



Swiss TPH



Climate variability impacts malaria
seasonal interventions

An 'In Silico' simulation combining two
mathematical models for malaria

Alexis Martin · October 2, 2024

IDM Symposium, Session 1B: Strategies for malaria model development

Mozambique



Cheringoma



Cheringoma



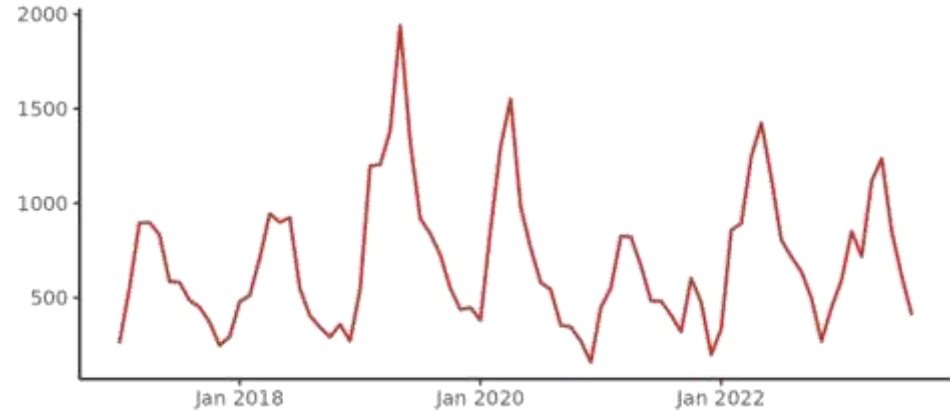
Cheringoma



Cheringoma

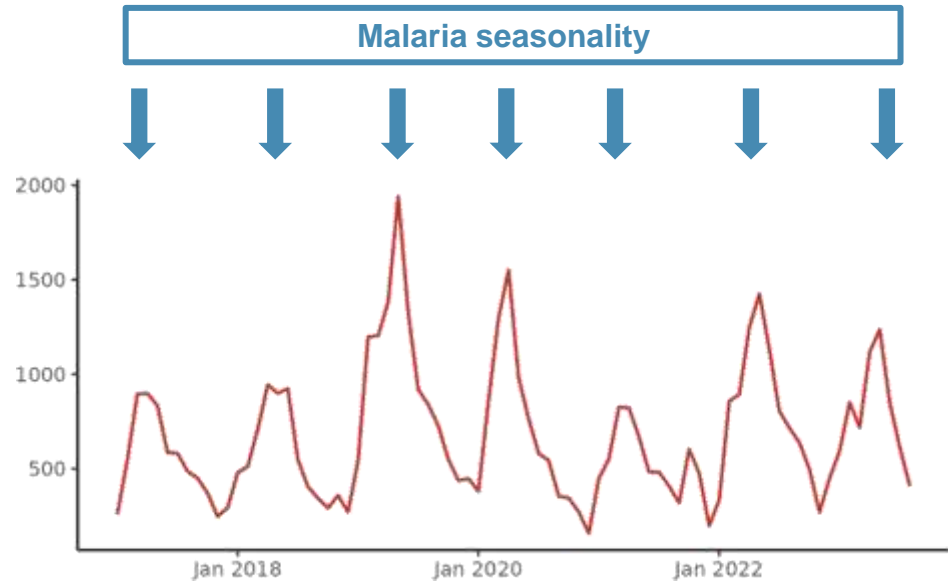
Malaria incidence (cases per 10,000 people) in Cheringoma district, Mozambique, from 2017 to 2023.

Data source: Courtesy of Dr. Candrinho, Mozambique National Malaria Control Program and NIH.



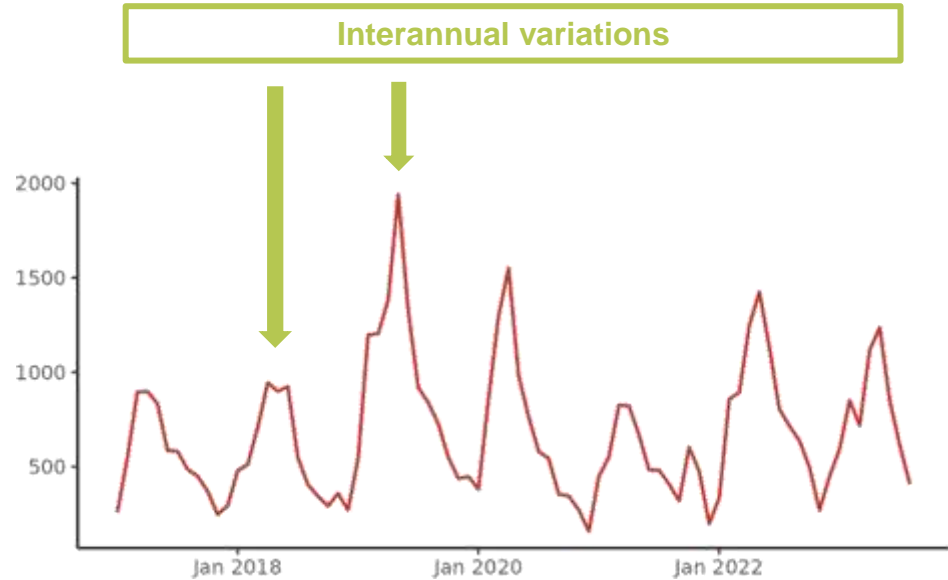
Cheringoma

- Malaria season usually peaks in March **every year**



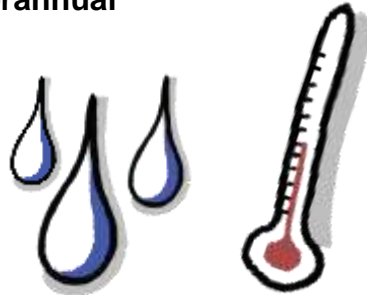
Cheringoma

- **Interannual** variability
- **Beginning, duration** and **intensity** of the malaria season might vary



