Development of a Detection and Early Warning System for Malaria in the Amazon

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Overview

Background
Malaria in the Amazon
…in Peru

Objectives & Data
Framework
Results
Conclusions

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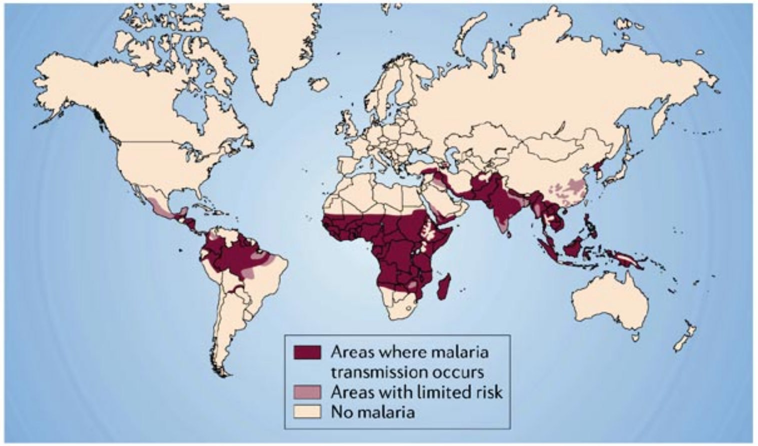
Malaria
Global Extent & Background



100 Countries, >2.3 **billion** at risk

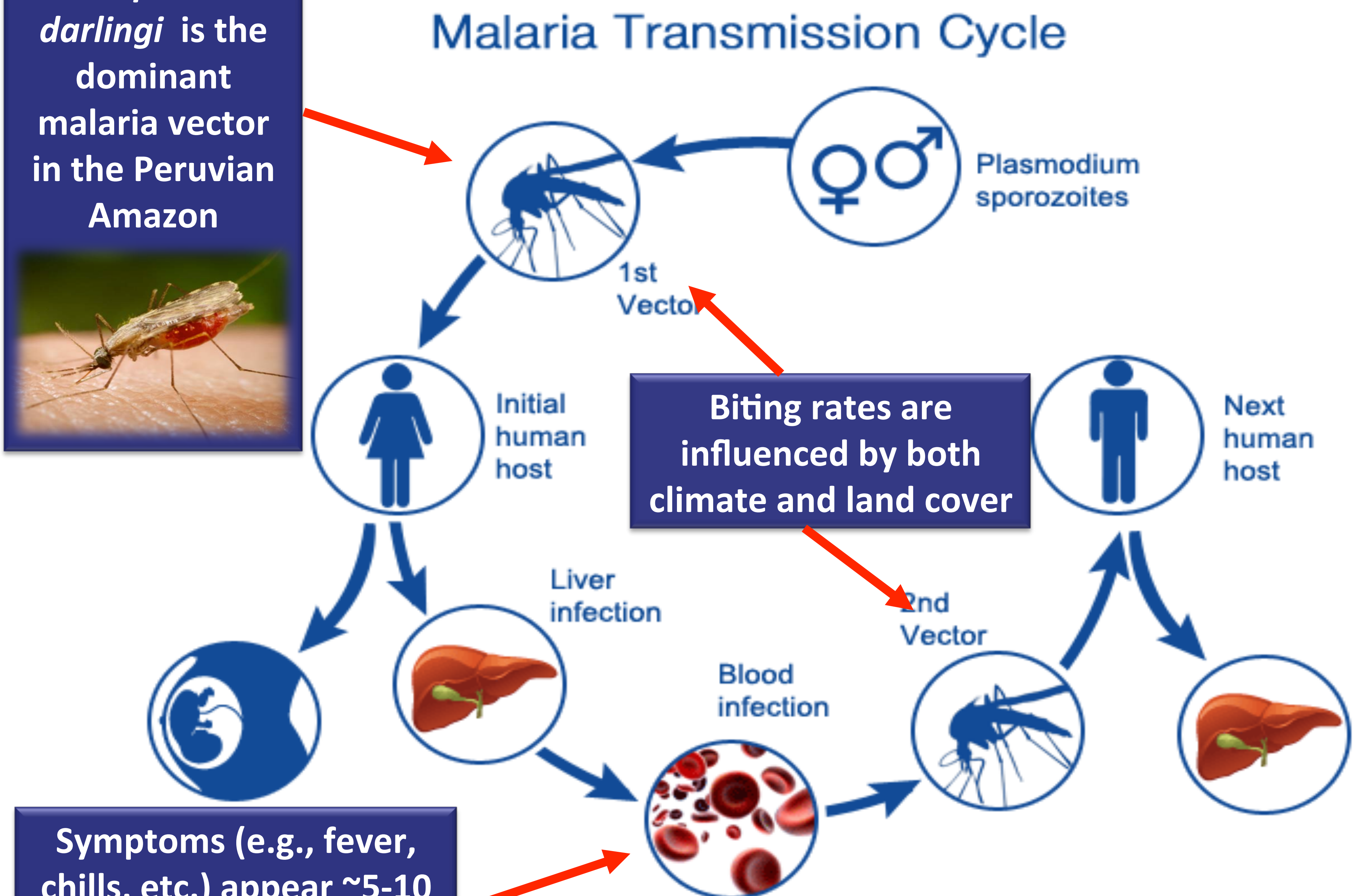
- 300-500M people infected annually
- 1-3 million deaths each year
    - 90% of mortality in children < 5

Occurs mostly in Africa, Asia, and Latin America

4 malaria species (identified in 1889) : *Plasmodium falciparum*, *P. vivax, P. ovale, P. malariae*

Spread person-person by **female** *Anopheles* mosquito (Ross discovered vector in 1897)

Anopheles darlingi is the dominant malaria vector in the Peruvian Amazon



Biting rates are influenced by both climate and land cover

Symptoms (e.g., fever, chills, etc.) appear ~5-10 days after being bitten by an infected mosquito.

Malaria in the Amazon

60-80% of malaria in the Americas is *P. vivax*

- Dominican Republic & Haiti are almost exclusively *P. falciparum*

95% of cases in the Americas occur in Amazon basin countries

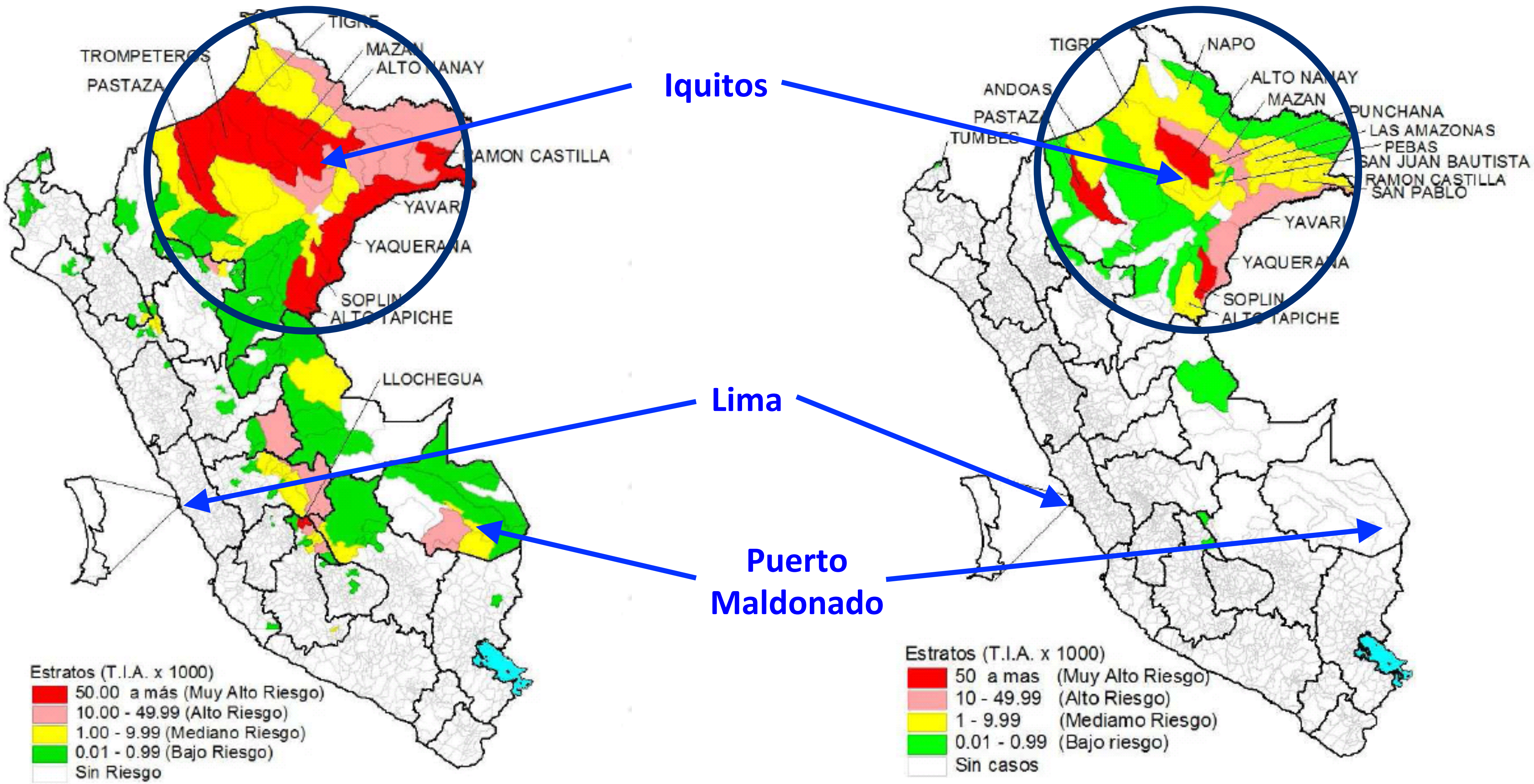
Confirmed cases declined 66% from 2000 to 2010 in the Amazon

