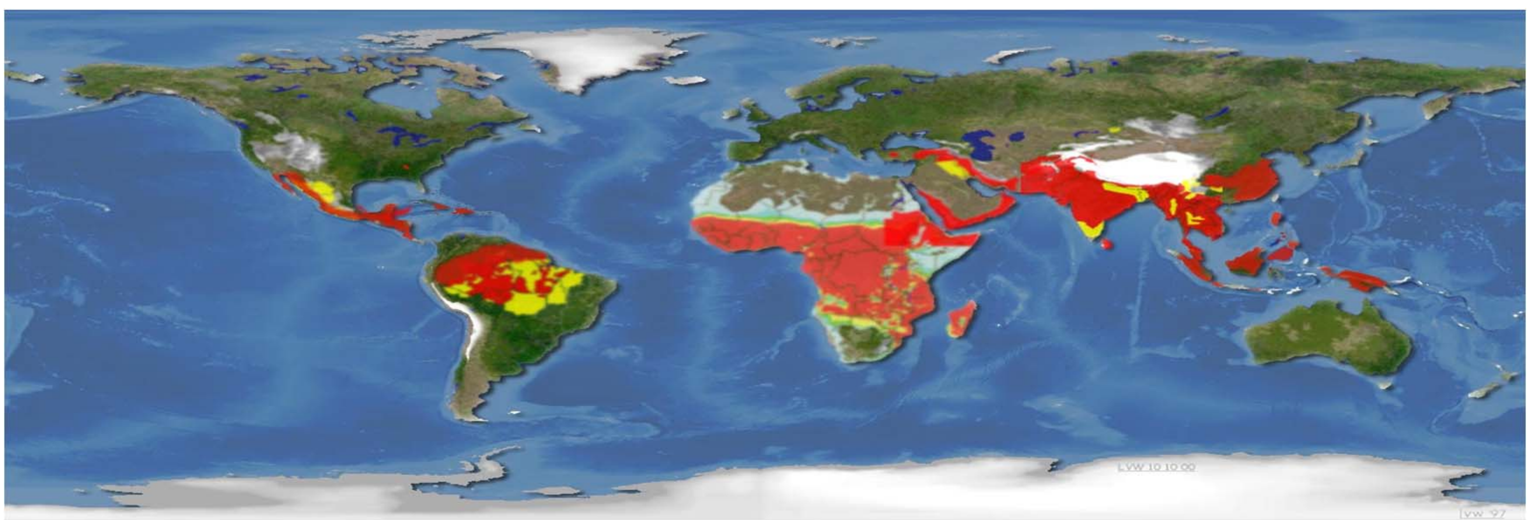


INTENSIVE MALARIA

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

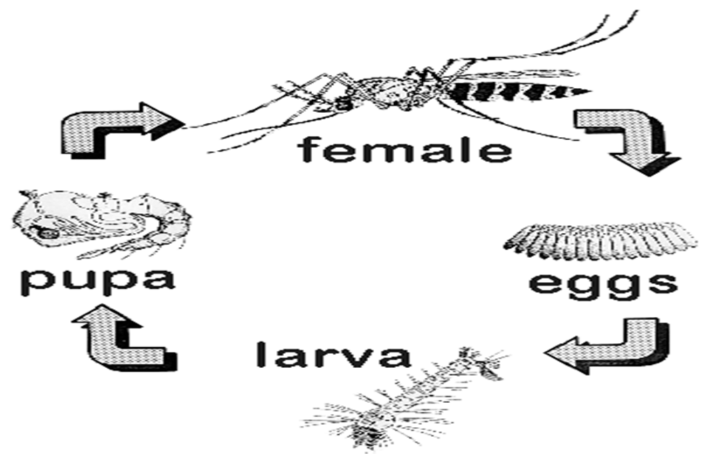
Malaria

- 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

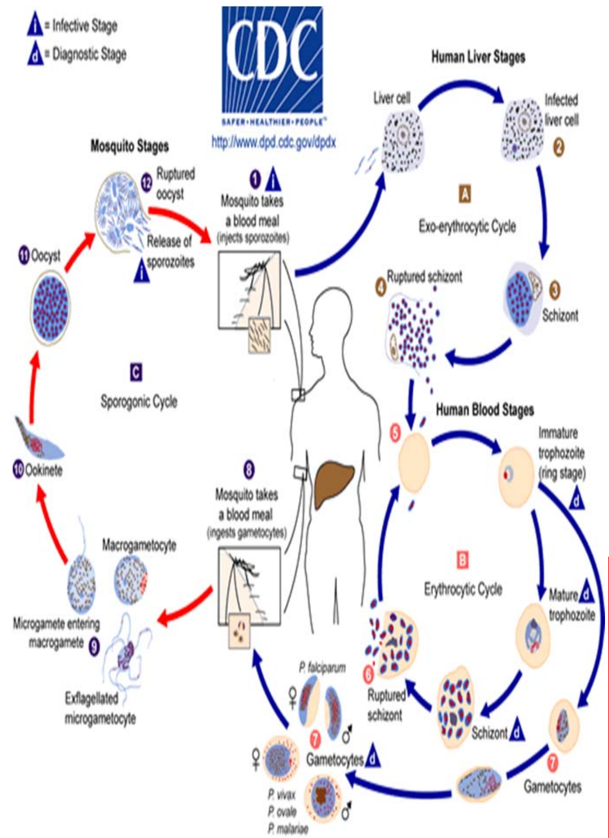


larvae lie along the water-air interface

Malaria Parasite

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

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



Malaria parasite life cycle

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

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

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 40^0 C

Data

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

Malaria Data