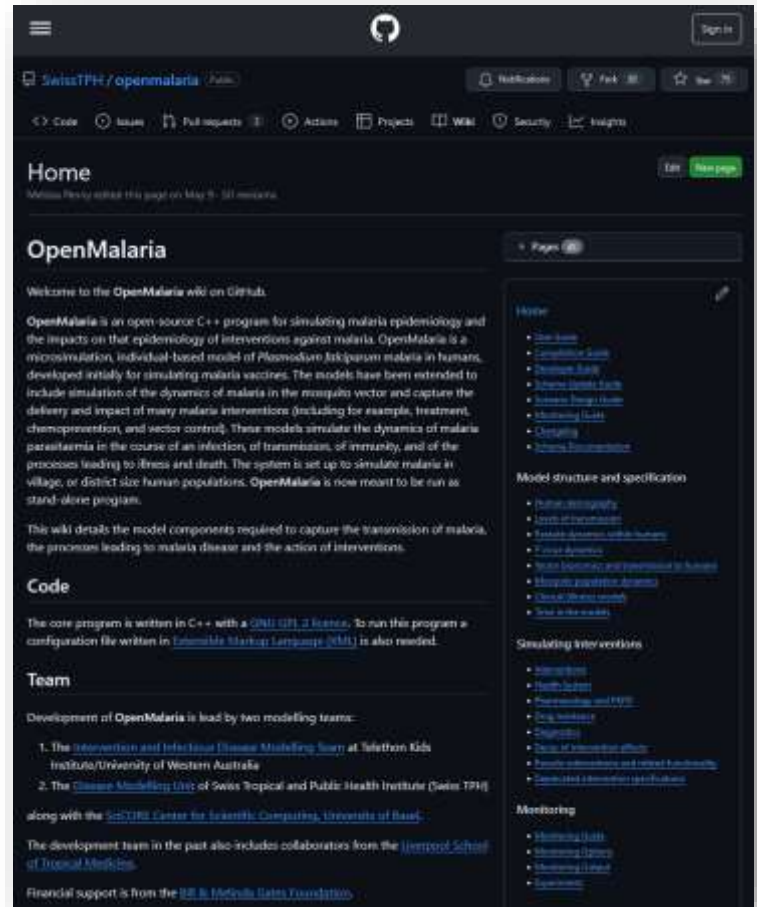
Why is malaria fluctuating?

- *Anopheles* mosquitoes are **highly sensitive to climate**
- Climate drives **interannual variability**



Our model: OpenMalaria

- Developed at **Swiss TPH**, maintained by Swiss TPH and the **Kids Institute**
- Financially supported by the **Bill & Melinda Gates Foundation**
- Written in **C++**
- Used for **intervention** modelling
- Has proven useful in supporting **decision making**



The screenshot shows the GitHub wiki page for the OpenMalaria project. The page title is "OpenMalaria" and it includes a welcome message, a detailed description of the model, and sections for "Code", "Team", "Model structure and specification", "Simulating other entities", and "Monitoring".

OpenMalaria

Welcome to the **OpenMalaria** wiki on GitHub.

OpenMalaria is an open-source C++ program for simulating malaria epidemiology and the impacts on that epidemiology of interventions against malaria. OpenMalaria is a microsimulation, individual-based model of Plasmodium falciparum malaria in humans, developed initially for simulating malaria vaccines. The models have been extended to include simulation of the dynamics of malaria in the mosquito vector and capture the delivery and impact of many malaria interventions (including for example, treatment, chemoprevention, and vector control). These models simulate the dynamics of malaria parasitaemia in the course of an infection, of transmission, of immunity, and of the processes leading to illness and death. The system is set up to simulate malaria in village, or district size human populations. **OpenMalaria** is now meant to be run as stand-alone program.

This wiki details the model components required to capture the transmission of malaria, the processes leading to malaria disease and the action of interventions.

Code

The core program is written in C++ with a GNU GPL 2 license. To run this program a configuration file written in [Executable Markup Language \(XML\)](#) is also needed.

Team

Development of **OpenMalaria** is lead by two modelling teams:

1. The [Intervention and Infectious Disease Modelling team](#) at [Ilsebeth Kids Institute/University of Western Australia](#)
2. The [Disease Modelling Unit](#) of [Swiss Tropical and Public Health Institute \(Swiss TPH\)](#)

along with the [SCYRIS Center for Scientific Computing, University of Basel](#).

The development team in the past also includes collaborators from the [Liverpool School of Tropical Medicine](#).

Financial support is from the [Bill & Melinda Gates Foundation](#).

Model structure and specification

- [Global demographics](#)
- [Types of transmission](#)
- [Epidemiological models and features](#)
- [Vector dynamics](#)
- [Vector immunity and transmission to human](#)
- [Human immunity and treatment](#)
- [Dose of blood smears](#)
- [Drug administration](#)

Simulating other entities

- [Interventions](#)
- [Health system](#)
- [Pharmaceutical and FPIs](#)
- [Drug resistance](#)
- [Diagnosis](#)
- [Types of transmission partners](#)
- [Parasite administration and related functionality](#)
- [Detailed simulation of individuals](#)