In 2011 (Amazon only):

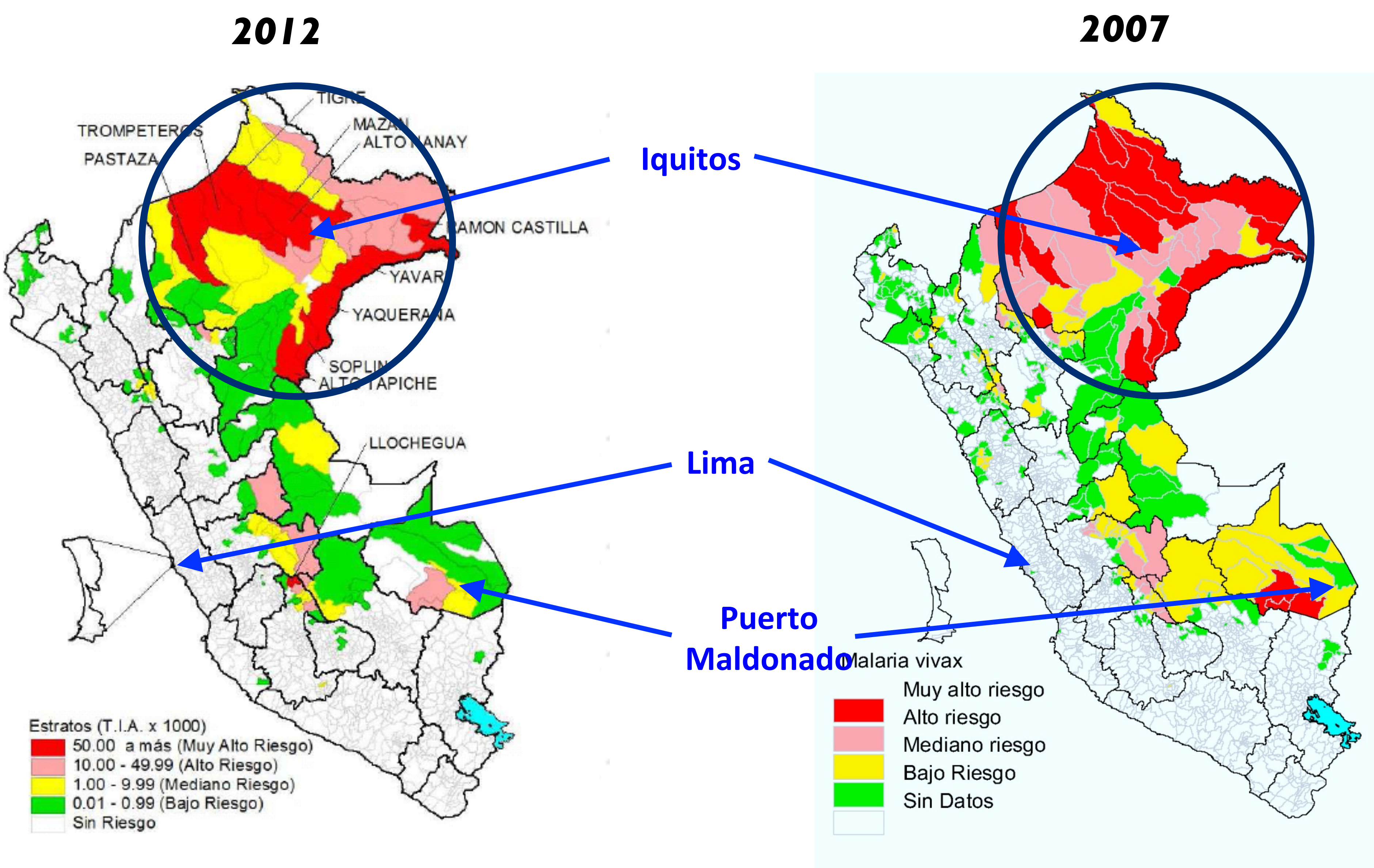
- 30% of the population live in areas of transmission risk
- 80% of cases reported in Brazil or Colombia
- Guyana, Colombia, Suriname – highest rates of infection (10-30 cases/ 1000); Ecuador, Bolivia, Peru – lowest rates (0.5-2.5 cases / 1000)