Malaria Statistics (Ministry of health)

Performance Indicator

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

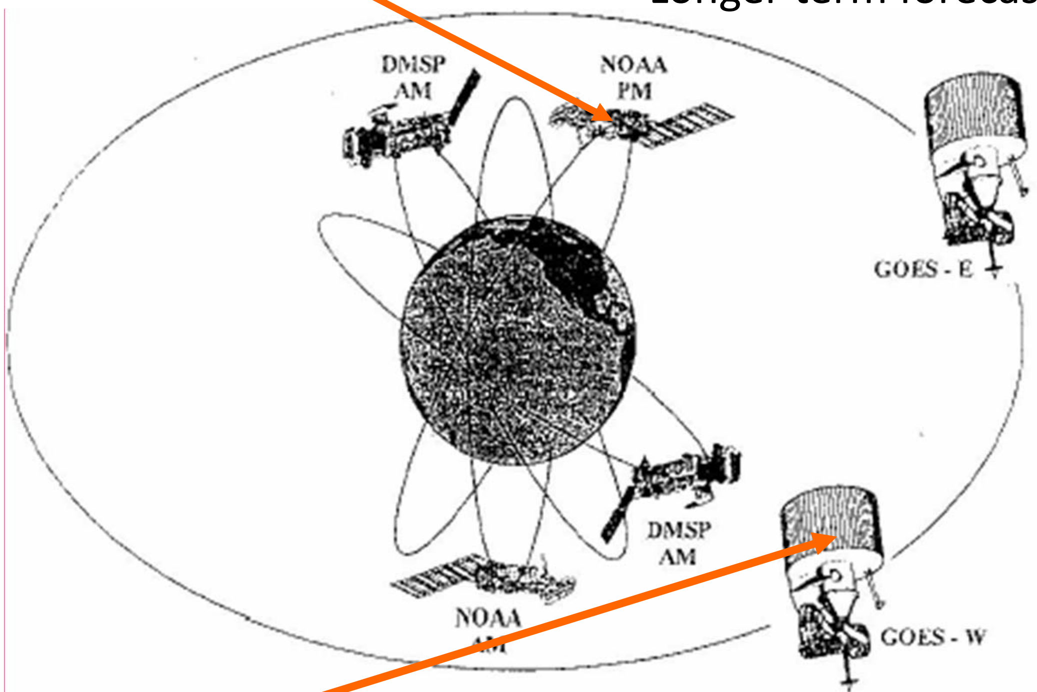
$$\text{Slide Positive rate (SPR)} = \frac{\text{Number of blood smears positive for malaria Parasite in a year}}{\text{Number of Blood smears examined}} \times 100$$

Number of positive cases of malaria from all patient with fever visited hospital

NOAA Operational Environmental Satellites

860 km altitude
north—south orbit
sun synchronous
1:40 p.m pass equator
Longer term forecasting

polar orbiting satellites



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:

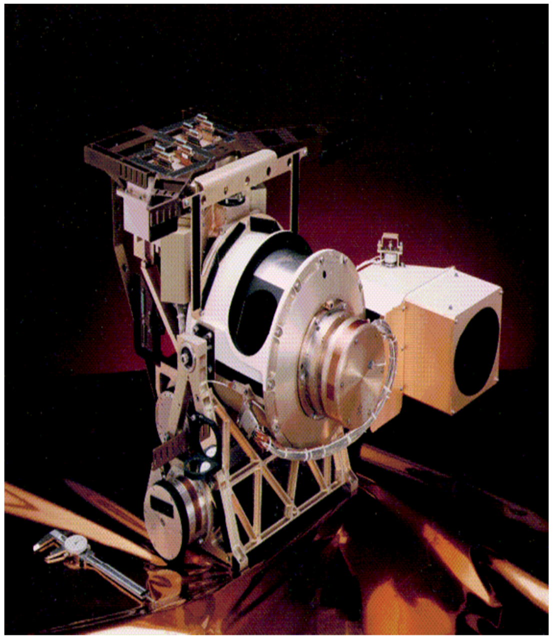
Spatial - 4 km GVI, sampled to 16 km;
Temporal - Daily sample 7-day composite