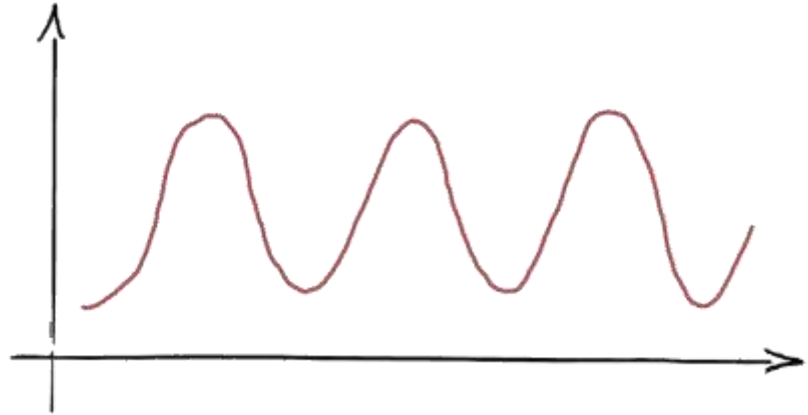
Monitoring

- [Reporting tools](#)
- [Monitoring systems](#)
- [Monitoring output](#)
- [Surveys](#)

<https://github.com/SwissTPH/openmalaria/wiki>

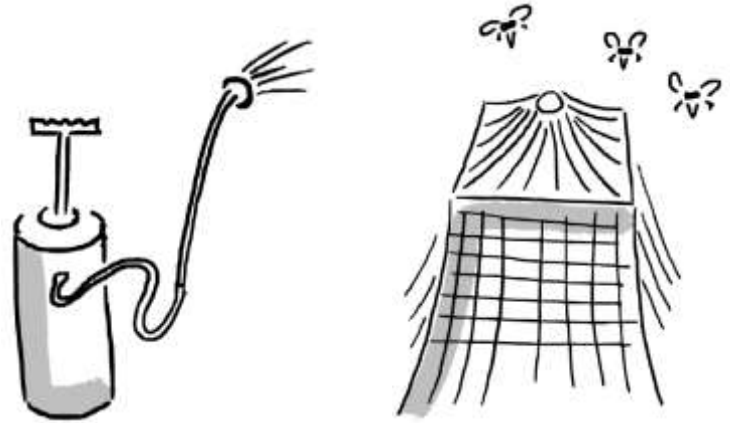
Our model: OpenMalaria

- In **OpenMalaria**, transmission is **assumed to be strictly seasonal**
- Usually not an issue for **comparing interventions/no intervention**
- But **some interventions are seasonal**



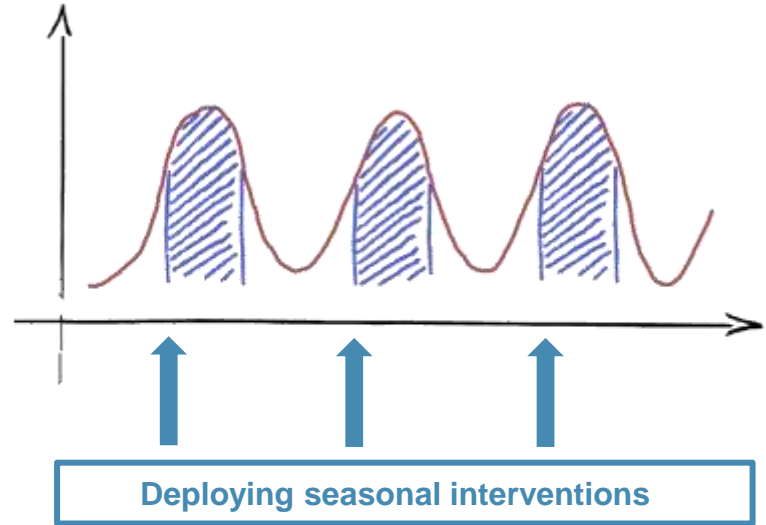
Seasonal interventions

- Indoor residual spraying
- Insecticide-treated nets
- Seasonal malaria chemoprevention
- ...



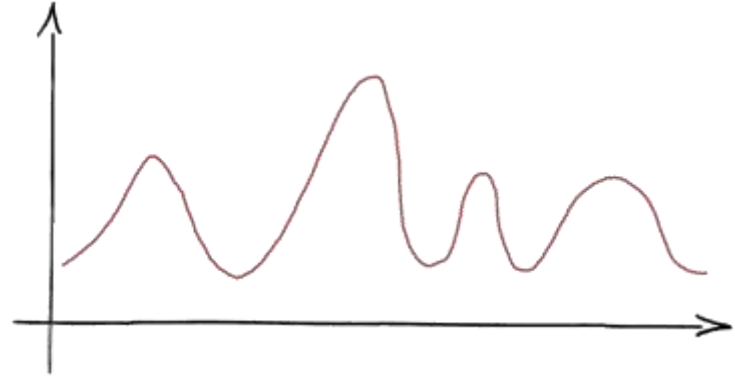
Seasonal interventions

- Easier to **optimally deploy** seasonal interventions when seasons are optimal



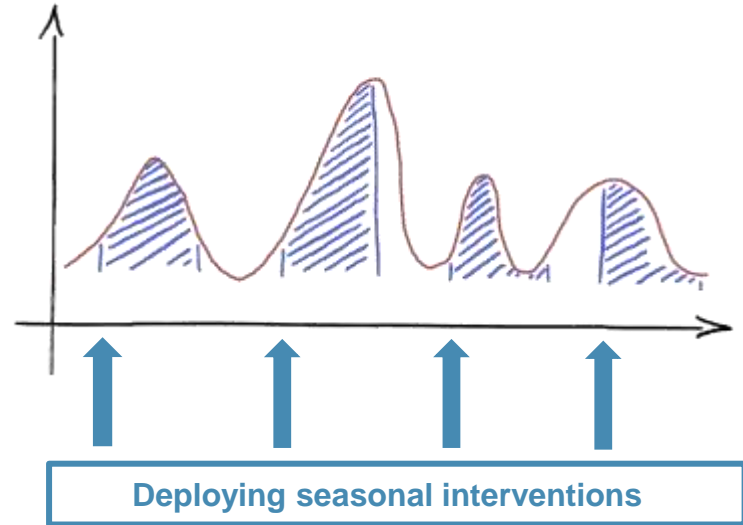
Seasonal interventions

- **Real-life data** are likely to have interannual variations



Seasonal interventions

- **Real-life data** are likely to have interannual variations
- Interannual variations may **interfere with optimal deployment** of seasonal interventions
- Goal: **include climate-induced interannual variations** into OpenMalaria



In short...