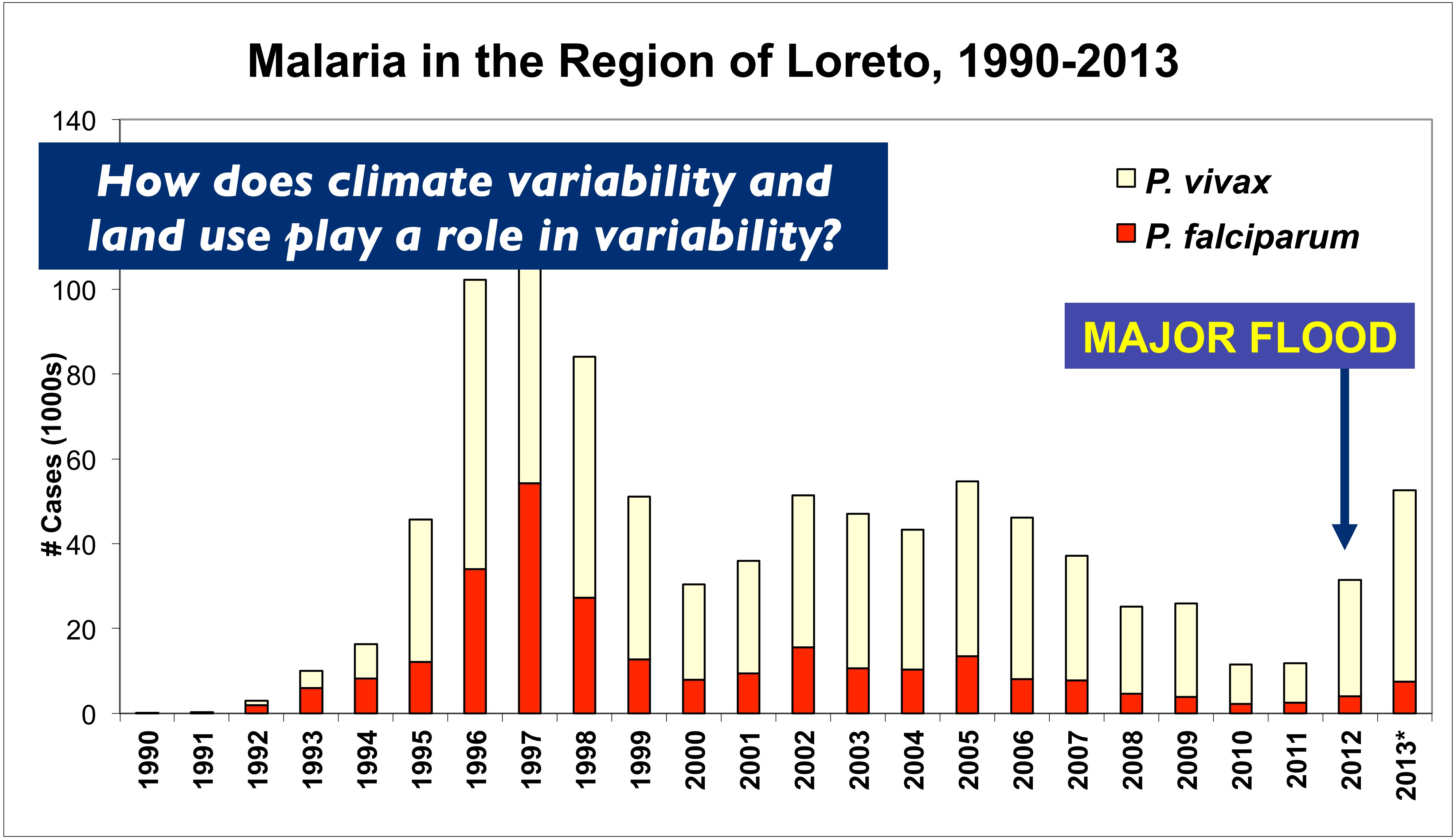
Malaria in Peru, 2012

P. vivax ***P. falciparum***



P. vivax malaria, 2012 vs. 2007





Highest Deforestation Rate in Peru

Iquitos-Nauta Road Paving & Fujimori logging concessions

Roll Back Malaria

61% decline 2000-2010

79% decline 2006-2010

Objectives

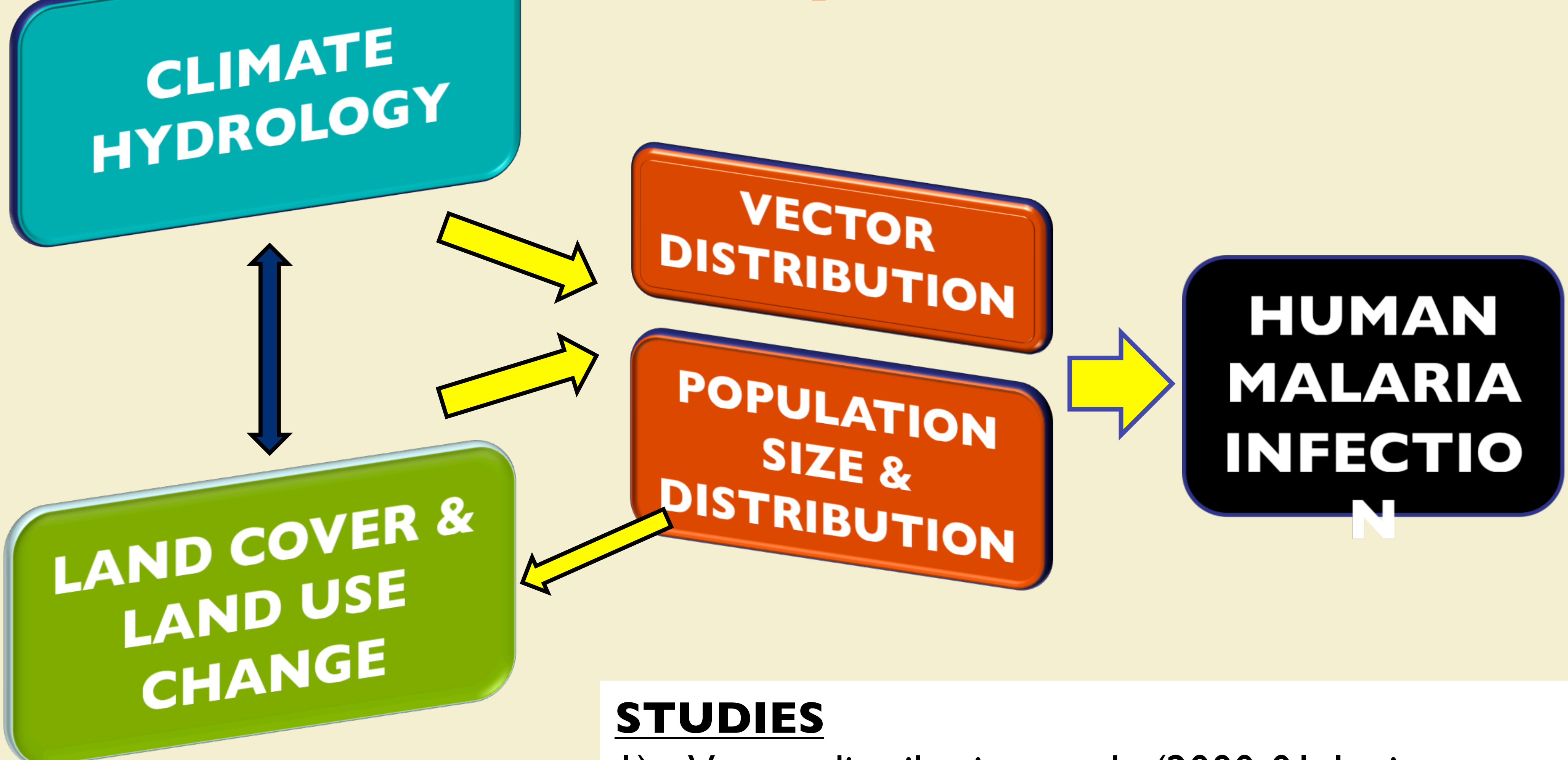
(1) Identify the relationship between climate, land use and malaria in Loreto between 2001 and 2011

(2) Develop a predictive model that improves spatial and temporal forecasting of malaria cases (~4-8 weeks in advance)

(0.1) Develop small-scale models of malaria vectors (*Anopheles* mosquitoes) as a function of land cover, hydrometerology, and human population

(0.2) Evaluate up- and down-scaling of aggregate vs. individual (human) estimates of malaria risk

Analytical Framework



STUDIES

1) Vector distribution study (2000-01, Iquitos-Nauta Road)
2) Vector distribution & Human malaria (2008-13, Iquitos-Mazan Road & Napo River)
3) District-level malaria modeling

VECTOR MODELS

- **October 2000-September 2001**
  - Larval & Adult *Anopheles* collection every 3 weeks
  - ~60 locations along the Iquitos-Nauta Road
  - Land cover, Climate, Site-collection characteristics
  - Simultaneous Bayesian equations
- **March 2009 – September 2013**
  - Adult mosquito collection every 2 weeks
  - 20 locations on Iquitos-Mazan Road; 8 communities Napo River; 8 communitions Mazan River
  - Annual human surveillance
  - Multilevel Spatial Poisson Models

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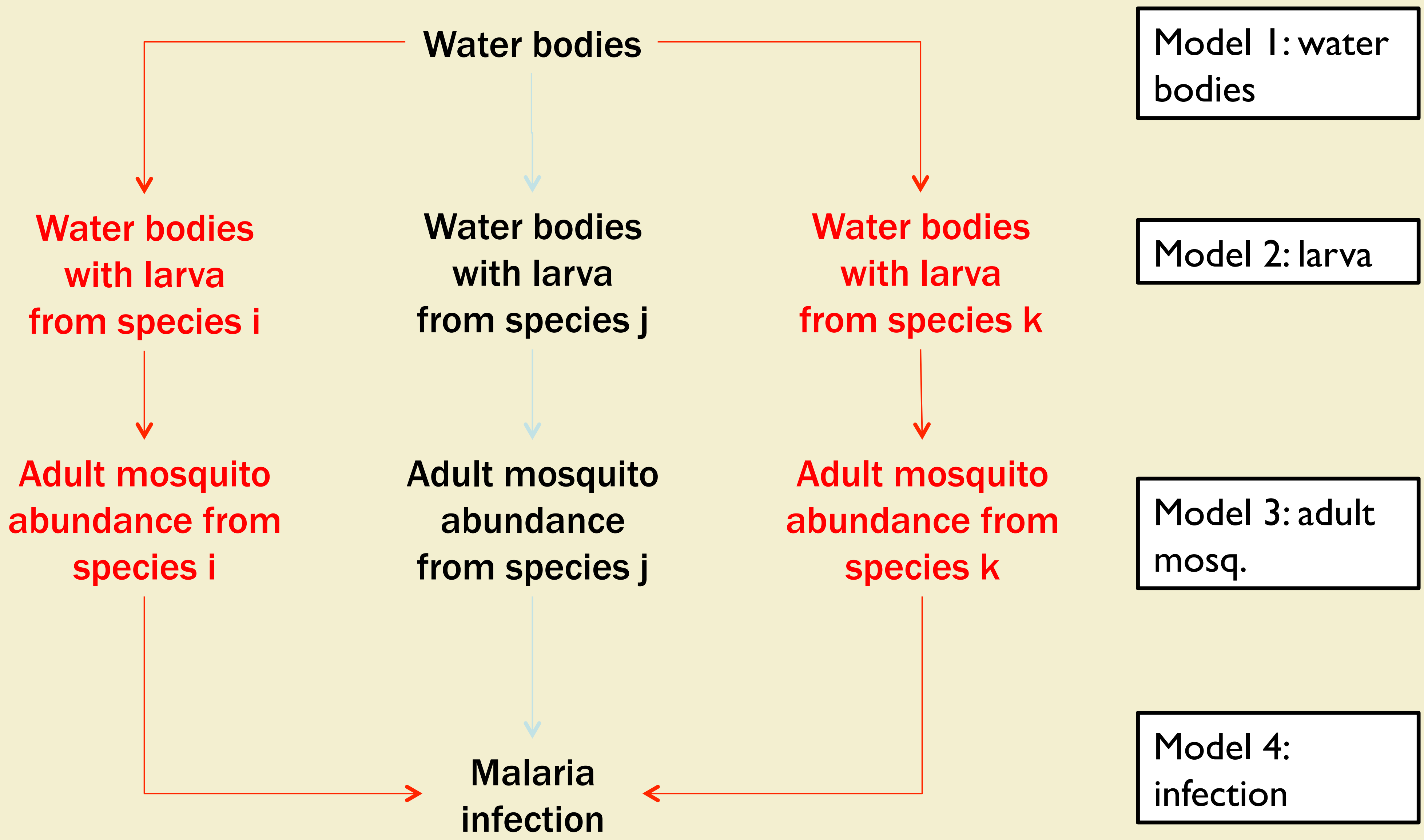
2000-2001 Models



