CLIMATE AND LAND USE DRIVERS OF MALARIA RISK IN THE PERUVIAN AMAZON, 2001-2012

Ben Zaitchik

Johns Hopkins University

Beth Feingold, Denis Valle, Alex Sandoval, Carlos Alvarez Antonio, Rosa Patricia Zegarra Vasquez, and William Pan

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.

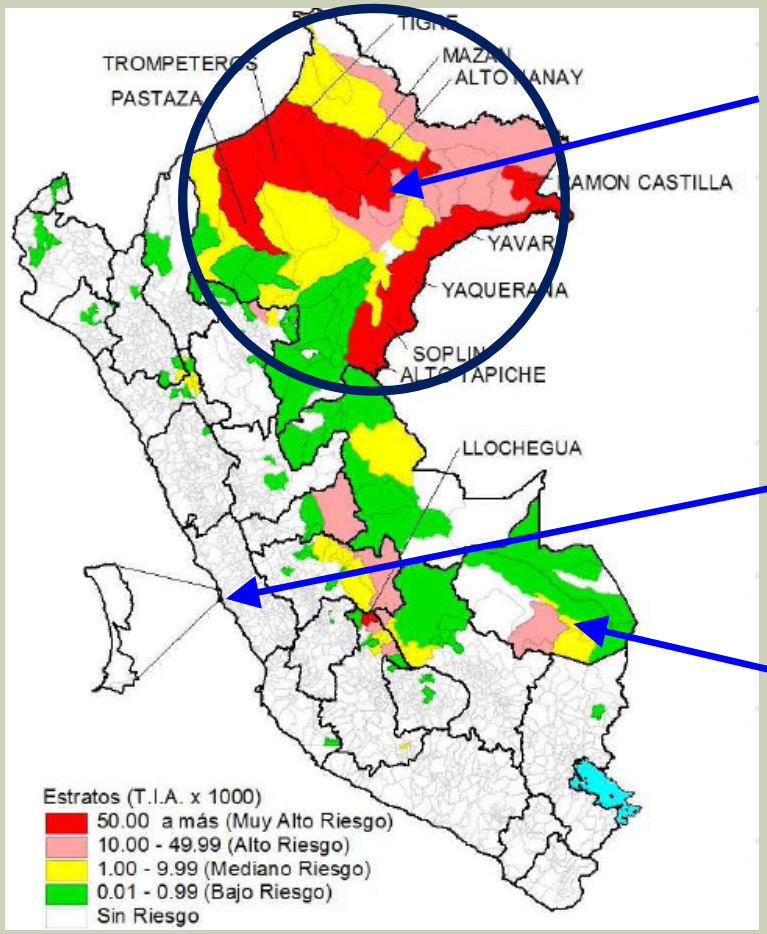
THE PERUVIAN AMAZON

- Over 90% of malaria in the Western Hemisphere is located in the Amazon
- In Peru, 75% of malaria cases occur in the Department of Loreto. 80% of these cases occur in just 10 of the department's 51 districts.

- Key factors related to continued malaria endemicity:
  - expansion of vector habitats from deforestation: logging and road development)
  - social and ecological processes that increase human exposure *Anopheles darlingi*