It is important for a model to **account for climate and its induced interannual variations!**

→ Potential **improvement for OpenMalaria**



In OpenMalaria

Entomological Inoculation Rate



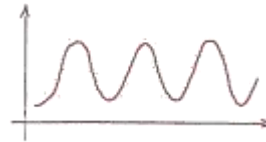
↓ FORCES

Emergence rate

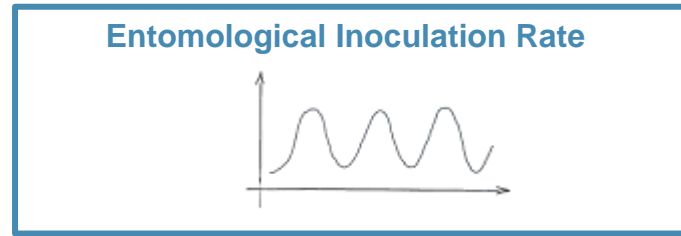


↓ DRIVES

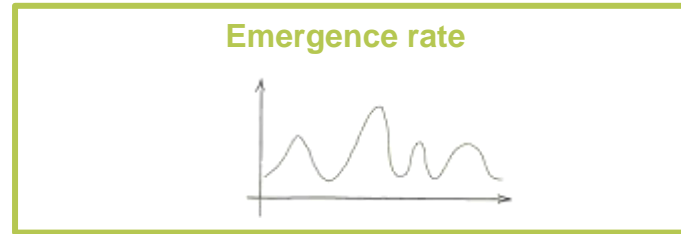
Malaria metrics (cases, incidence,...)