Dissertation work by Denis Valle
Data from Amy Vittor

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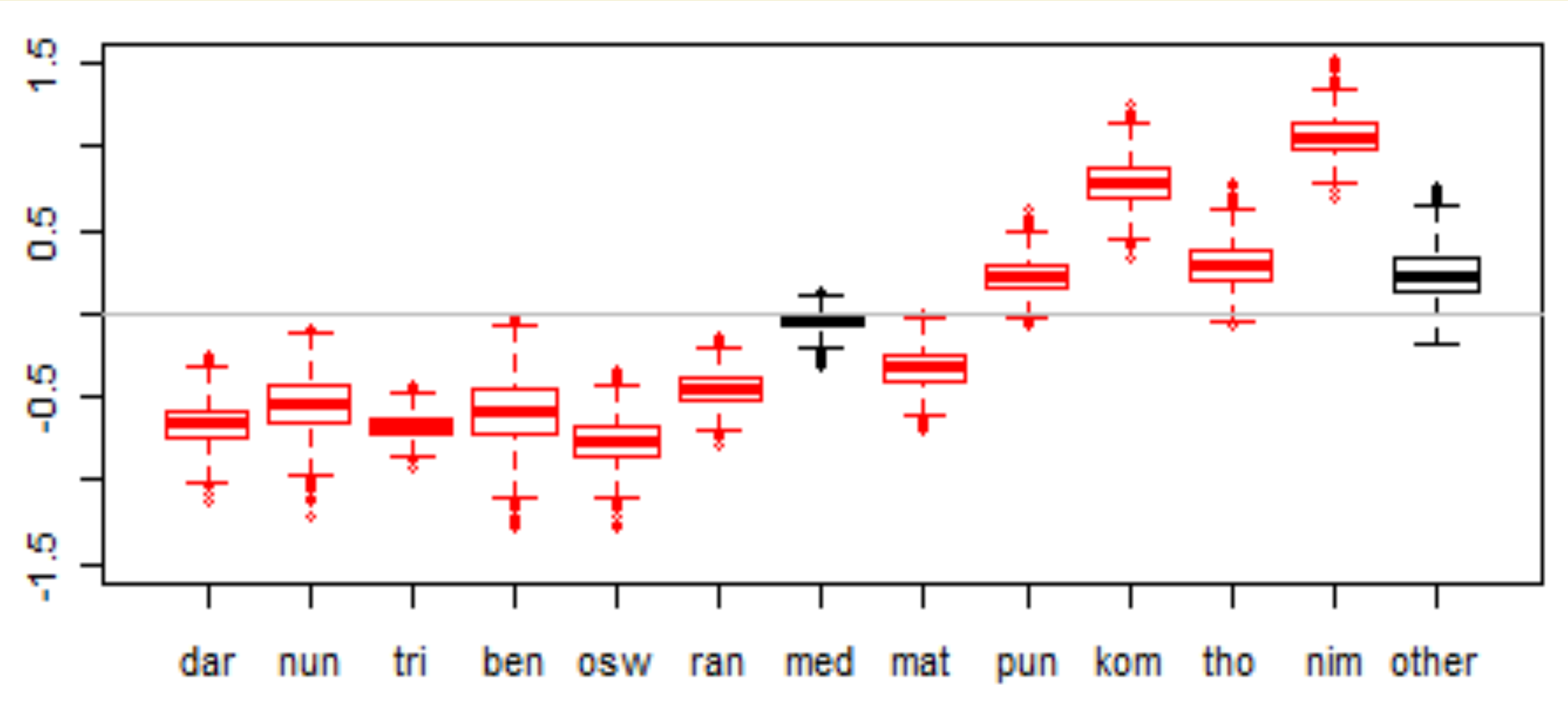
Preliminary Results

Forest Cover (larva):



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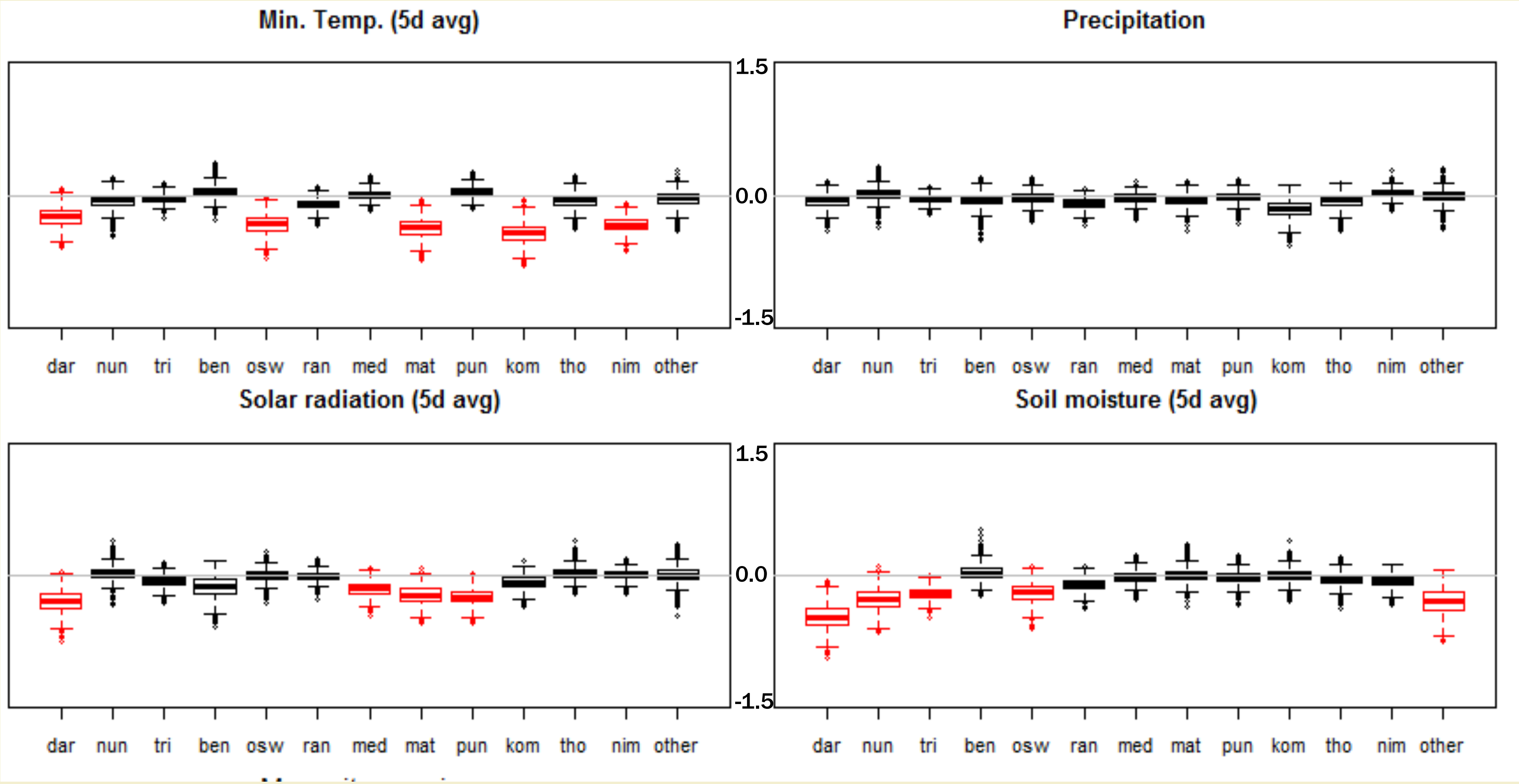
Preliminary Results