MALARIA IN PERU, 2012

P. vivax

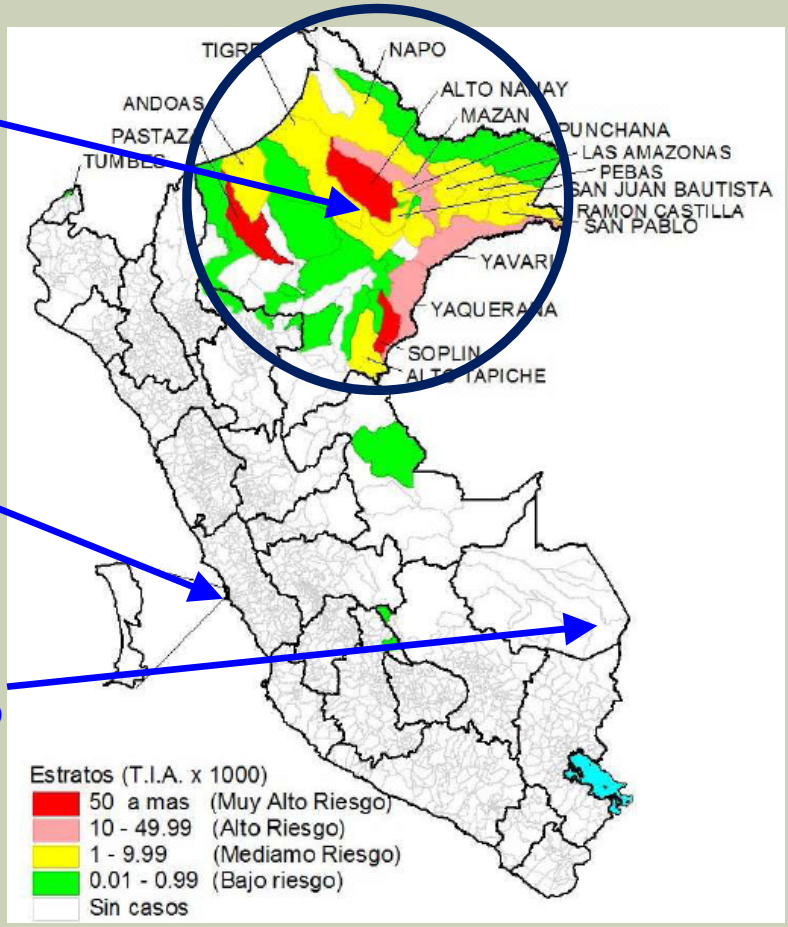


Iquitos

Lima

Puerto Maldonado

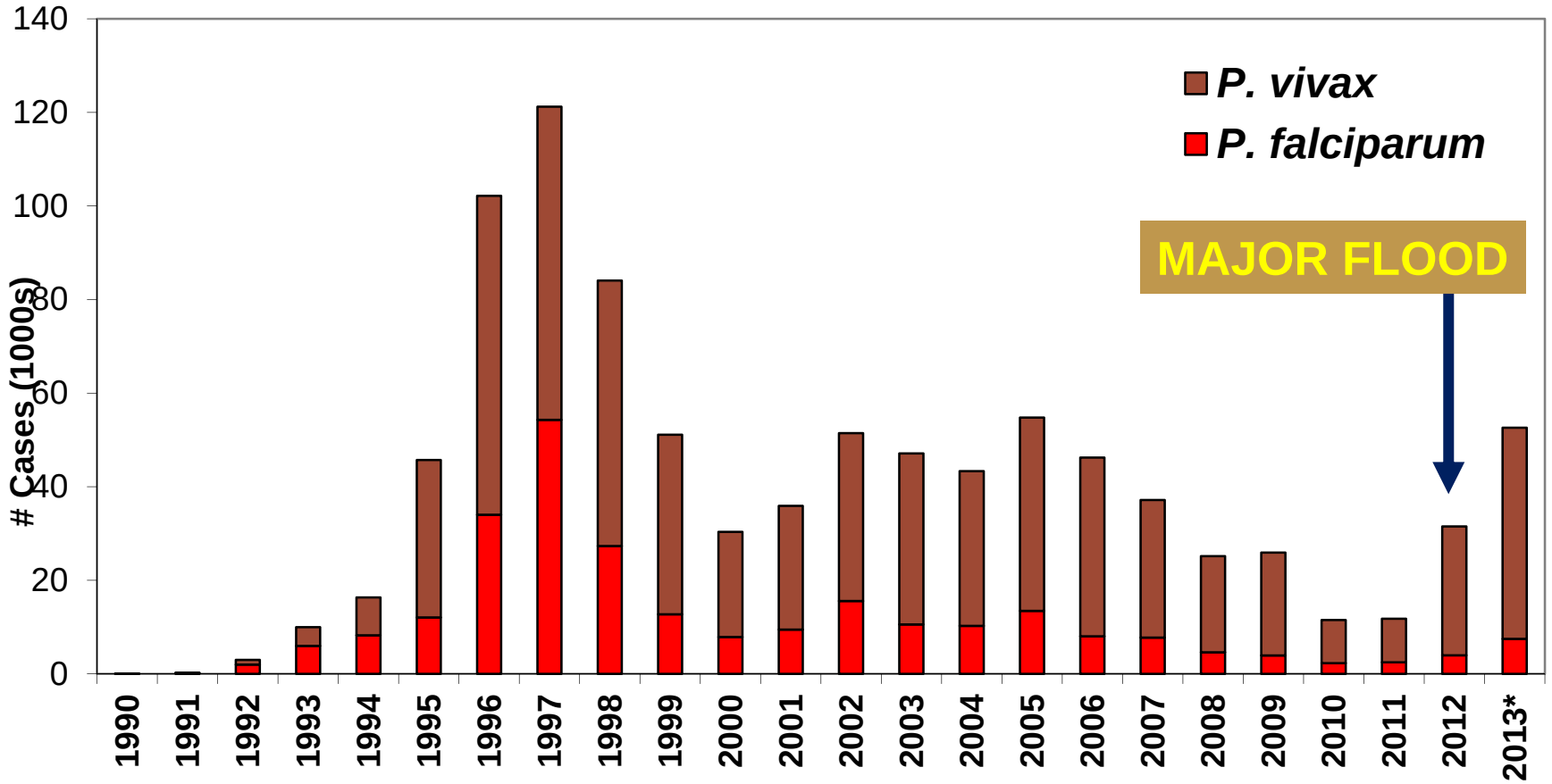
P. falciparum



THE PERUVIAN AMAZON

- The total number of confirmed Malaria cases in the Amazon declined by 43% between 2000 and 2009
- However, there has been evidence of a resurgence in the past three years
- Climate variability may play a role in the recent increase

Reported Malaria, Loreto Province 1990-2013



Highest Deforestation Rate in Peru

Iquitos-Nauta Road Paving & Fujimori logging concessions

Roll Back Malaria

2nd highest increase in the Amazon to 2006,

Major decline to 2011

AIMS

1. Model and predict the distribution of malaria **vectors**—*Anopheles* mosquitoes—as a function of land cover and hydrometeorology.