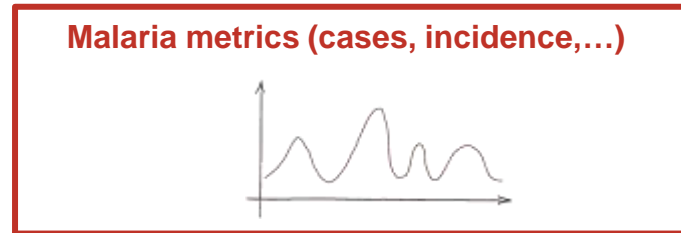
In OpenMalaria



FORCES



DRIVES



ADJUST

Using VECTRI

The VECTRI model

The OpenMalaria model

Building the hybrid model

Validation of the hybrid model



The VECTRI model

The OpenMalaria model

Building the hybrid model

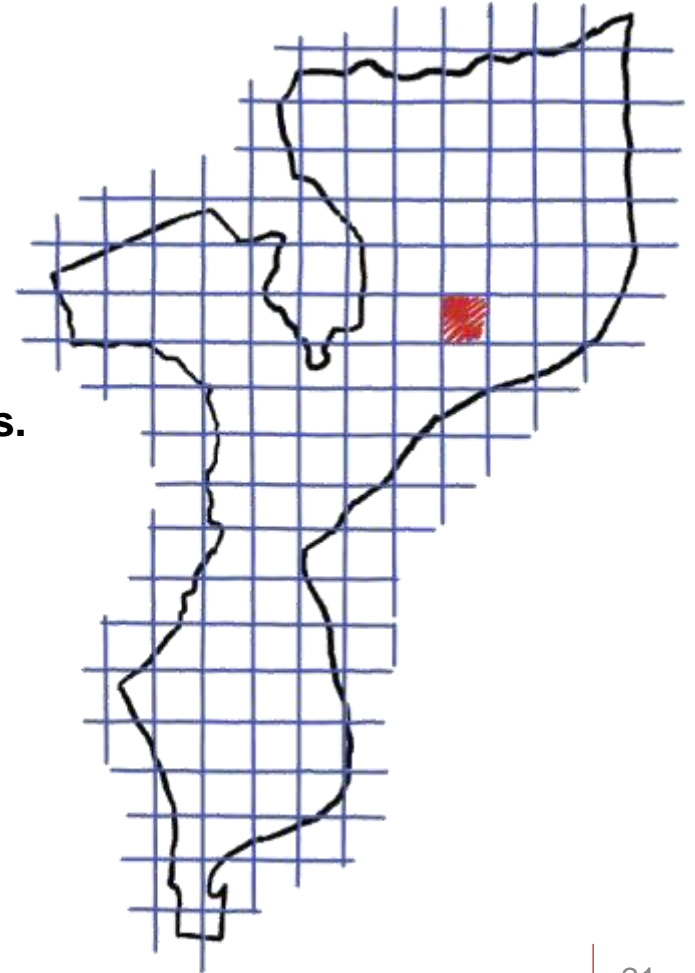
Validation of the hybrid model

Main objective: merging models



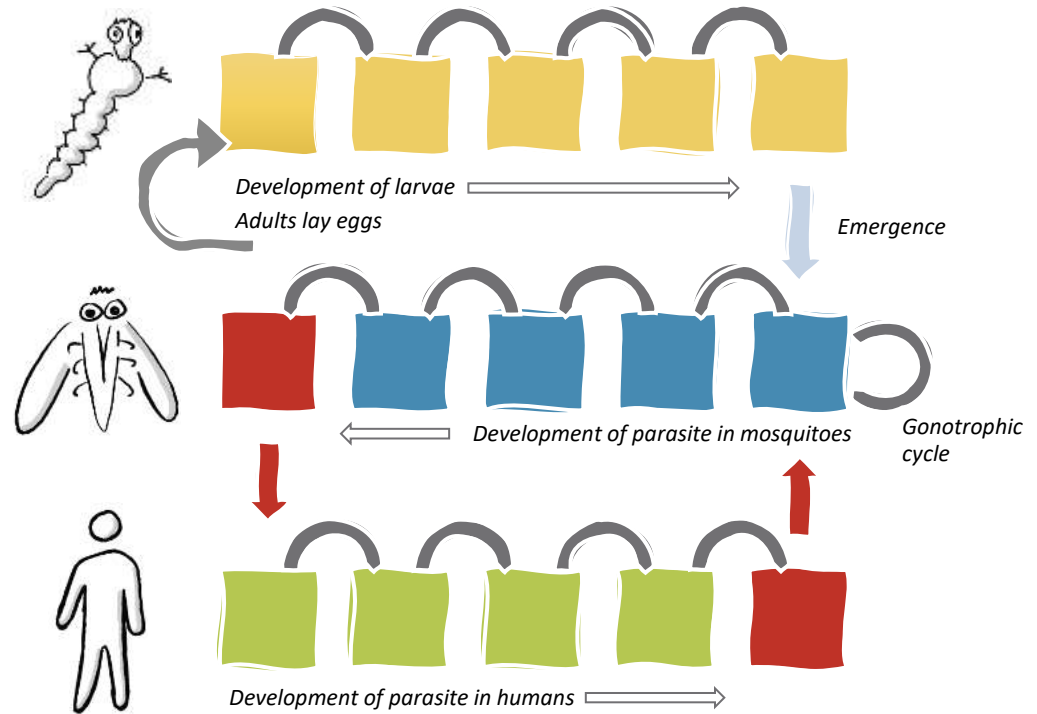
The VECTRI model

- Practically, a map is divided into **grid cells**.
- In each cell, we collect information about **climate and surface hydrology**.
- We can run the **simulation for every cell** (independently).



The VECTRI model

- Survival of larvae depends of **availability of breeding sites**
- Development rate of larvae depends on **water temperature**
- Gonotrophic cycles of adult mosquitoes depends on **air temperature**