Period: 1981-2009

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

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

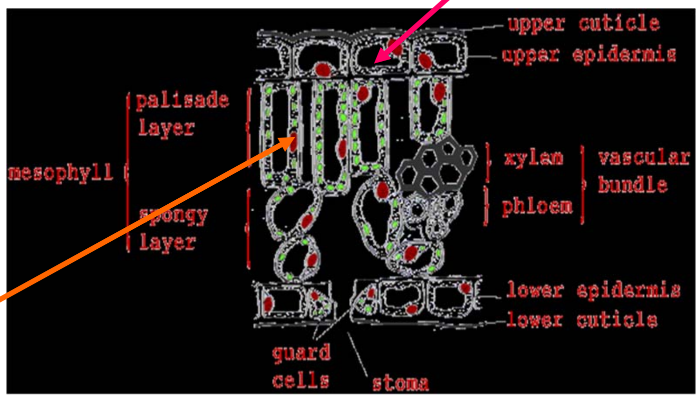
Radiation detection imager used to detect earth surface temperature

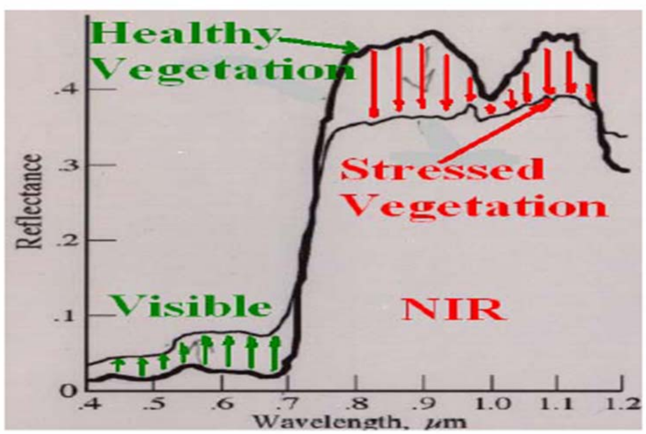


AVHRR Reflectance

Chlorophyll controls much of spectra response in visible part of spectrum

Inner Structure Controls NIR spectral Response





NDVI = (NIR-VIS)/(NIR + VIS)

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

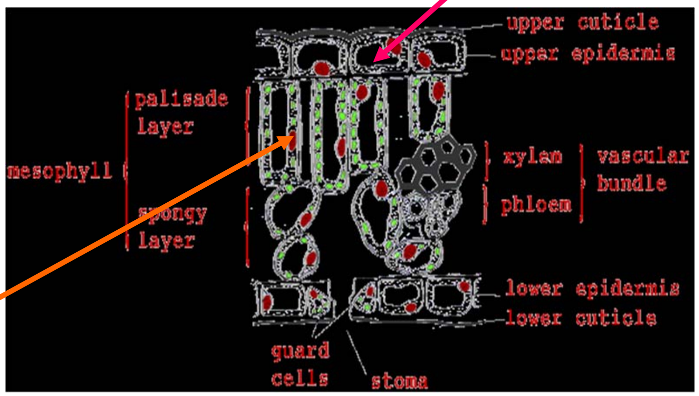
Derivation of 24-year climatology

Derivation of indices

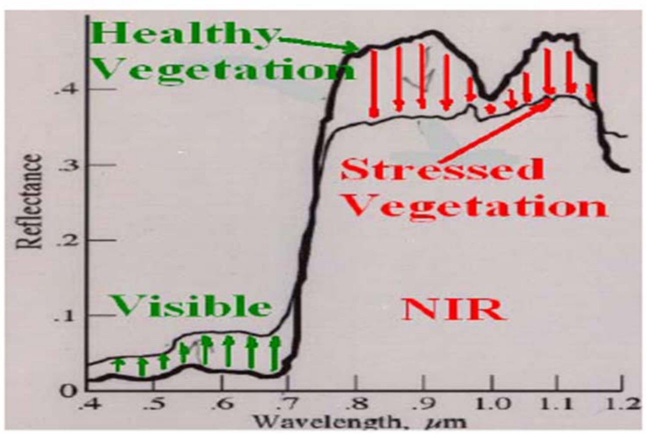
- Vegetation Condition (VCI)
- Temperature Condition (TCI)
- Vegetation Health (VHI)