2. Model and predict **transmission risk** as a function of hydrometeorology, land cover, and human activities.

ANALYTIC FRAMEWORK

LAND COVER
&
LAND COVER
CHANGE

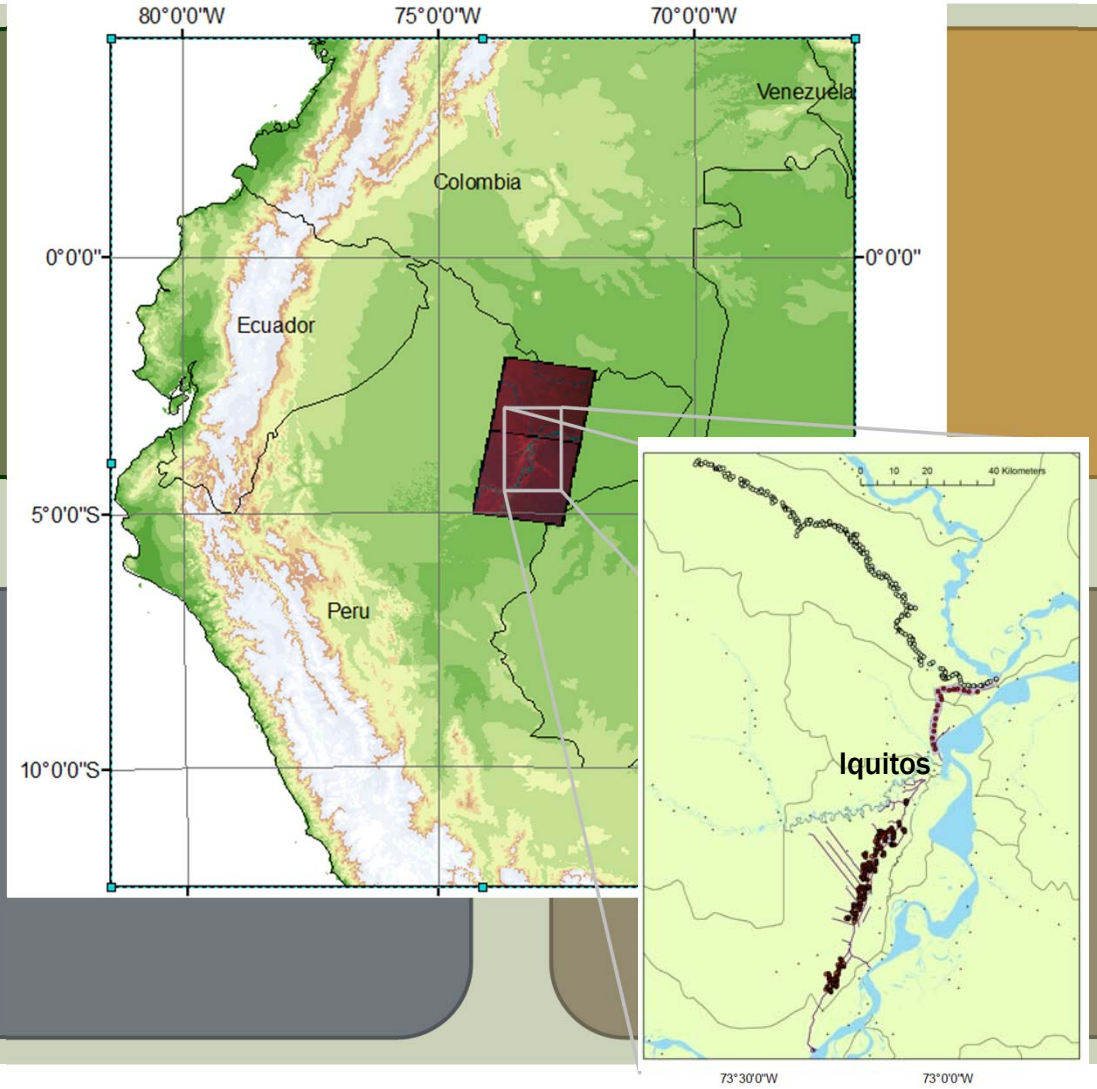
VECTOR
DISTRIBUTION

MALARIA CASES

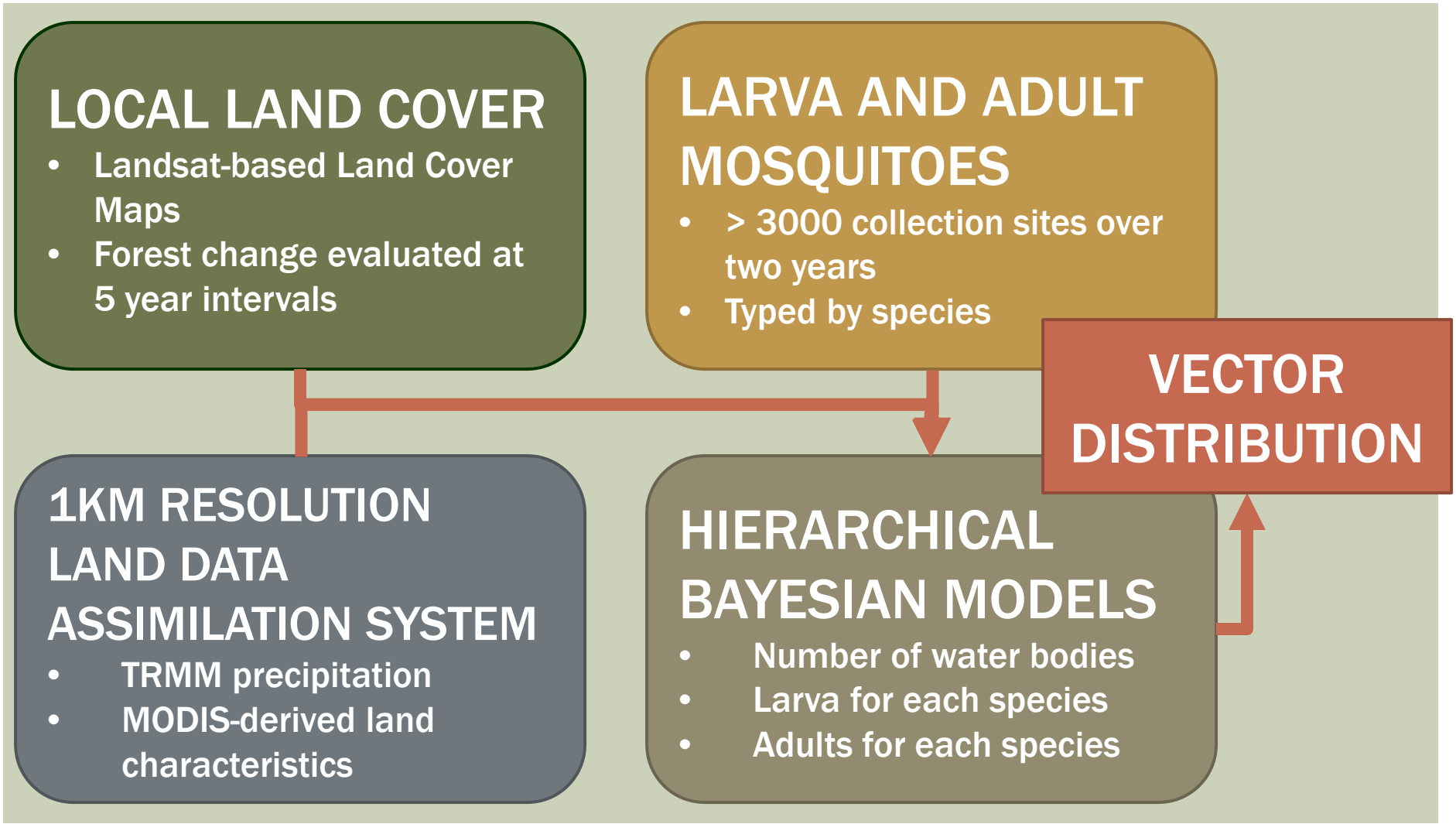
CLIMATE
HYDROLOGY