Hydrometeorology (larva)



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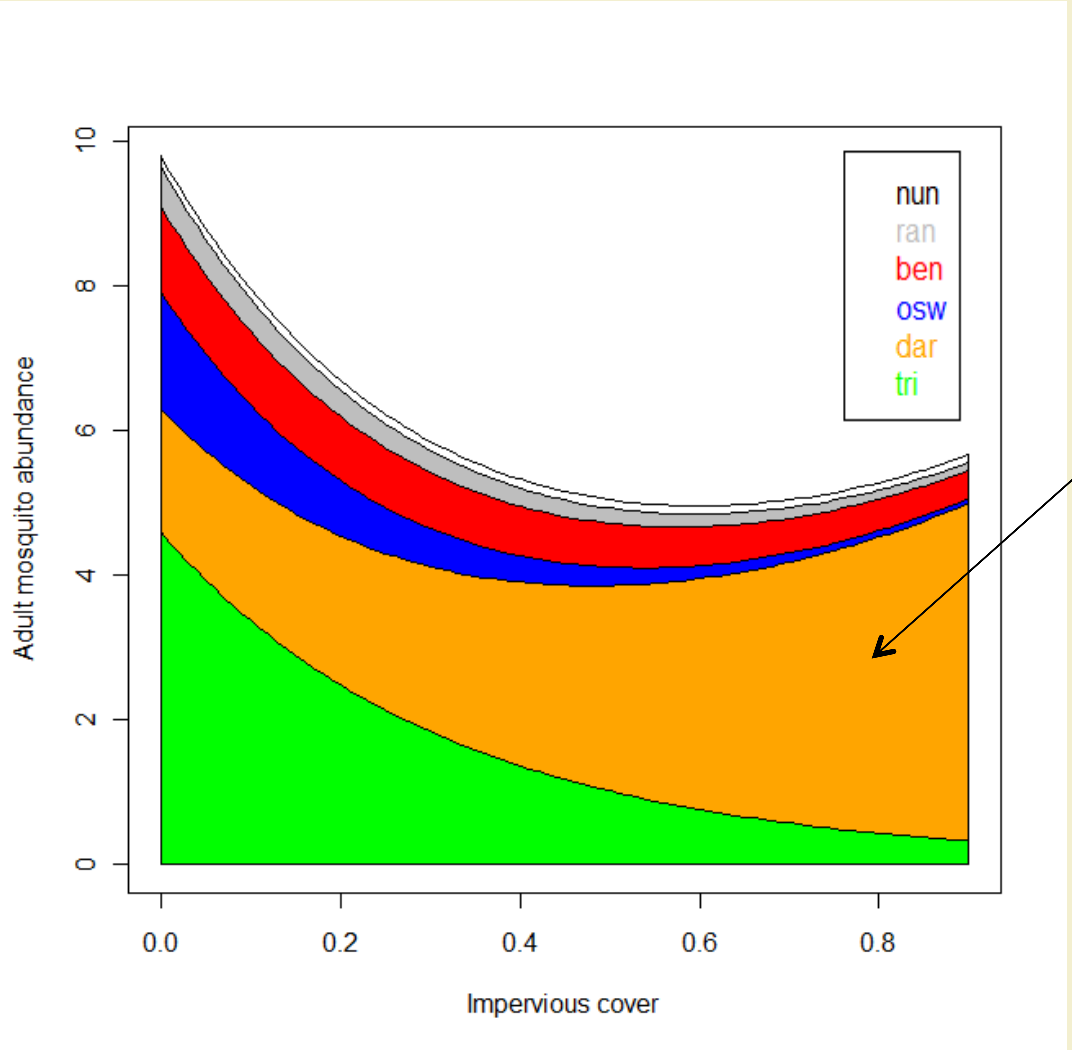
Preliminary Results

Impervious Area (Adults)



Anopheles darlingi

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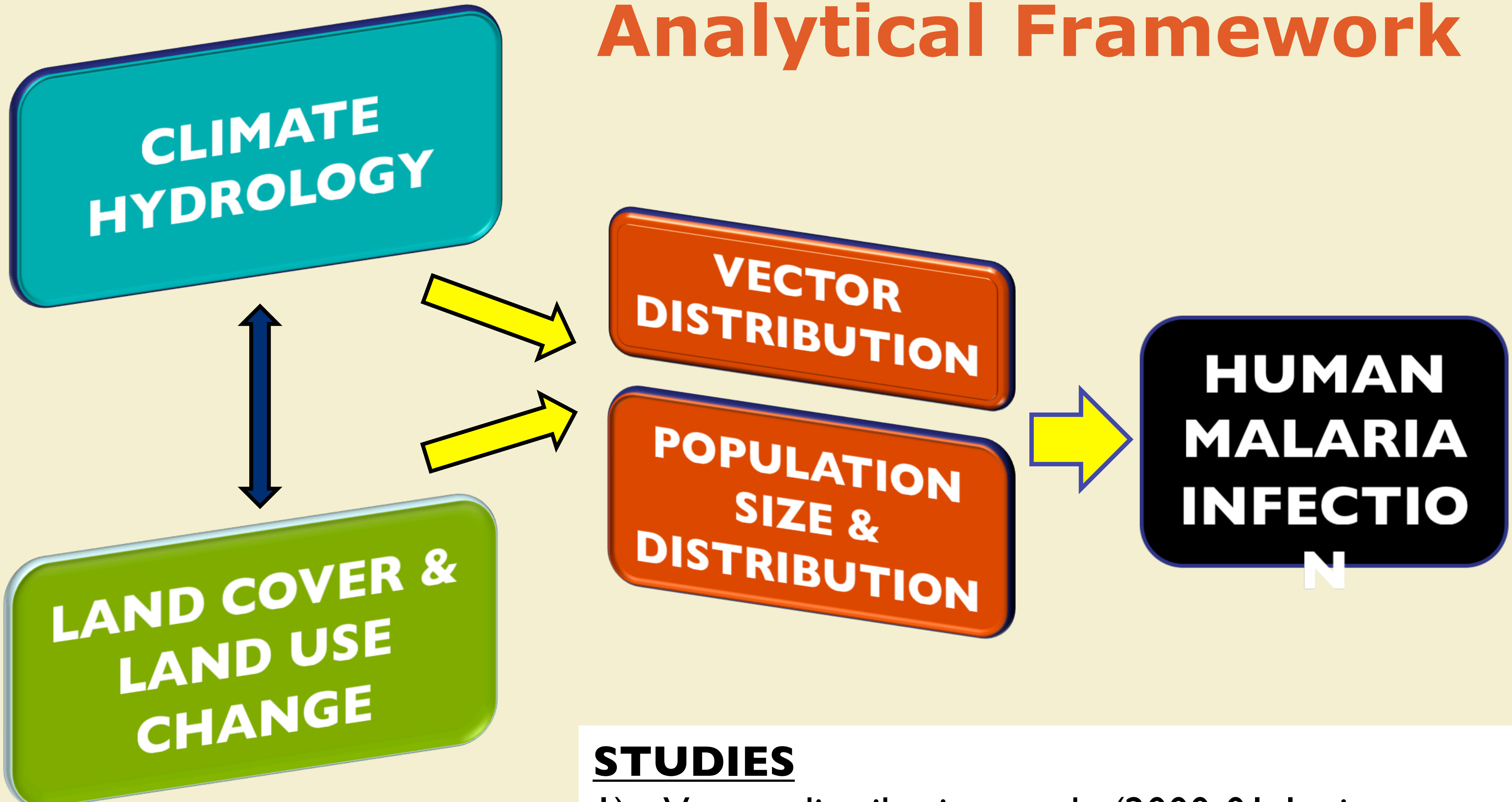
Analytical Framework



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DATA OVERVIEW

- **Weekly malaria counts** from ALL Government Health Posts (n=356) between 2001 and 2011
  - Aggregated to administrative district (n=51) due to geographic misalignment of surveillance and political administrative systems
- Satellite-derived **weekly climate & soil parameters**
  - LDAS – *Land Data Assimilation System* – to create measures of precipitation, temperature and soil moisture
- **Land cover**
  - Both EcoRegions and land cover from NatureServe
- **Census population** data from 2007 & population estimates between 2005 and 2011