AVHRR Reflectance

Chlorophyll controls much of spectra response in visible part of spectrum

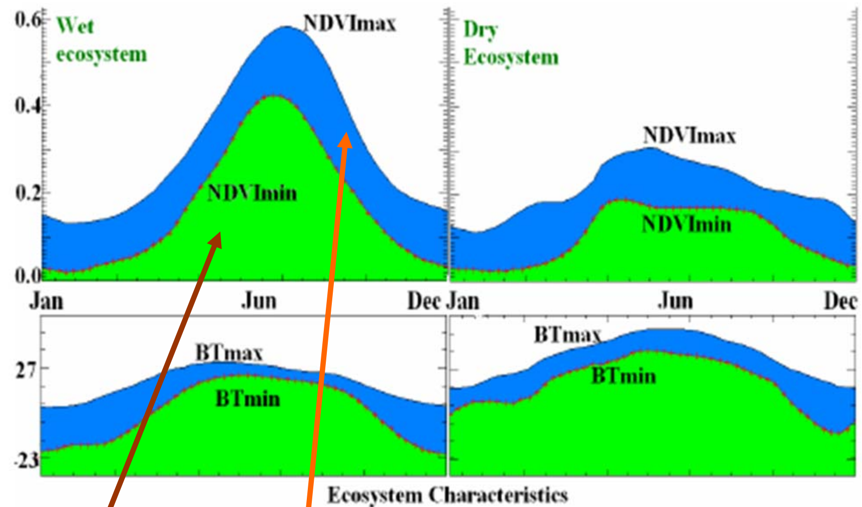


Inner Structure Controls NIR spectral Response



NDVI = (NIR-VIS)/(NIR + VIS)

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

Vegetation Health Indices and Algorithm

- Normalized Difference Vegetation Index

  NDVI= (CH2- CH1)/(CH2+CH1)

- Vegetation Condition Index (VCI)

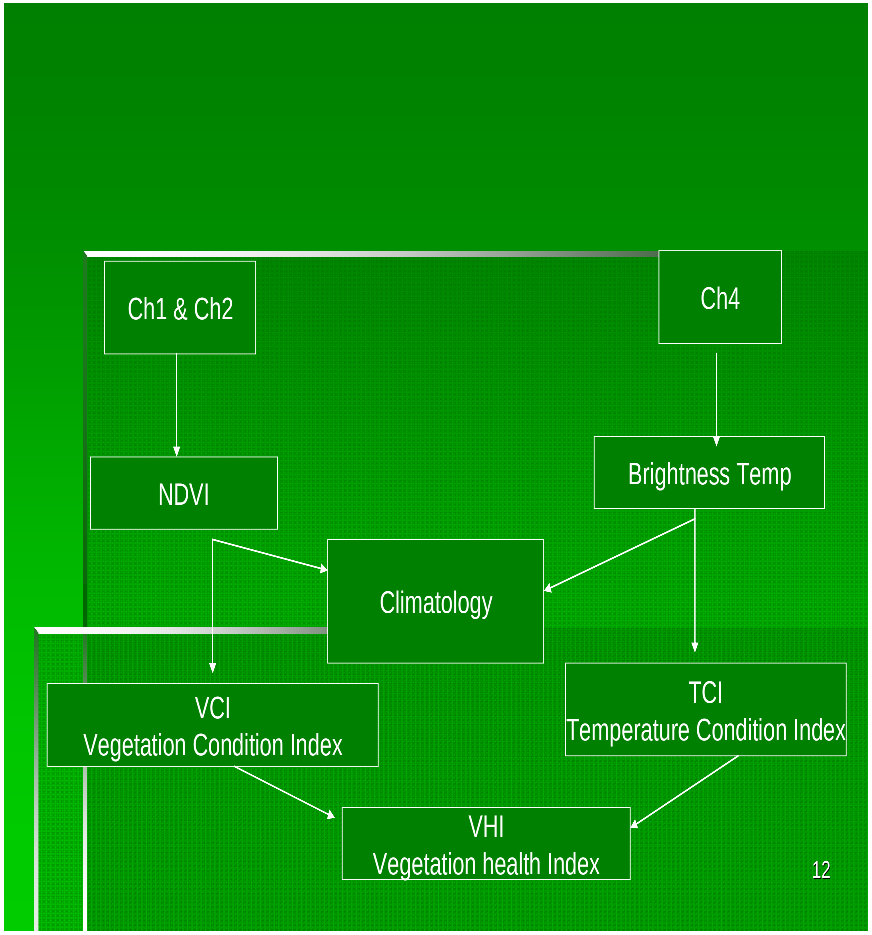
  VCI=100*(NDVI – NDVI min)/ (NDVImax – NDVImin)

- Temperature Condition Index (TCI)

  TCI=100*(BTmax – BT)/ (BTmax – BTmin)