PREDICTIVE MODEL

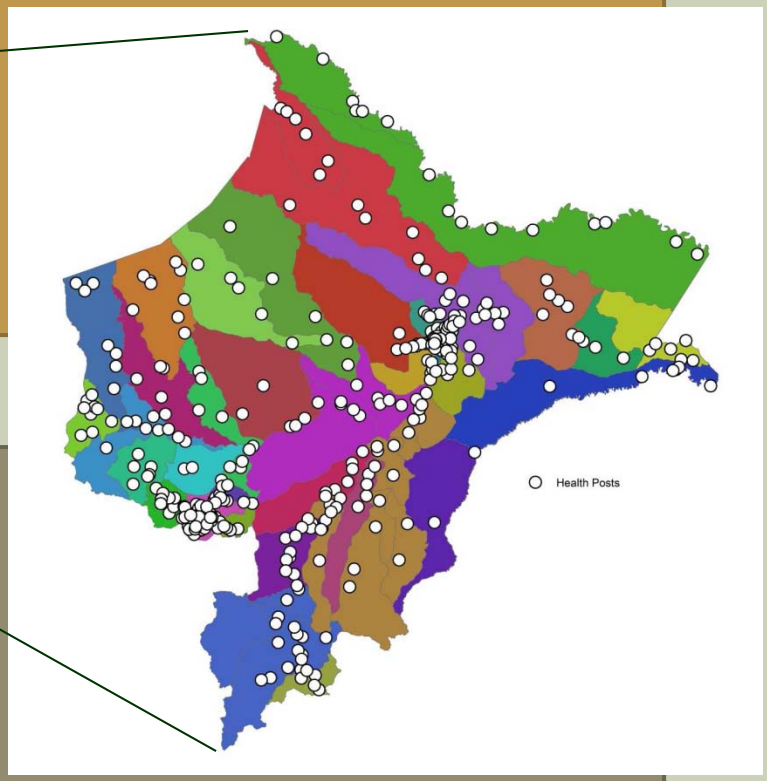
ANALYTIC FRAMEWORK: VECTORS



ANALYTIC FRAMEWORK: VECTORS



ANALYTIC FRAMEWORK: TRANSMISSION RISK



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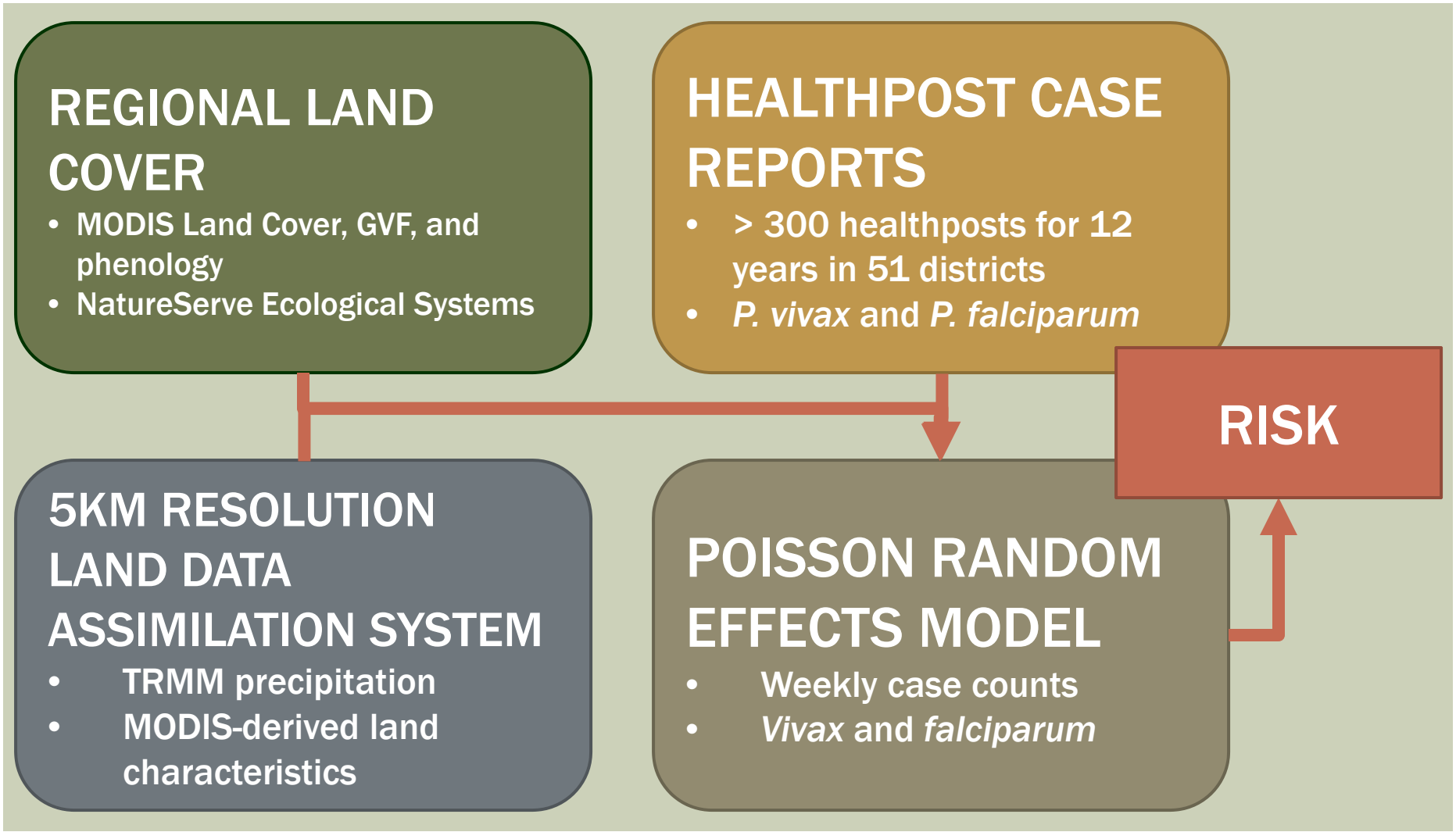
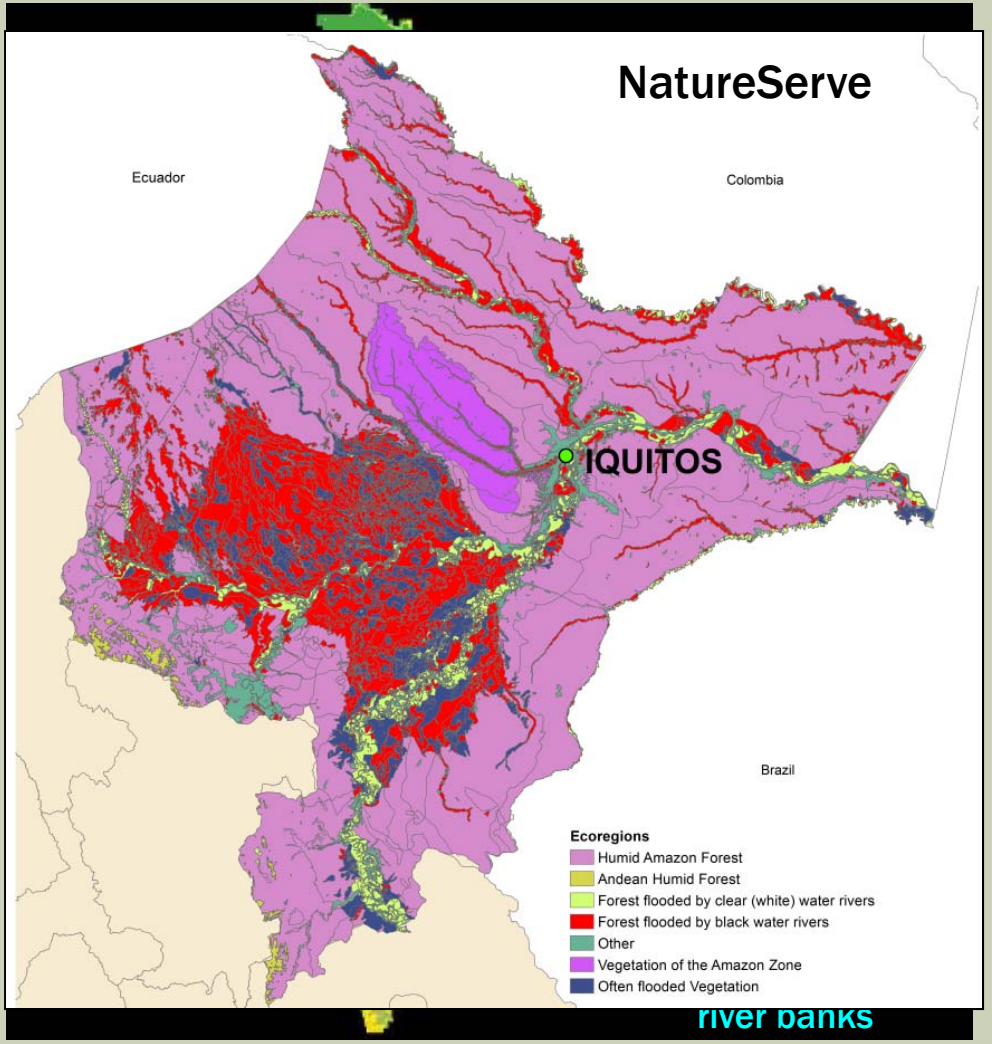