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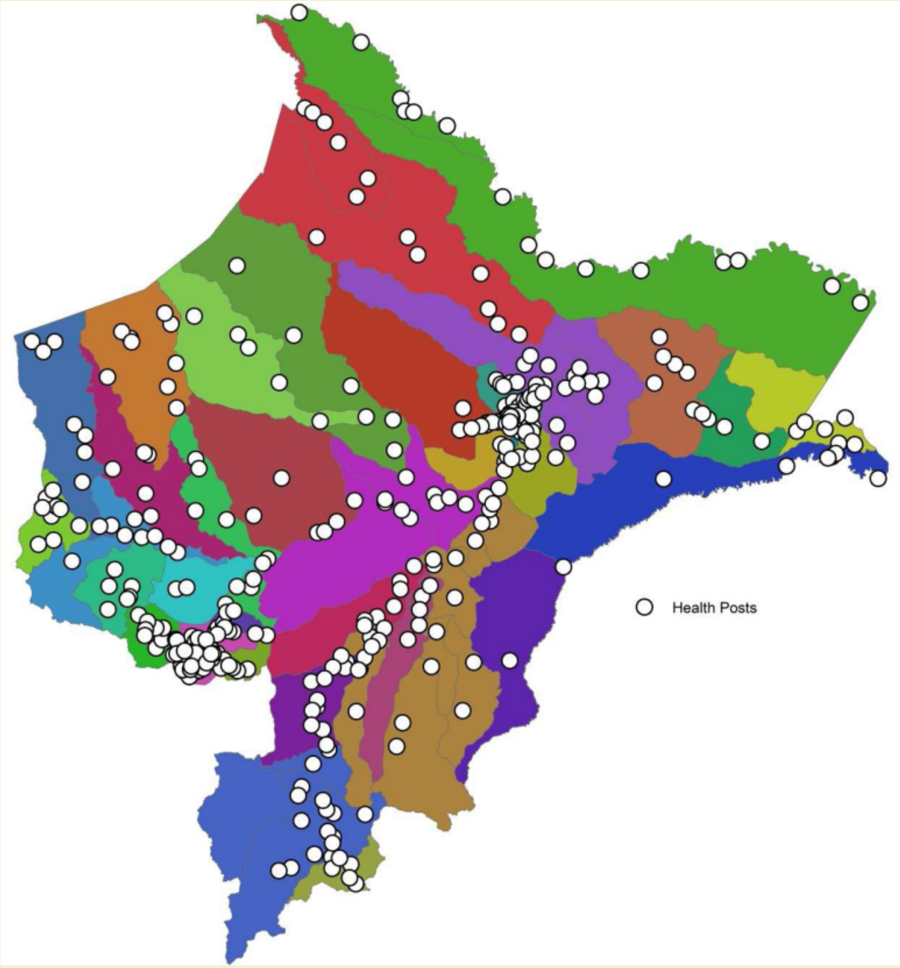
DATA
Weekly Malaria Counts

Components of malaria surveillance in Peru

- Mandatory malaria reporting system
- Confirmation with microscopy prior to treatment (*P. vivax*: 3d CQ, 7d PQ; *P. falciparum*: 3d MQ + AS)
- Case reported to *MicroRED* of residence

Problems / Limitations

- Quality of microscopy
- Surveillance only -- <u>not a true Risk Ratio</u>
- Place of residence is not always accurately reported



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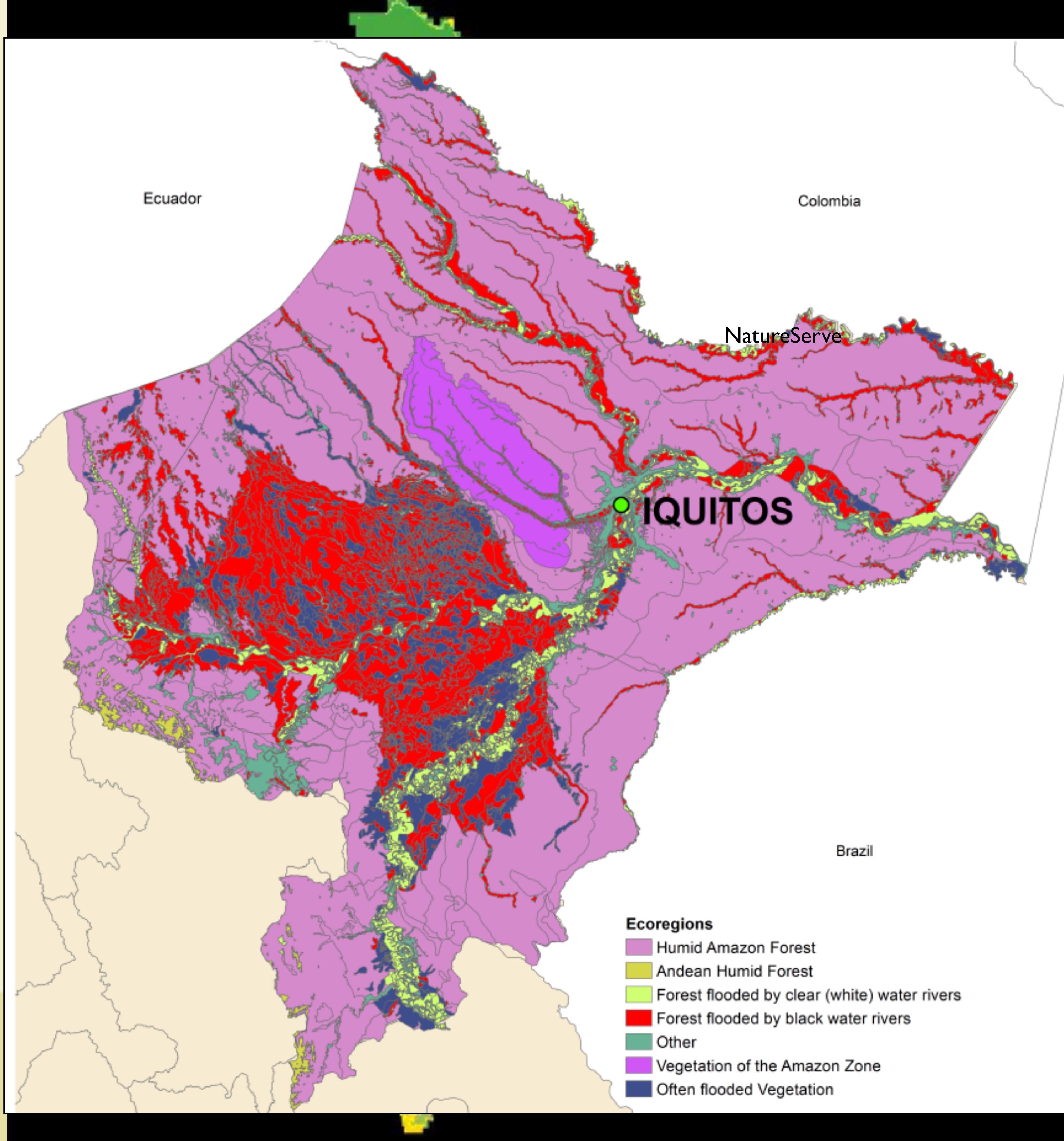
DATA
Land Cover

- MCD12Q1 (MODIS) captures variability within the Amazon Forest
- Phenology-based classifications using 16-day MODIS 250m NDVI product offer complementary information
- *NatureServe sistemas ecologicos* capture complementary and additional information



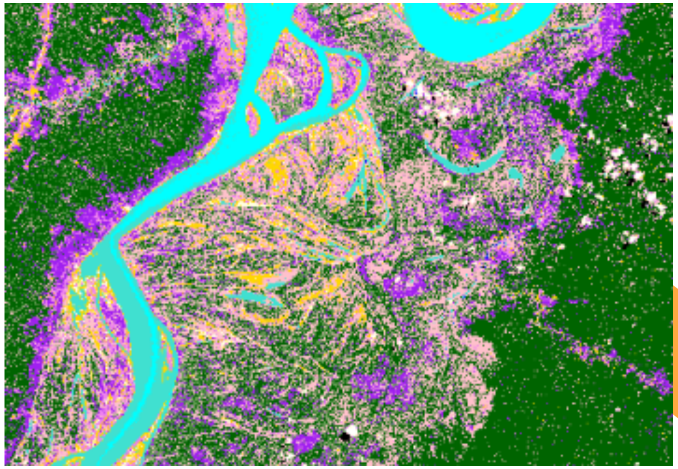
DATA
Climate & Soil Moisture

LAND DATA ASSIMILATION SYSTEM

LDAS is a computational tool that merges **observations** with **numerical models** to produce optimal estimates of **land surface states and fluxes**.