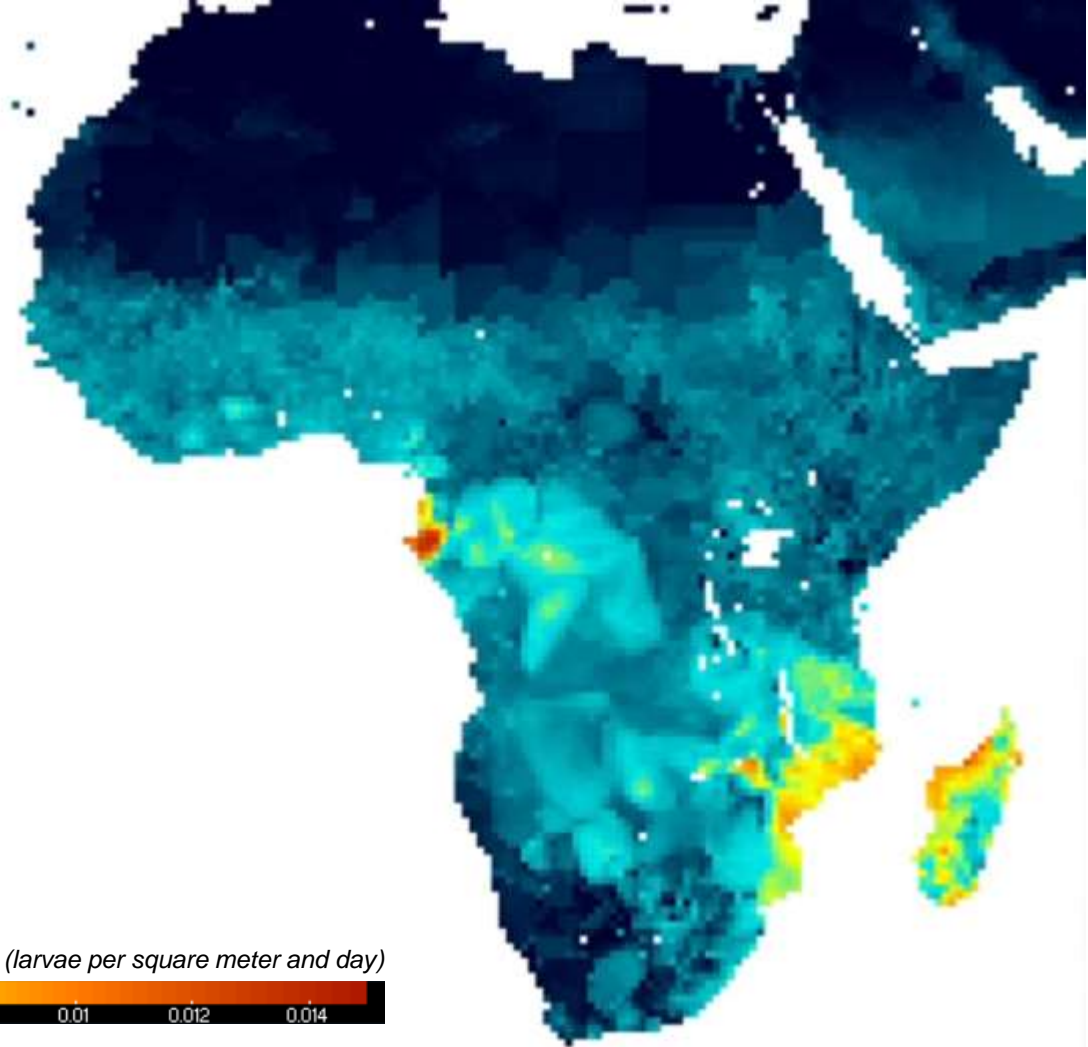


Additional notes on VECTRI

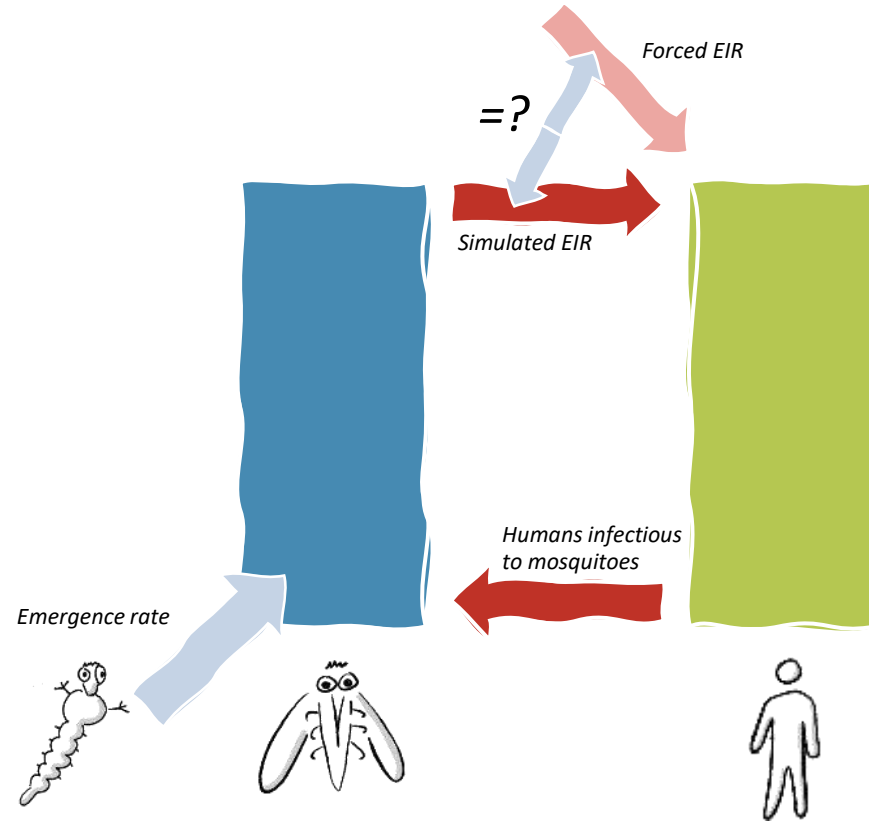
- Developed and maintained at the International Centre for Theoretical Physics (**ICTP**).
- Written in **Fortran**.

Emergence rate in VECTRI

Modelled emergence rate in Africa, 1990-2024 (larvae per square meter and day)

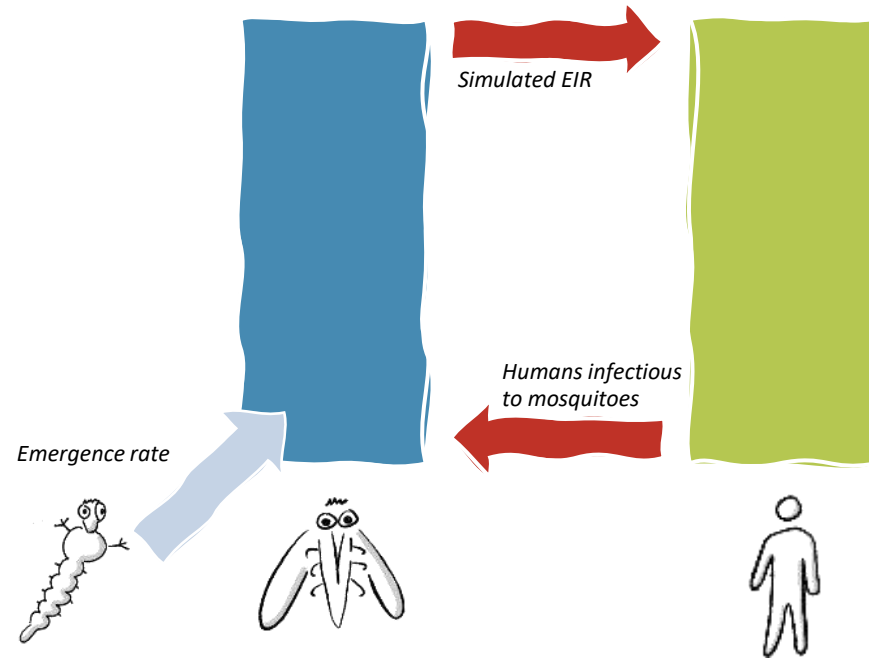


The OpenMalaria model



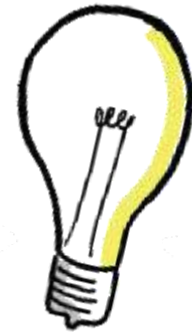
The OpenMalaria model

- Designed to integrate **interventions** – flexible!
 - **Within-host** dynamics for the human model
 - Detailed **health systems**
- But emergence rate is only **strictly seasonal**