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

$\mathbf{T_t = a_0 + a_{1*}\, t_{year}}$

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

$\mathbf{DY= (Y_{actual} / T_t)*100}$

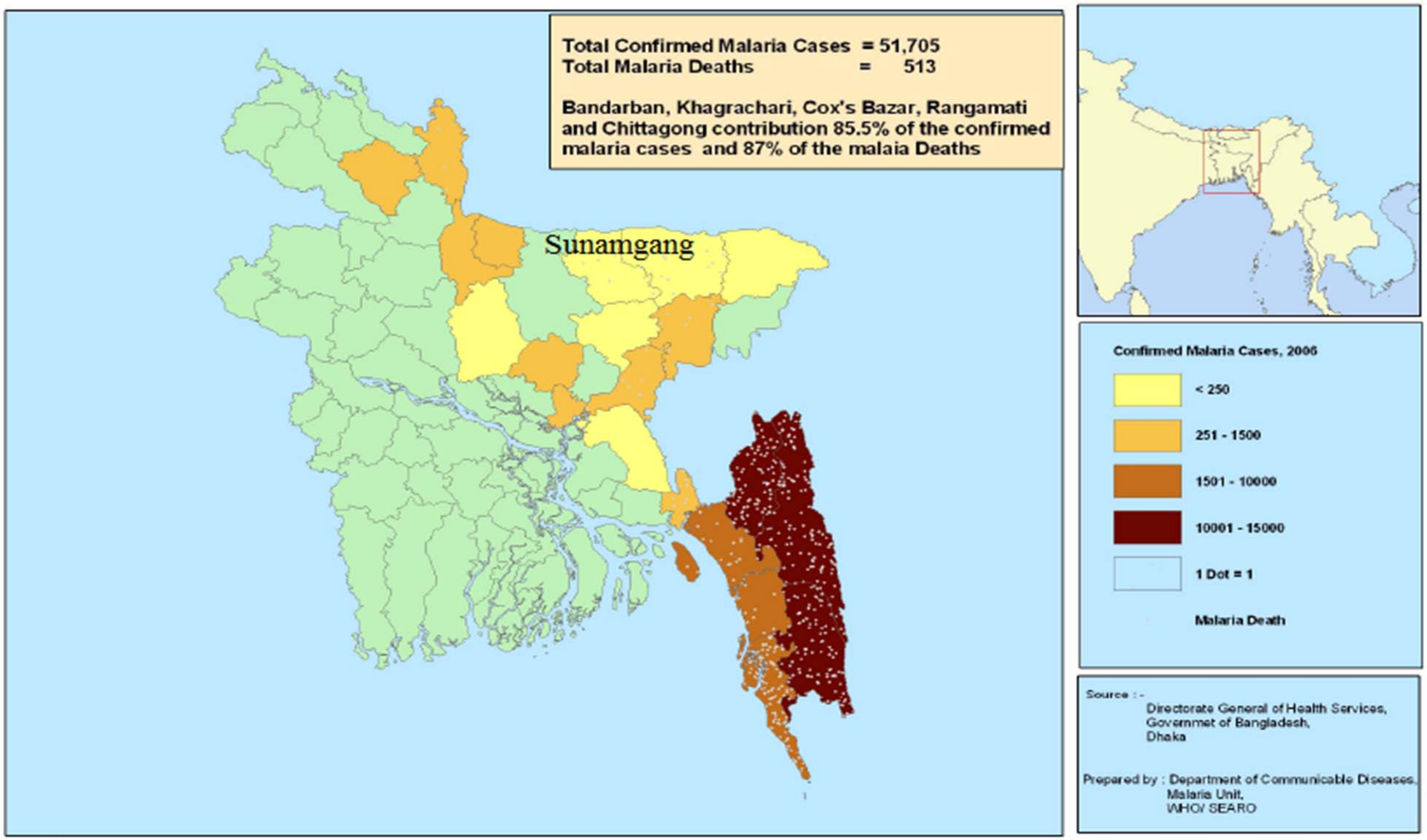
random component regulated by weather fluctuations (Deviation around trend line)

Correlation Dynamics

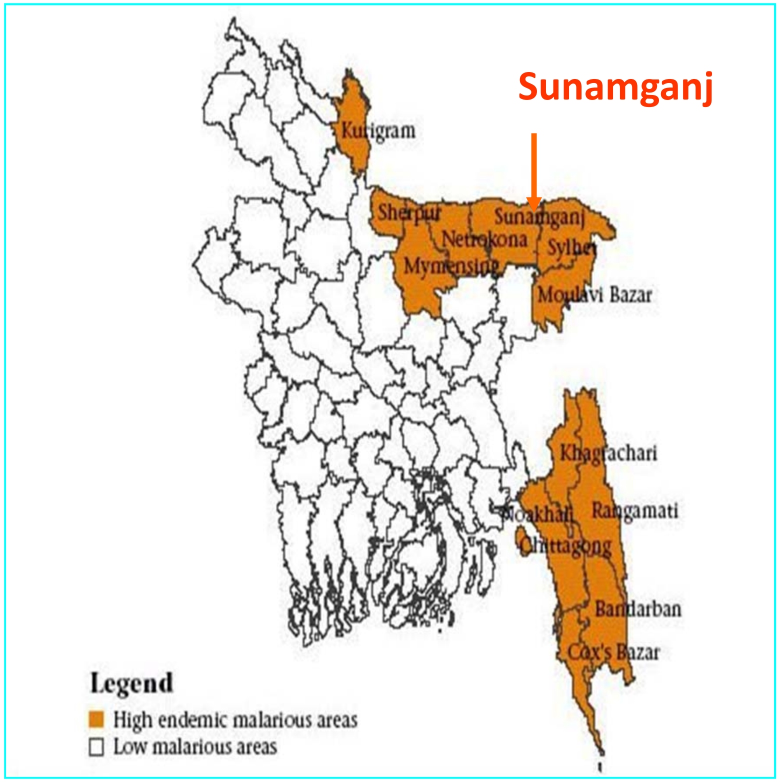
Correlation of 13 years (depends on Malarial data) of Deviation from Trend Line (DY) with 13 years of thermal and moisture condition indices (TCI and VCI) for all 52 weeks are calculated, Level of inundation has been correlated with Malaria for 365 days all 13 years