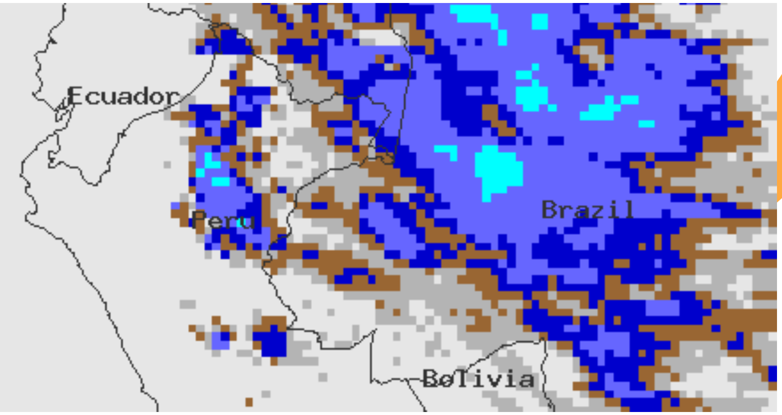
LDAS Methodology

Landscape Information

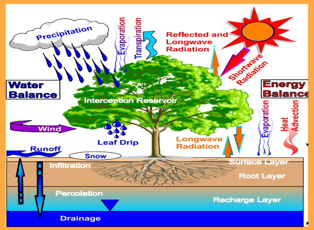


Update Observations

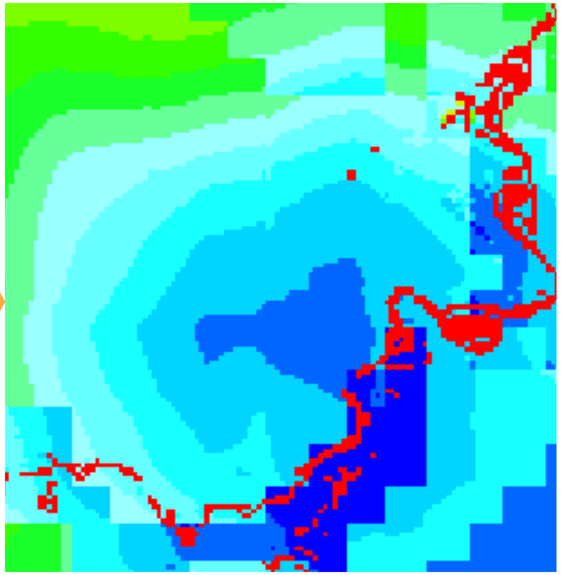
Meteorological Data



Numerical Model



LDAS Output

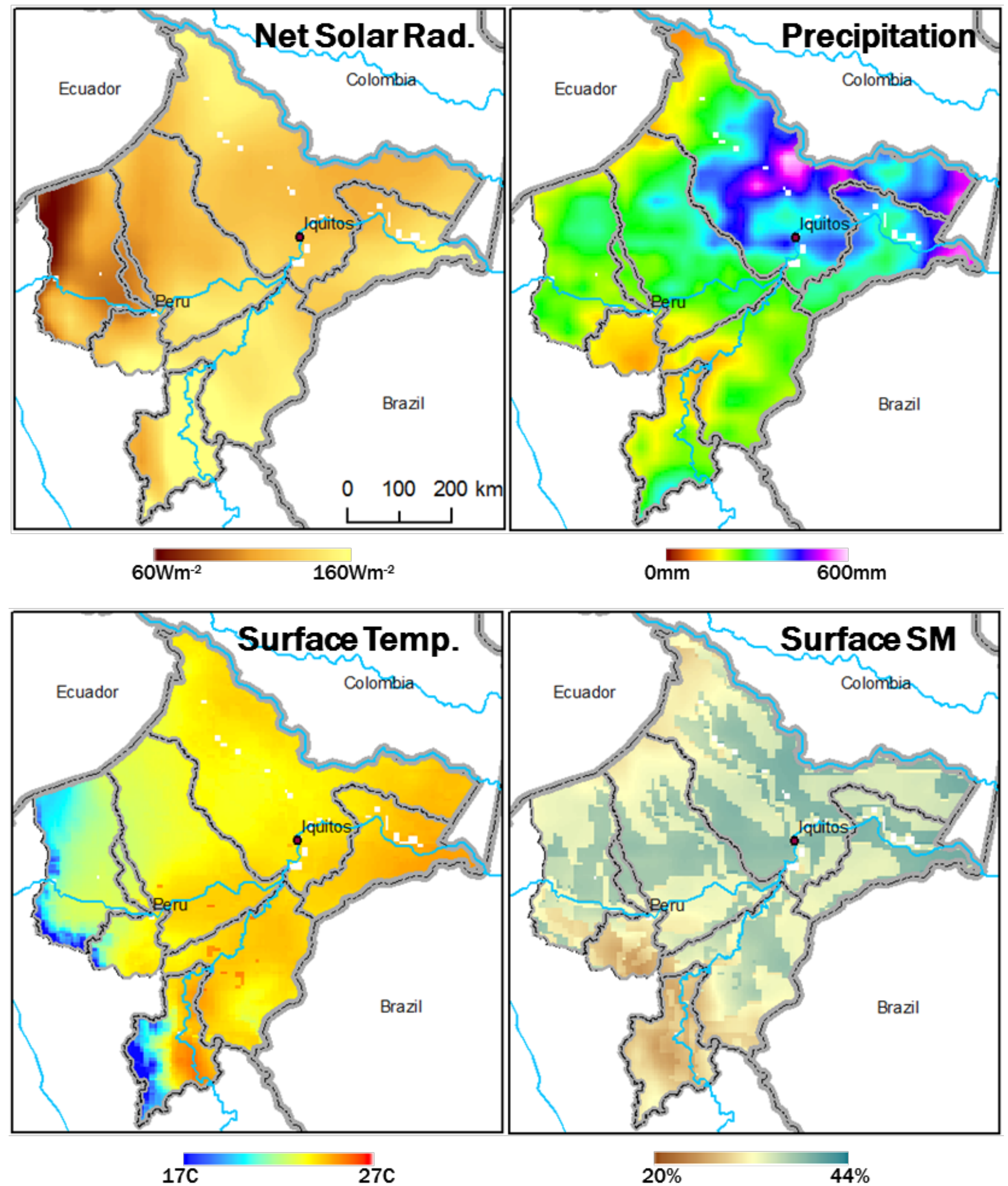


- Hydrological fluxes & storage
- Localized meteorology
- Surface energy balance

LDAS Data Generation

- TMPA + GDAS forcing is effective
- MODIS GVF and Land Cover add spatial structure
- Noah LSM simulations show significant spatial and temporal variability

- Resolution and quality of soil maps should be improved
- Evaluation data are limited
- Data Assimilation has had a marginal effect



DATA
Population

Annual district-level population estimates from the Peruvian Census Bureau (INEI)

Prediction Model

Requirements & Constraints:

- Weekly forecasts of cases by district
- 4-8 weeks in advance, continual updating
- Integrated into the LORETO DIRESA Surveillance Program
  - Must be able to be run using R (free statistical software)
  - Cannot require complex computations

    ** Computers at DIRESA are not as powerful

Original Model Results

- Spatial RE Poisson Model
  - ❑ **Climate:**
    - Precipitation, lag 10 → positive effect
    - Temperature, MIN-lag 9 → positive effect
      MIN-lag 9 → negative effect
      MEAN-lag 2) → negative effect
  - ❑ **Land Characteristics**
    - Soil Moisture (lag 5) → negative effect
    - Flooded forest, clear water → negative effect
  - ❑ **Space-Time Factors:**
    - Spatial lag of cases (lag 6) AND a spatial trend
    - Fourier transform (sin/cos) on weeks