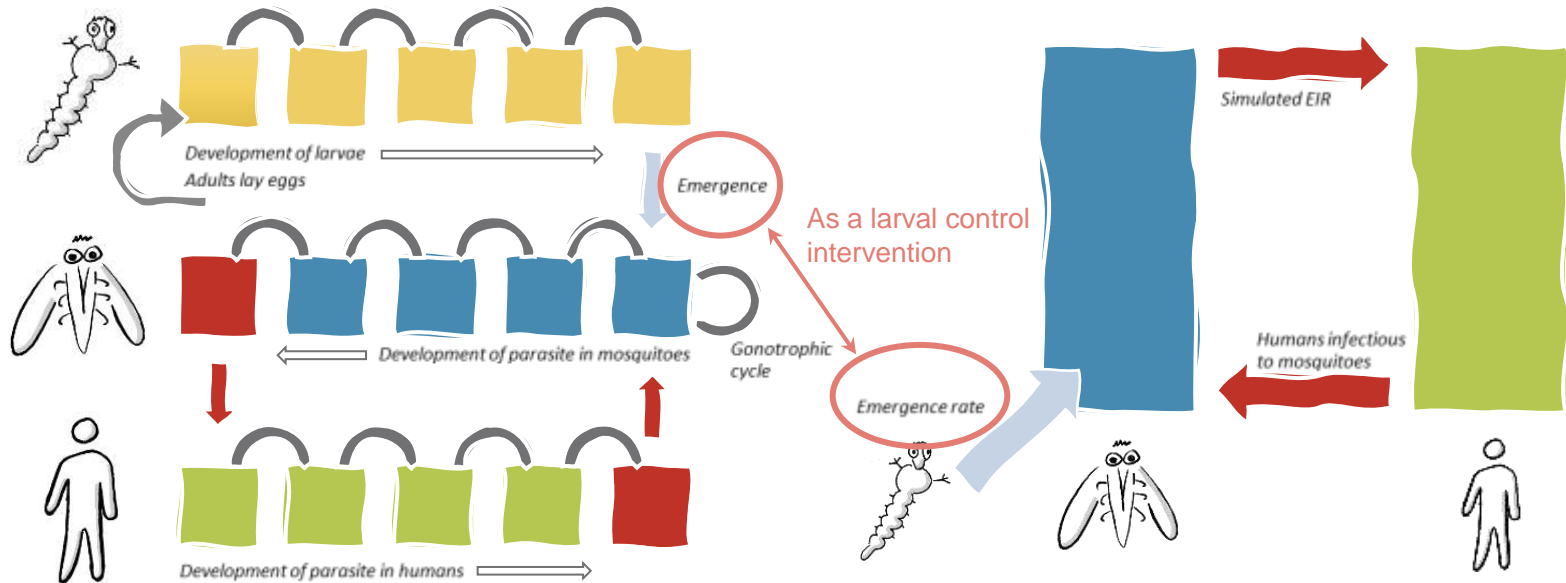


OpenMalaria and VECTRI

We can force the emergence rate in OpenMalaria to follow the cycles of the **emergence rate from VECTRI**.



OpenMalaria and VECTRI



The hybrid model...

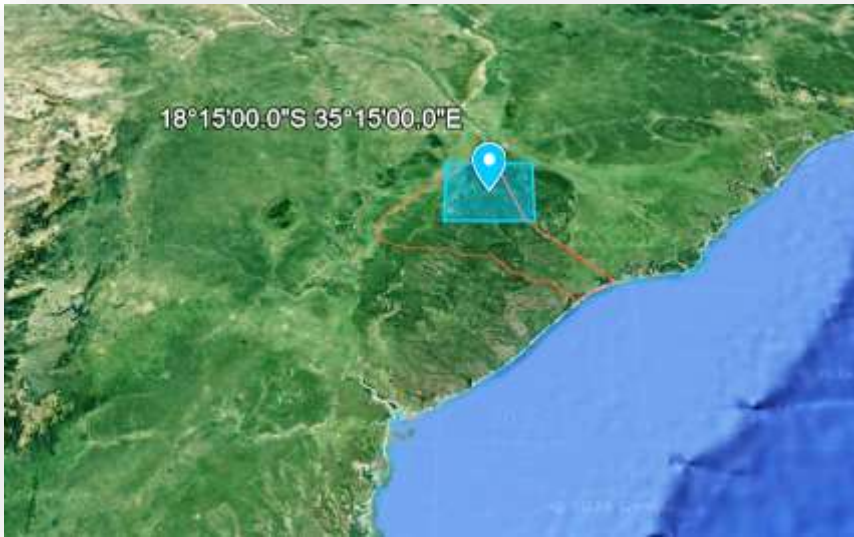
- Runs for a **specific location/study site**. Extract **climate data** (temperature and rainfall).
- Runs a climate-driven **VECTRI** simulation. Outputs annual entomological inoculation rate (EIR) and daily emergence rate.
- Runs **OpenMalaria** with constant year-round EIR values, using annual cumulated EIR from VECTRI.
- **Forces emergence rate** from VECTRI, as a larval control intervention.
- Accounts for **climate and interannual variations**.
- Might include **other interventions**.

In short...

We developed an **hybrid model** accounting for both **climate and interventions**.