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



Malaria endemic districts of Bangladesh



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

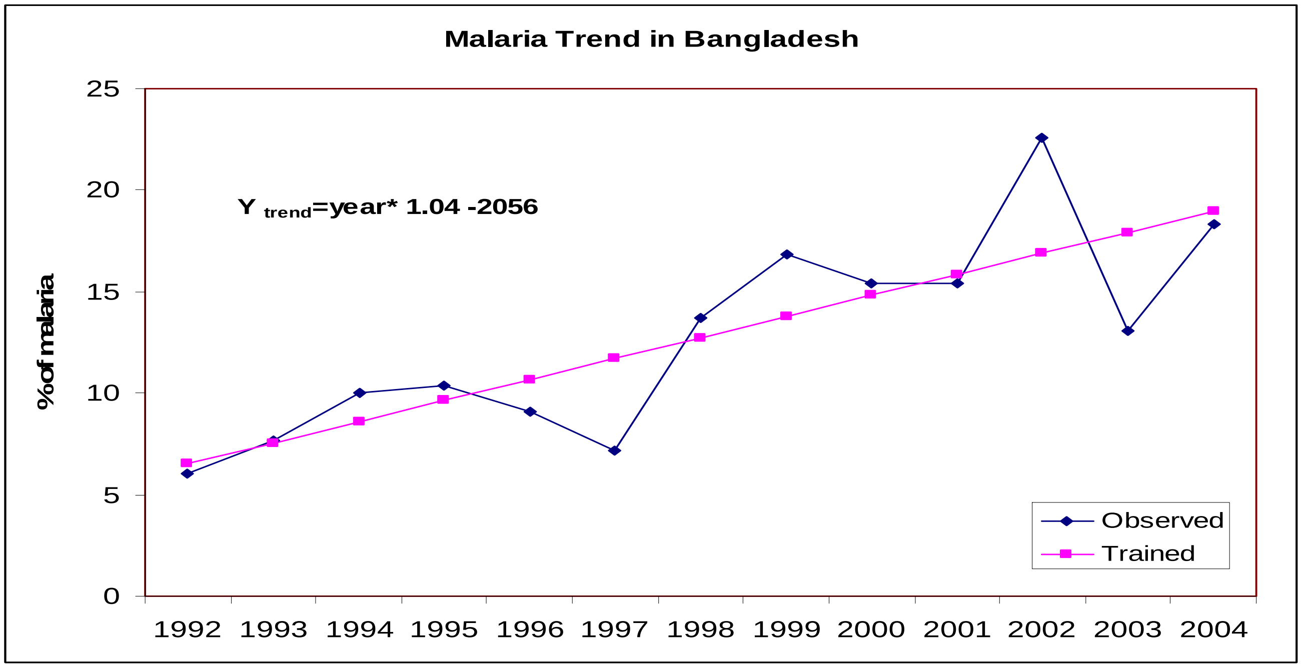
Climate of Bangladesh

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

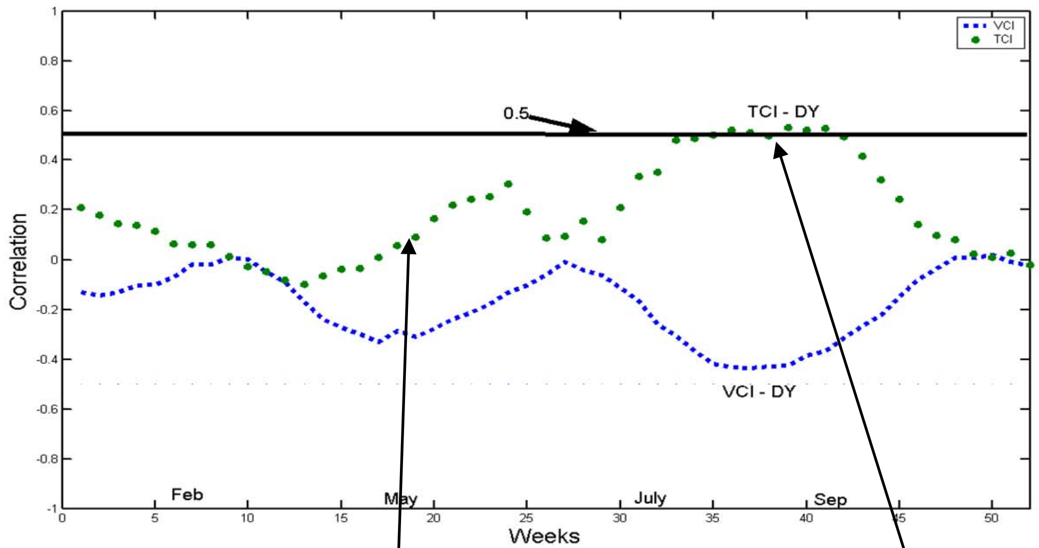
Bangladesh_Situation

- 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

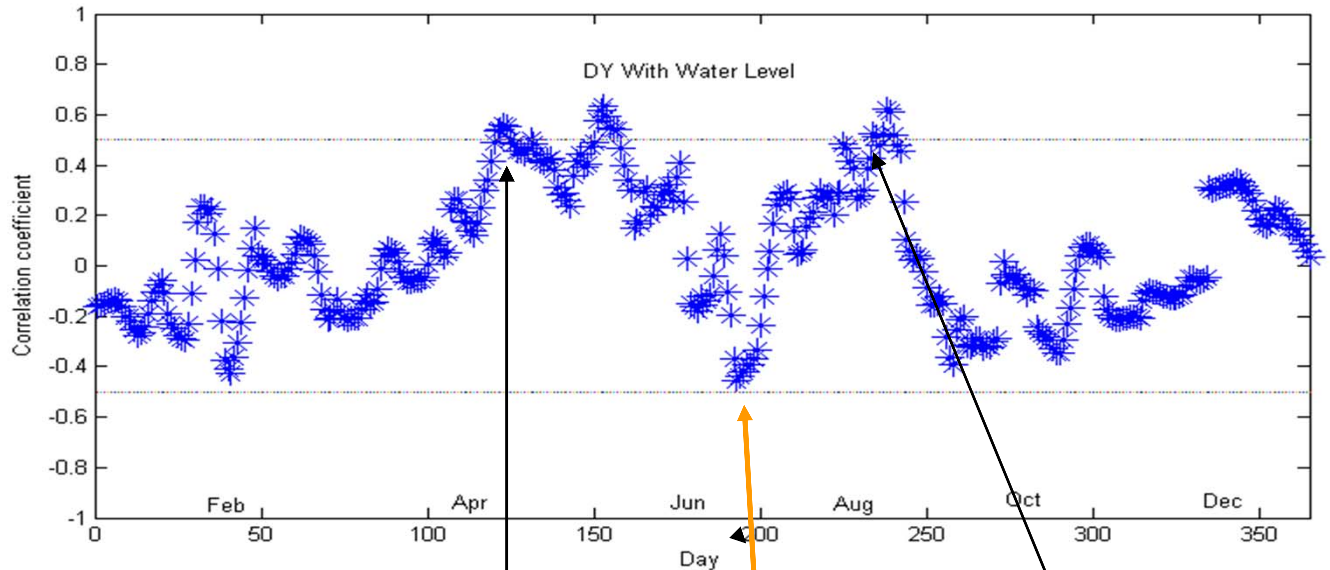


Malaria season