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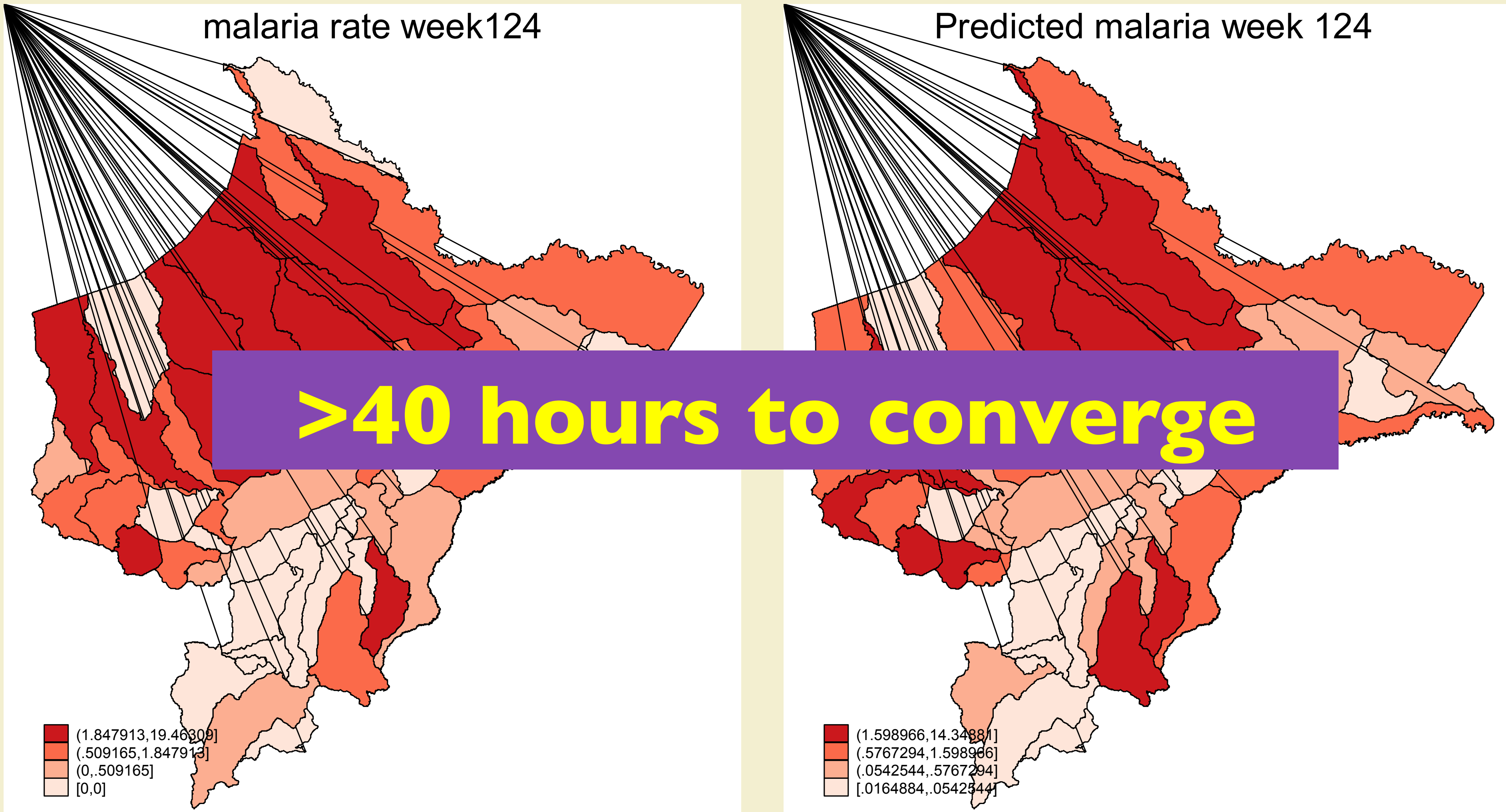
Original Model Results



METHODS

Bayesian Spatial Poisson Time Series

<u>Model for each district:</u>

CASES / POP = Observed **TREND** + **SEASONA**
L Cycles + **CLIMAT**
E Drivers + **LAND COVER** Characteristics

Observed TREND: Captures the long-term change in the mean of malaria cases in the district

SEASONAL Cycles: Regular variation in the series (weekly, monthly, annually)

CLIMATE Drivers and LAND COVER Characteristics: Influences both human exposure (e.g., occupational labor) and *Anopheles* density

METHODS
Multilevel Spatial Poisson Time Series

<u>Model for each district:</u>

CASES / POP = | Observed TREND | SEASONAL Cycles | CLIMATE Drivers | LAND COVER Characteristics |

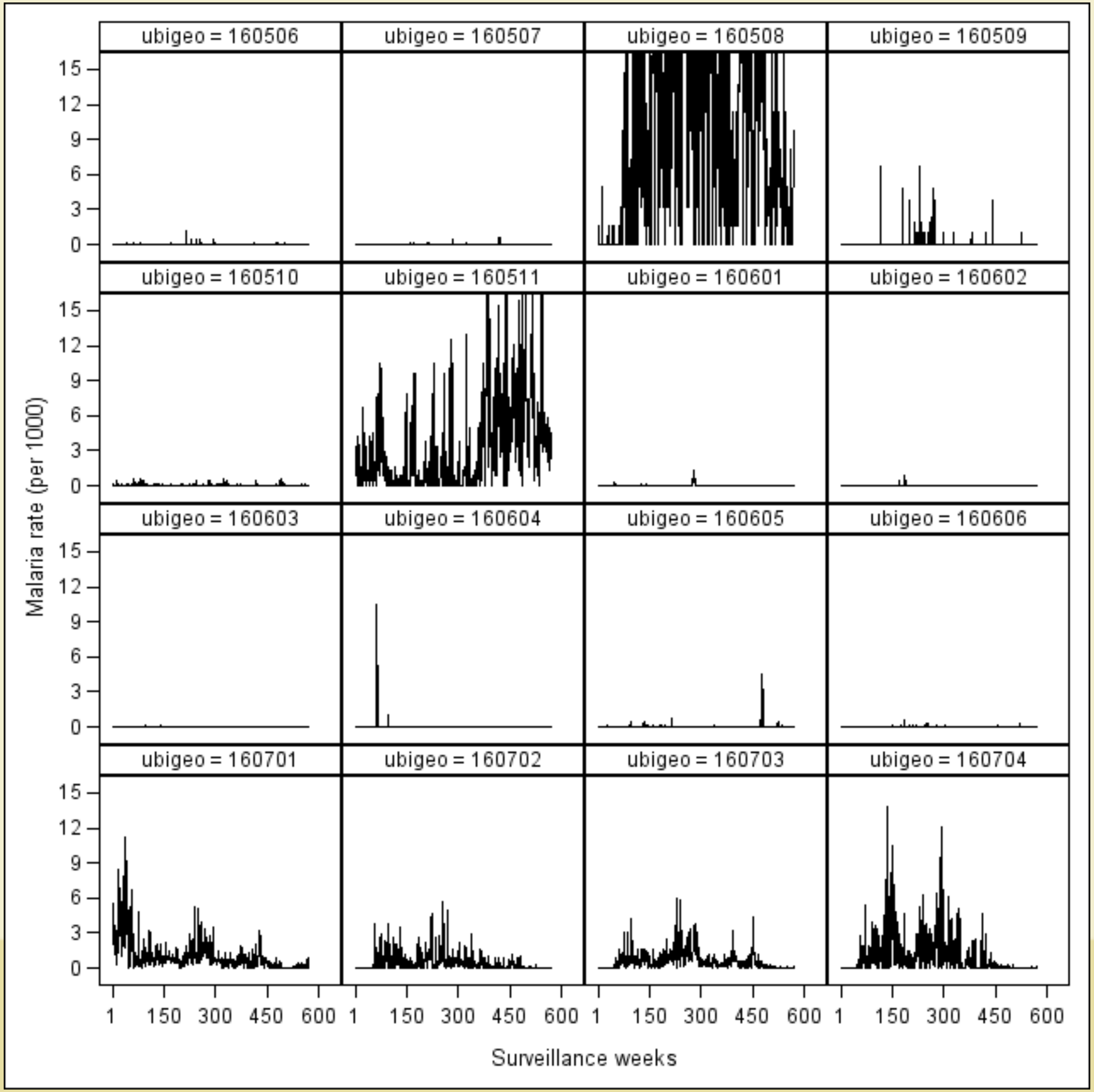
Observed TREND + SEASONAL Cycles: Time Series Model

CLIMATE Drivers + LAND COVER Characteristics: Multilevel Model

Time series component

Selecting the model

- Count outcome
- Repeated measures → 51 time series
- Non-stationary mean
- Seasonality
- Spatial correlation (between time series)



Conclusions / Insights

- Human drivers of transmission cannot be modeled at large scales, but predictive models must be informed by focused studies

- Satellite-derived land cover, meteorology and soil moisture can drive skillful models of vectors and inform models of malaria risk.

- Land Surface Models increase the predictive value of satellite observations.

- Mosquito species respond differently to land cover change but similarly to hydrometeorology.

Next Steps

- **2000-01 data:**
  - Integrate human malaria infection into models
  - Compare scaling of model to district (or higher admin) level
- **2009-13 data:**
  - Ensure quality of final data collection and entry
  - Finish testing of *Anopheles* for parasitemia
  - Begin development of models
- **District-level analysis**
  - Acquire weak stationarity model across all districts
  - Work with Peru Ministry of Health to operationalize the models
  - *Begin parameterization of an Agent-Based Model of transmission*

Acknowledgements

Other Collaborators

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Prediction is very difficult, especially about the future

-Niels Bohr

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