GENERATING INPUTS: LAND COVER

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



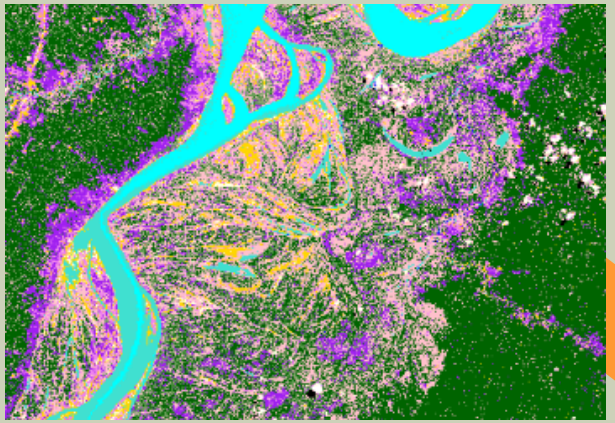
GENERATING INPUTS: LDAS

- A *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.**

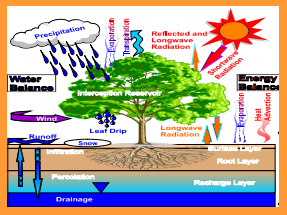
GENERATING INPUTS: LDAS

Update Observations

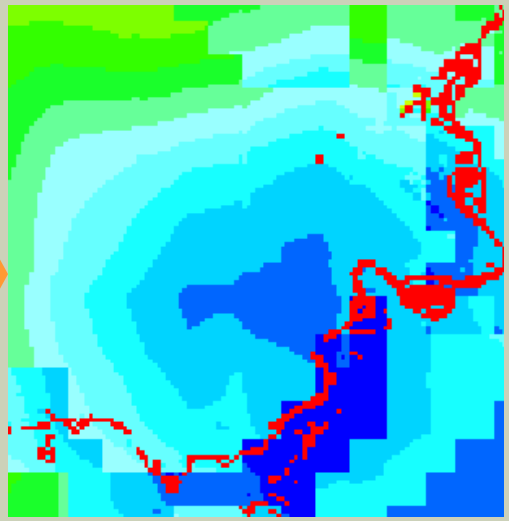
Landscape Information



Numerical Model

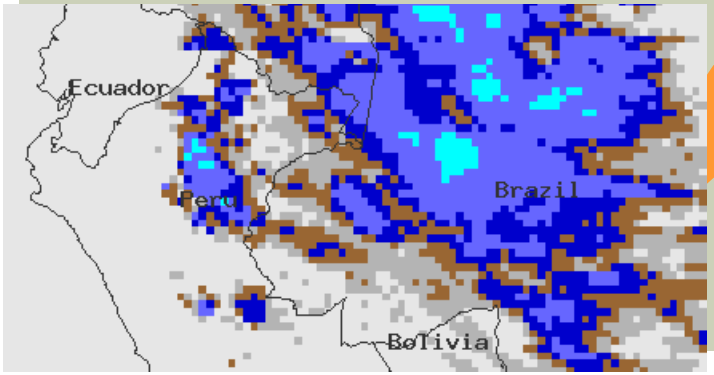