Pre monsoon
Not correlated

Post monsoon
Correlated

Correlation dynamics of DY versus Water Level at Sunamgong



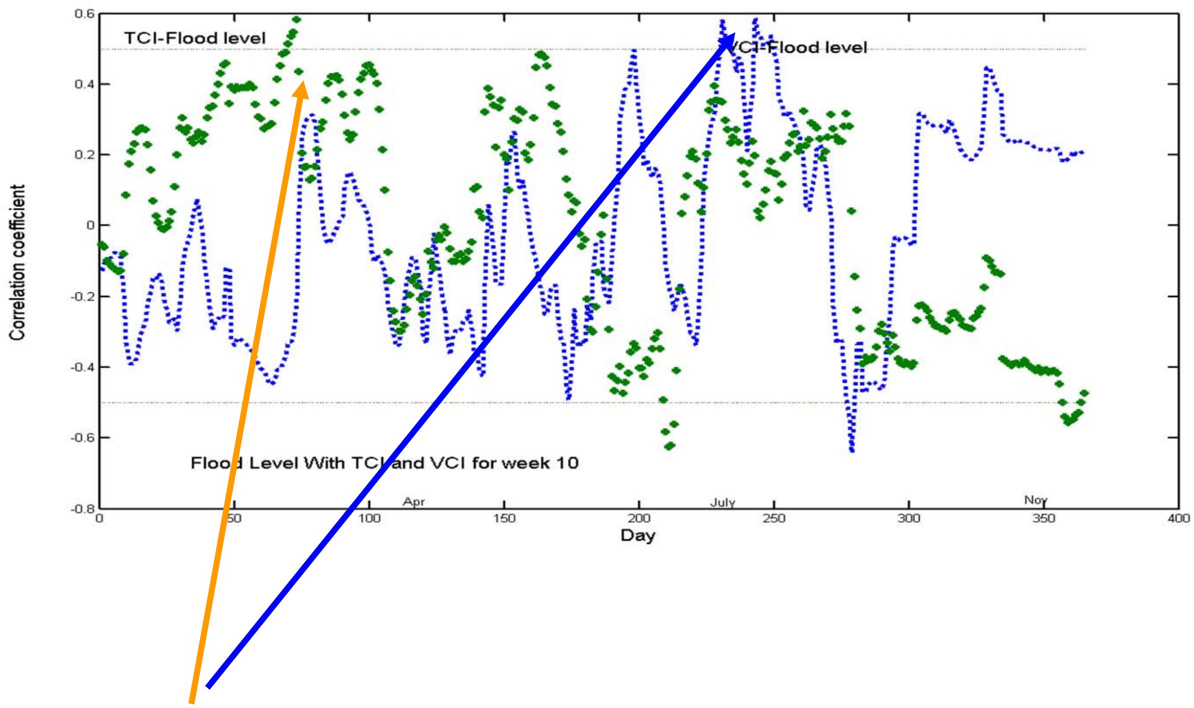
Malaria season

Pre monsoon Correlated

Post monsoon Correlated

Too much Flood
Wash away malaria Larva
Negatives correlation

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

$DY=b_0 +$

Small Tolerance
High variance inflation
P>10%

Variable	Parameter Estimate	Variance 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	0.8855	0.65676	1.52262

Correlation matrix

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

	TCI34	day120	VCI34
TCI34	1	0.146	-0.2221
day120	0.146	1	-0.5688
VCI34	-0.2221	-0.5688	1

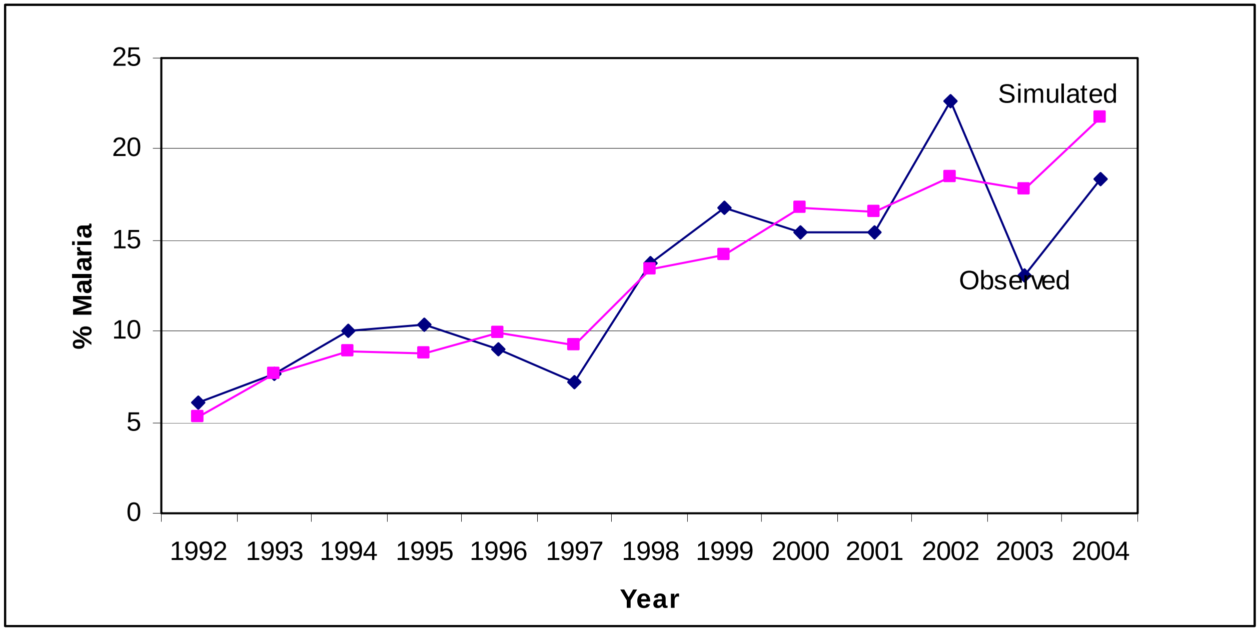
Principal Component Regression

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

Variable	Parameter Estimate	Standard 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

Back Up Slide