LDAS Output



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

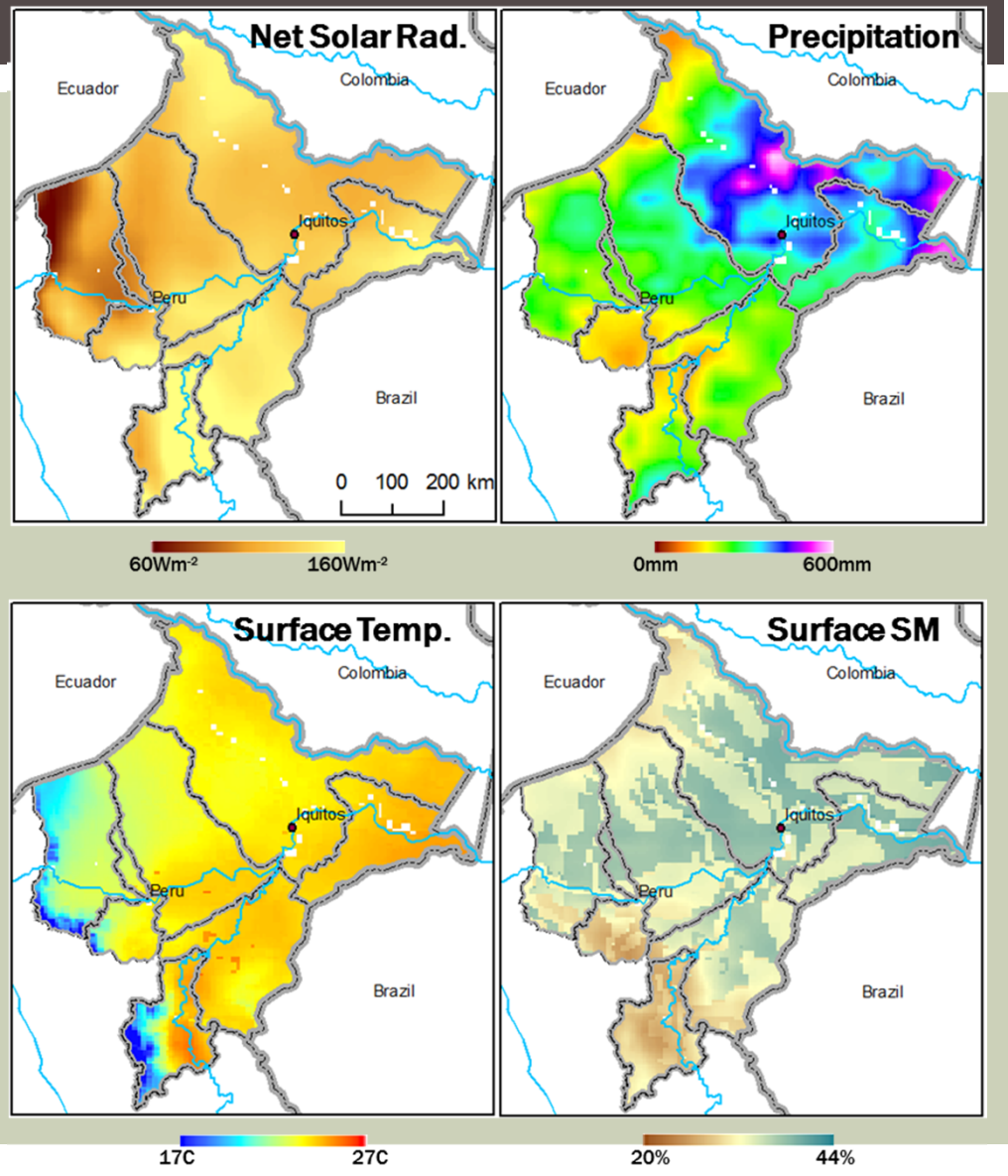
Meteorological Data



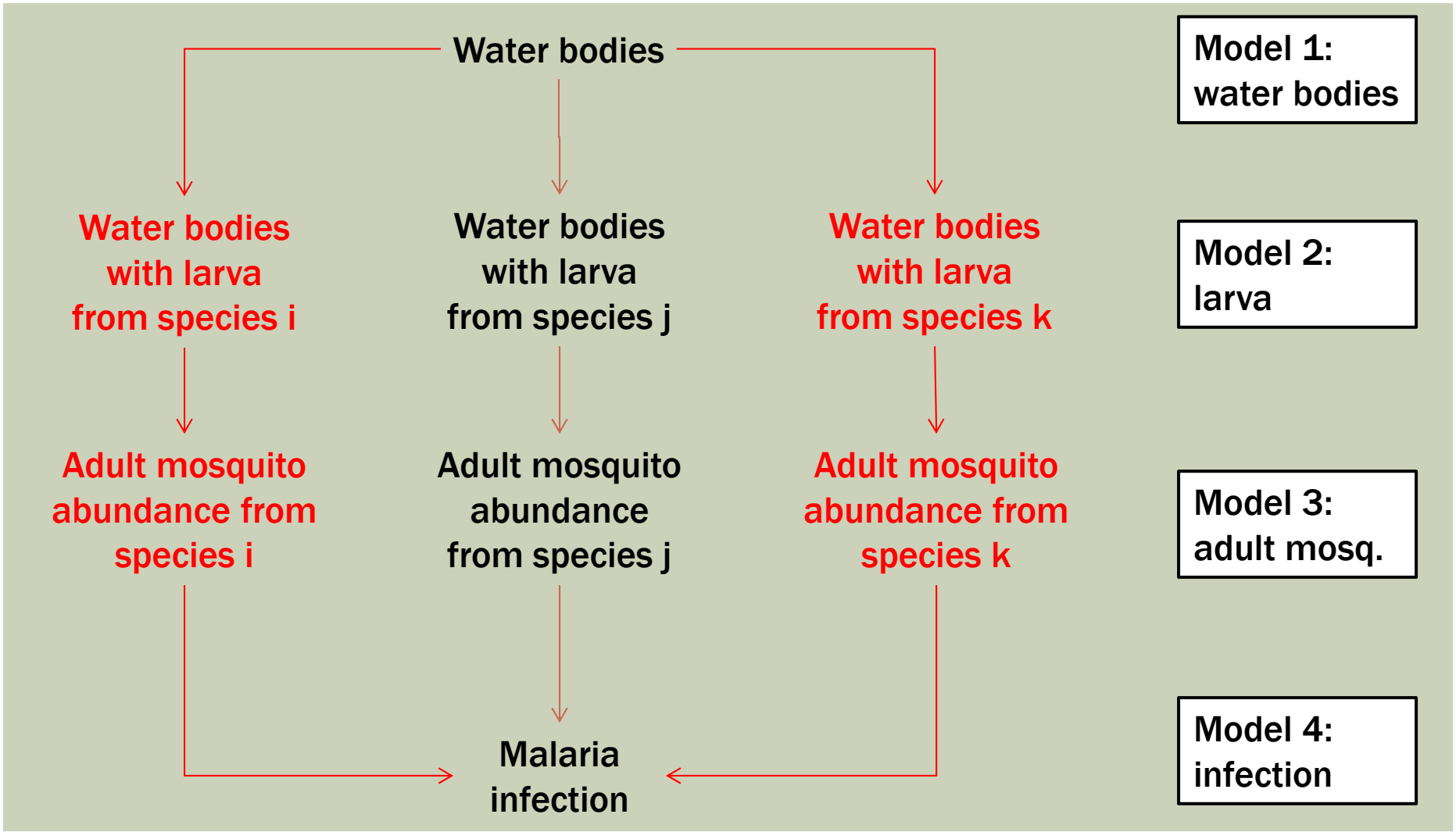
GENERATING INPUTS: LDAS

- 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

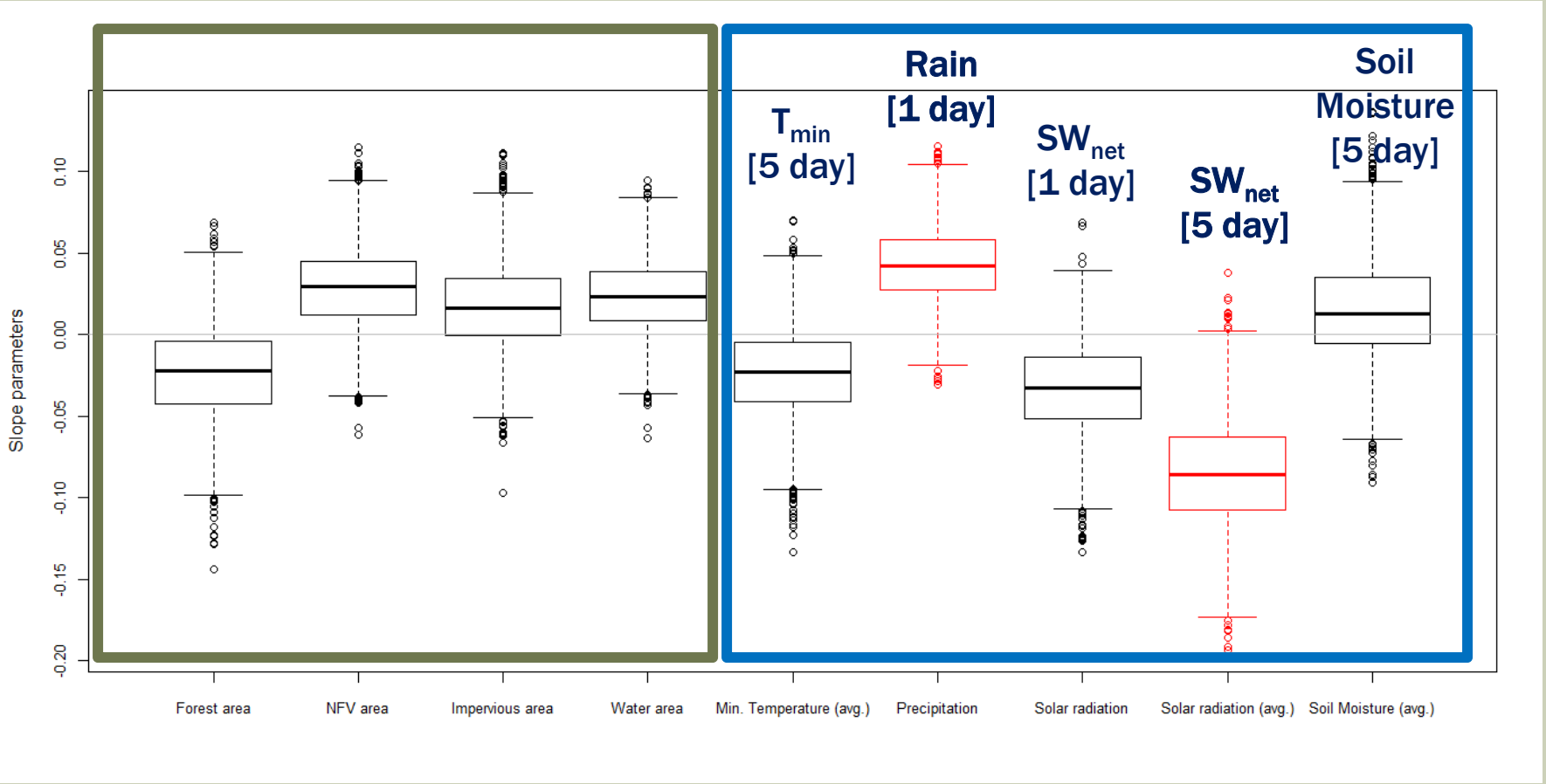


VECTORS: SPATIALLY-EXPLICIT *ANOPHELES* MODEL



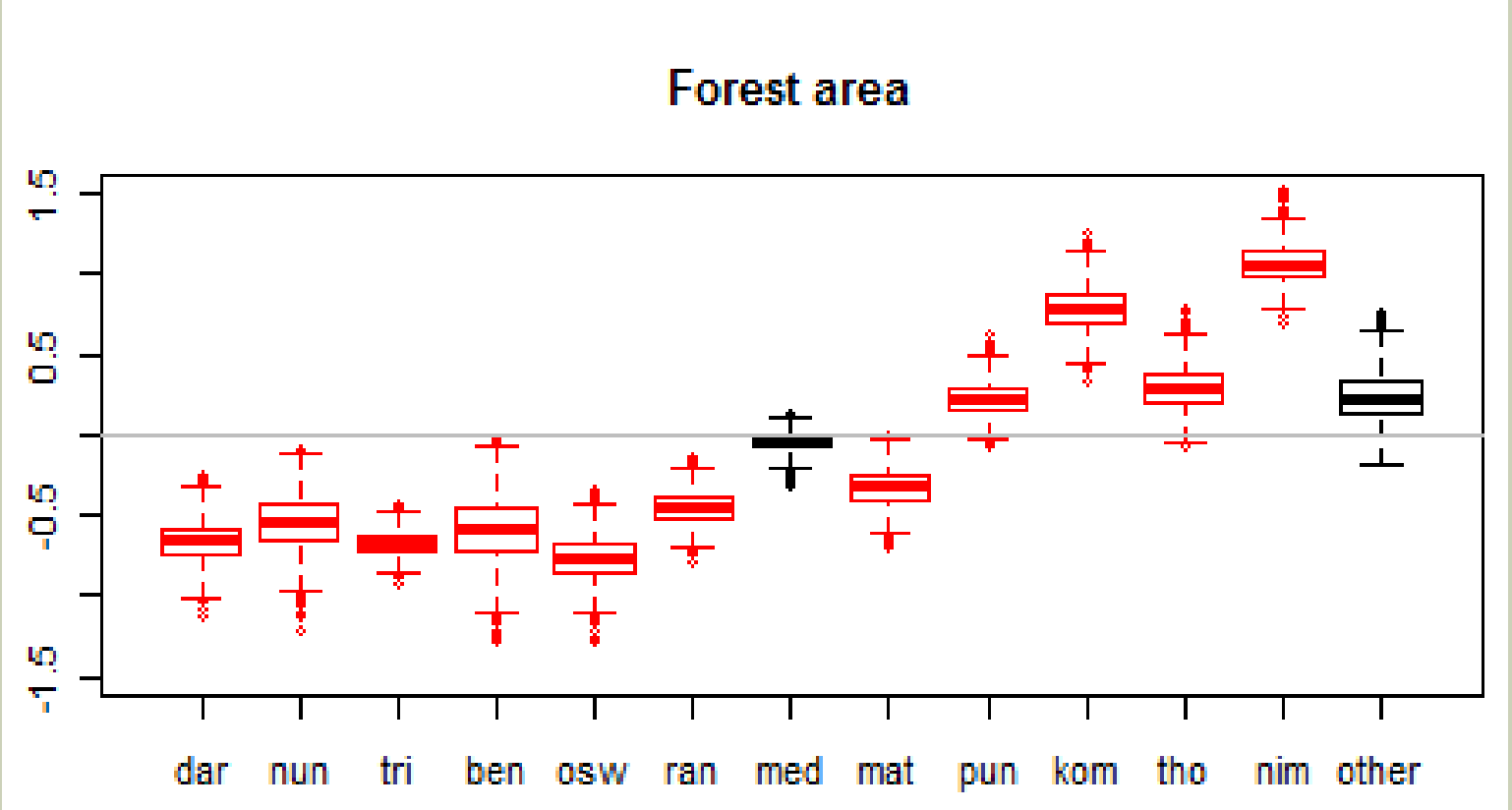
RESULTS: VECTOR MODEL

Water Bodies:



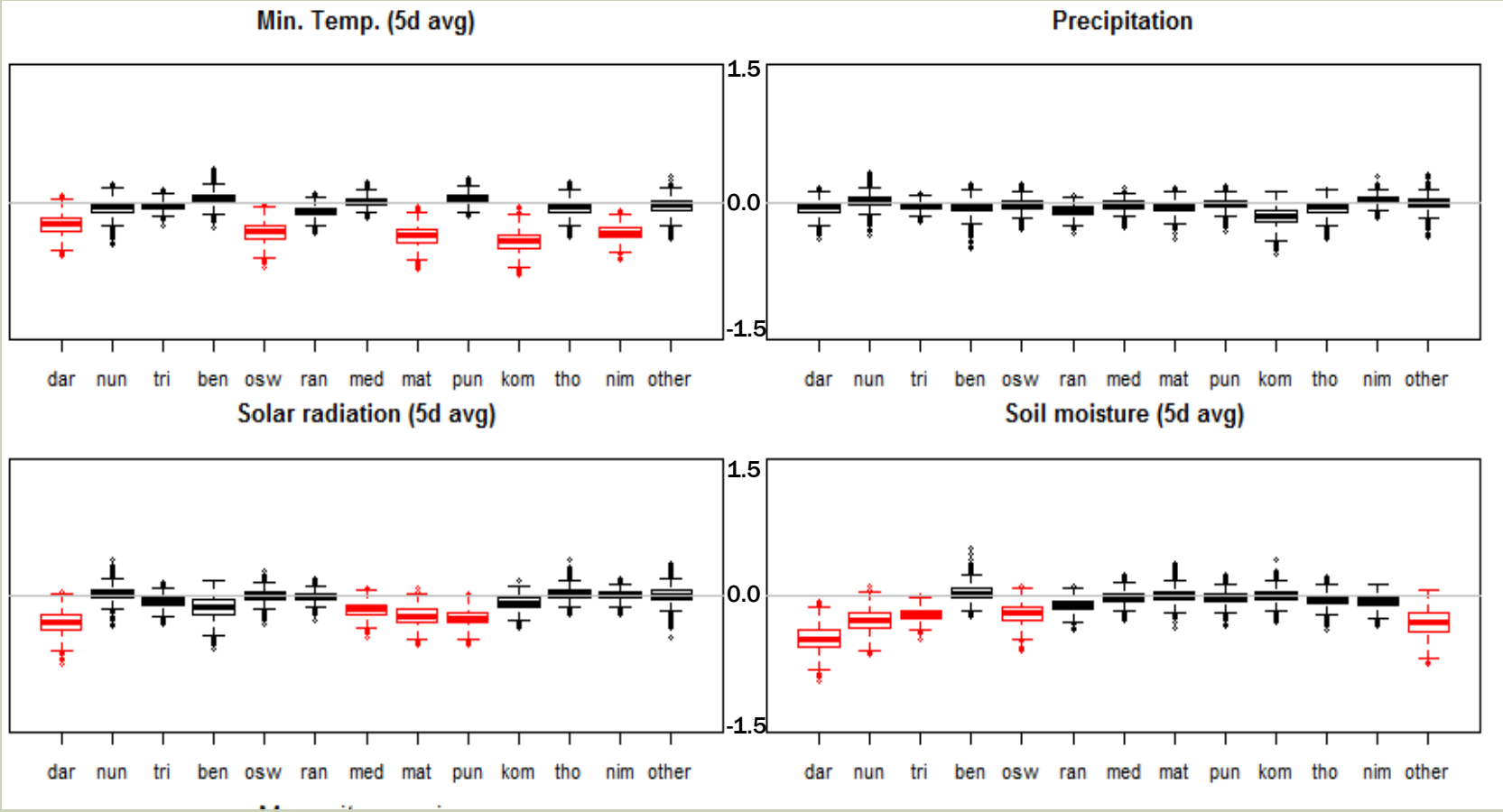
RESULTS: VECTOR MODEL

Larva: Forest Cover



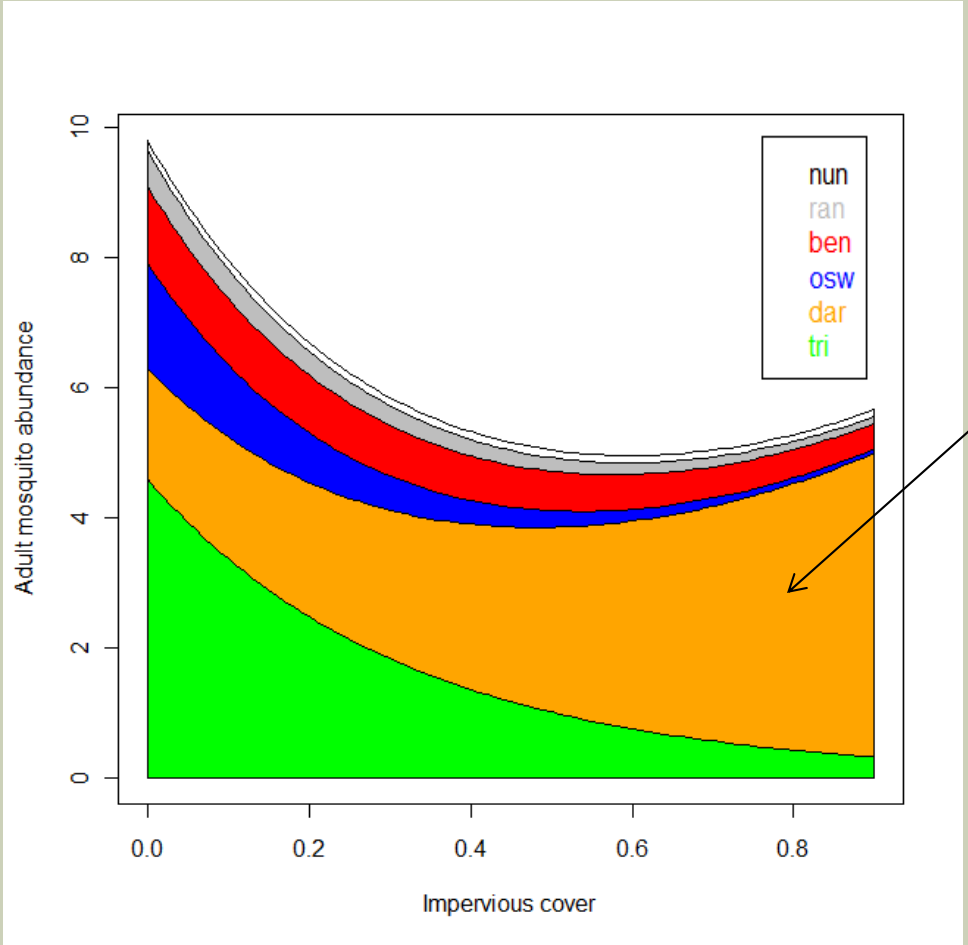
RESULTS: VECTOR MODEL

Larva: Hydrometeorology



RESULTS: VECTOR MODEL

Adults: Impervious Area



Anopheles darlingi

TRANSMISSION RISK: MULTILEVEL SPATIAL POISSON MODEL

- Goal: a predictive model operating on the district (n=51) scale
- Weekly malaria case data (*vivax* and *falciperum*) is drawn from all health posts (n=356) for 2001-2011
- The model considers land cover, population distribution (c. 2007), malaria trends, and weekly meteorological and hydrological conditions over multiple lag times
- In contrast to previous predictive efforts, we aim to distinguish trends from seasonality
  - The model informs both forecasts and understanding

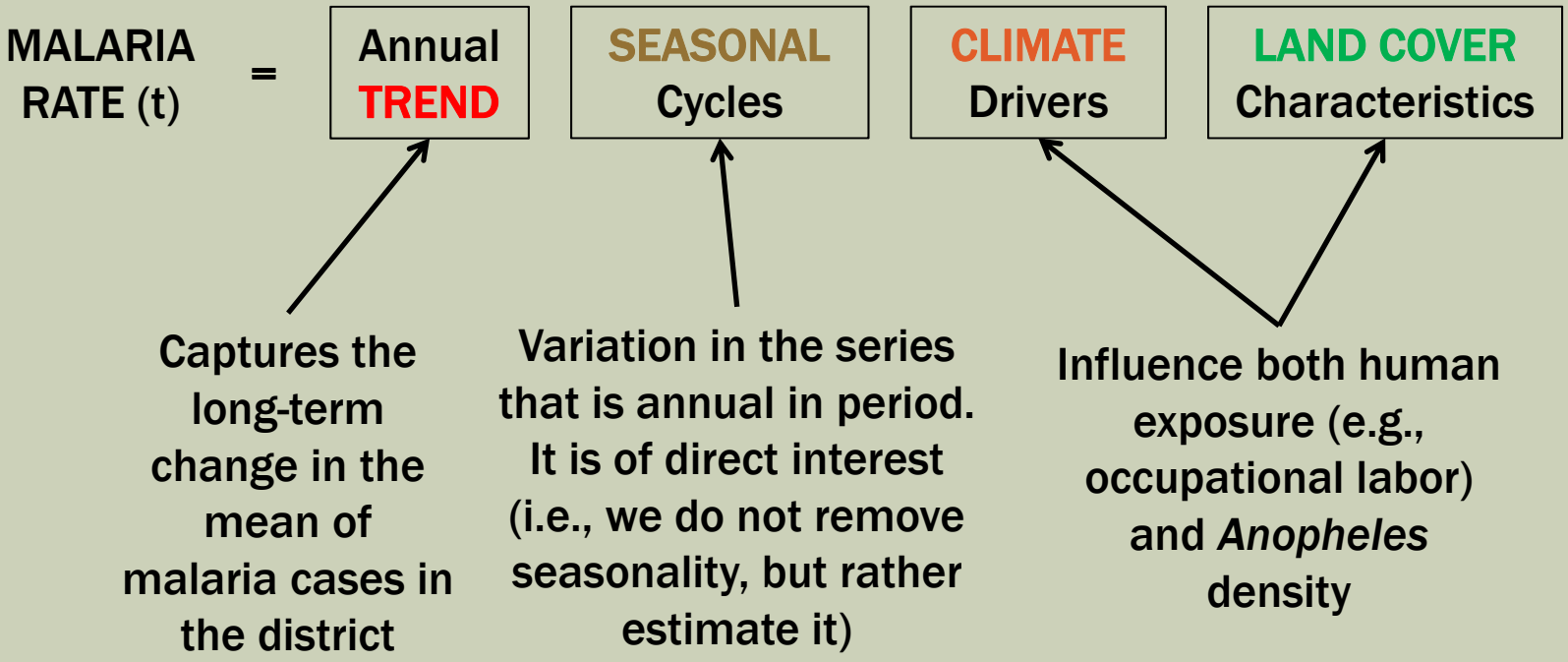
TRANSMISSION RISK: MULTILEVEL SPATIAL POISSON MODEL

Model for each district:

MALARIA RATE (t) = Annual TREND + SEASONAL Cycles + CLIMATE Drivers + LAND COVER Characteristics

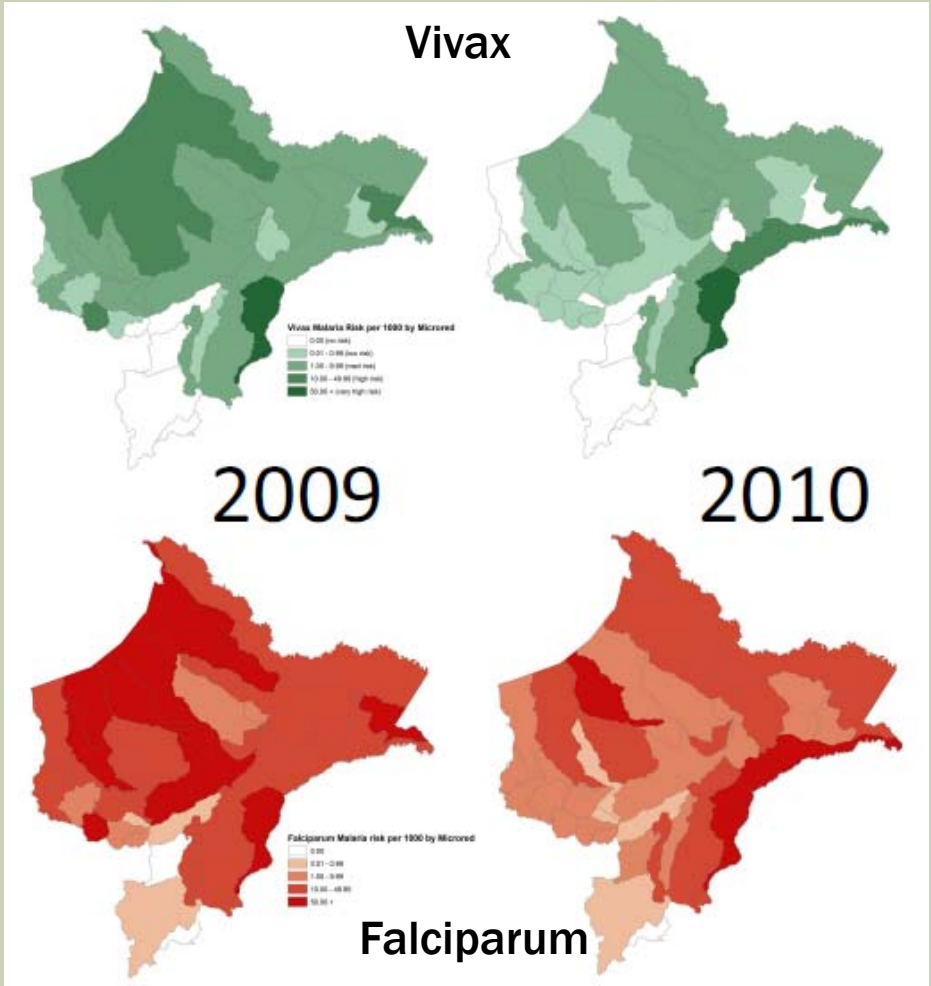
TRANSMISSION RISK: MULTILEVEL SPATIAL POISSON MODEL

Model for each district:



RESULTS: MALARIA TRANSMISSION MODEL

- Preliminary analysis: 2009-2011 (earlier version of Poisson model)
- Significant climate predictors include **soil moisture** and **rainfall.**
- Temperature predictors are not, at present, significant.
- **Forest type** is a significant predictor, as is the nature of **inundation patterns.**
- Model fit scores are high (AIC), but over-dispersion exists, likely due to spatial correlation.



CONCLUSIONS & NEXT STEPS

- Satellite-derived land cover and meteorology 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.
- Satellite-derived precipitation and simulated soil moisture both inform predictions of transmission risk.

- Refine malaria transmission model using 2001-2011 data and being applied to hindcasts of 2012.
- Work with health officials to operationalize the models.

THANK YOU

zaitchik@jhu.edu