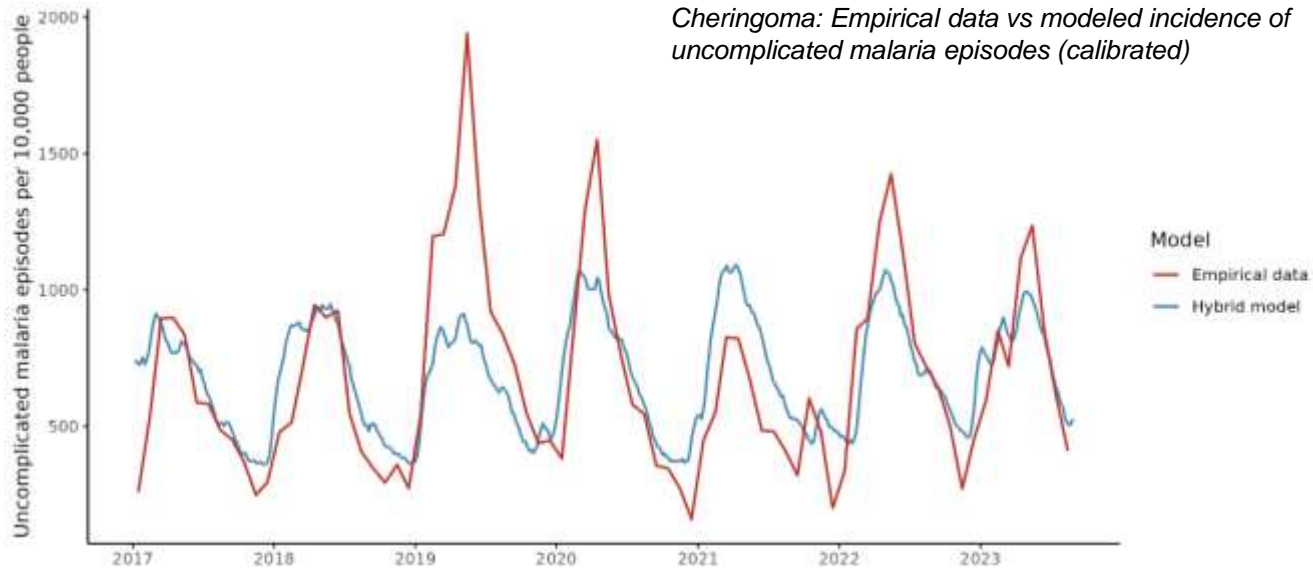
Model validation



Cheringoma district

Grid cell used for simulation

Model validation



Future work

- **Full calibration** of the model using Demographic and Health Surveys (DHS) data in Sub-Saharan Africa.
- Climate-interventions **interactions**.



Conclusion

- Development of OpenMalaria into a **climate and interventions**-based model.
 - Suited to analyzing the **impact of seasonal interventions**.
 - Accounts for **geographical** specificities.
- The hybrid model allows us to take the **best out of each model**.



Swiss TPH



Thank you for your attention!



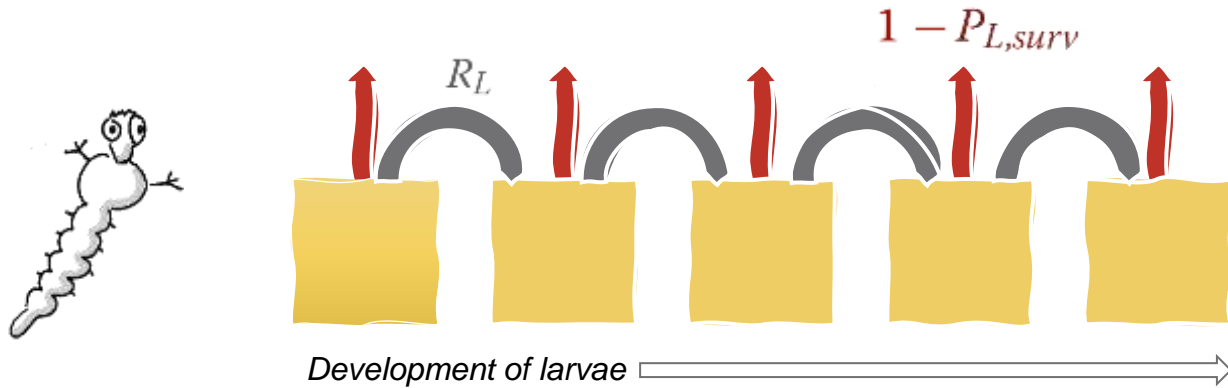
Acknowledgement

Nakul Chitnis, Swiss TPH

Adrian Tompkins & Cyril Caminade, ICTP

BILL & MELINDA
GATES foundation

VECTRI: larval stage



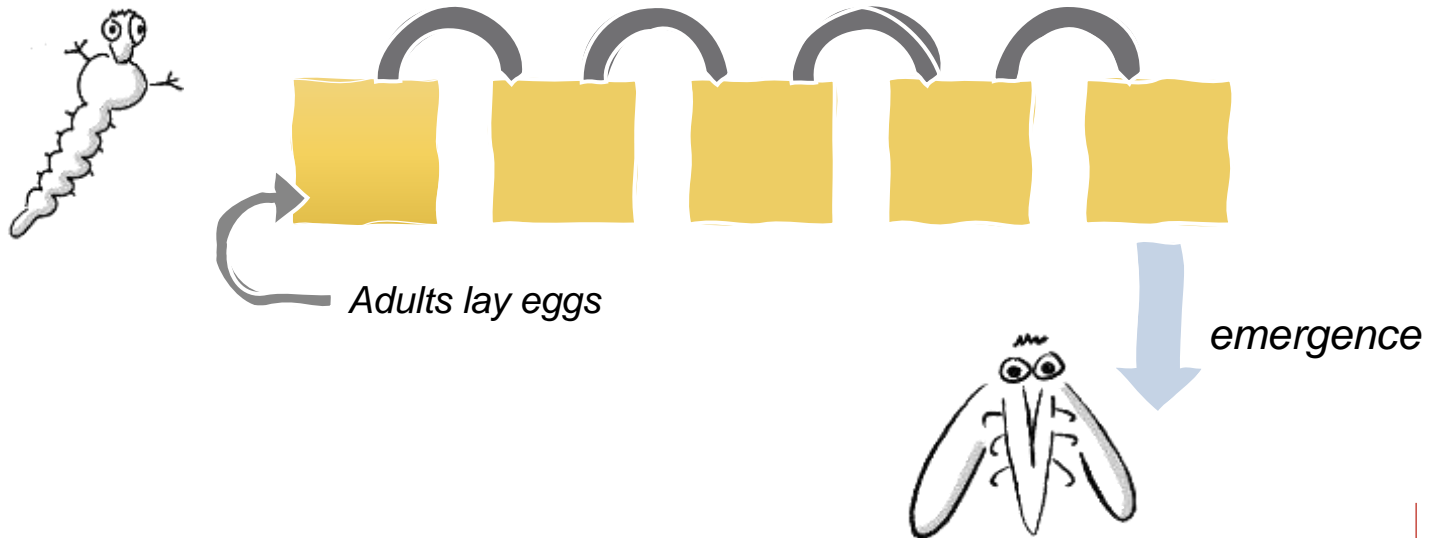
$$R_L = \frac{T_{wat} - T_{L,min}}{K_L}$$

Water temperature

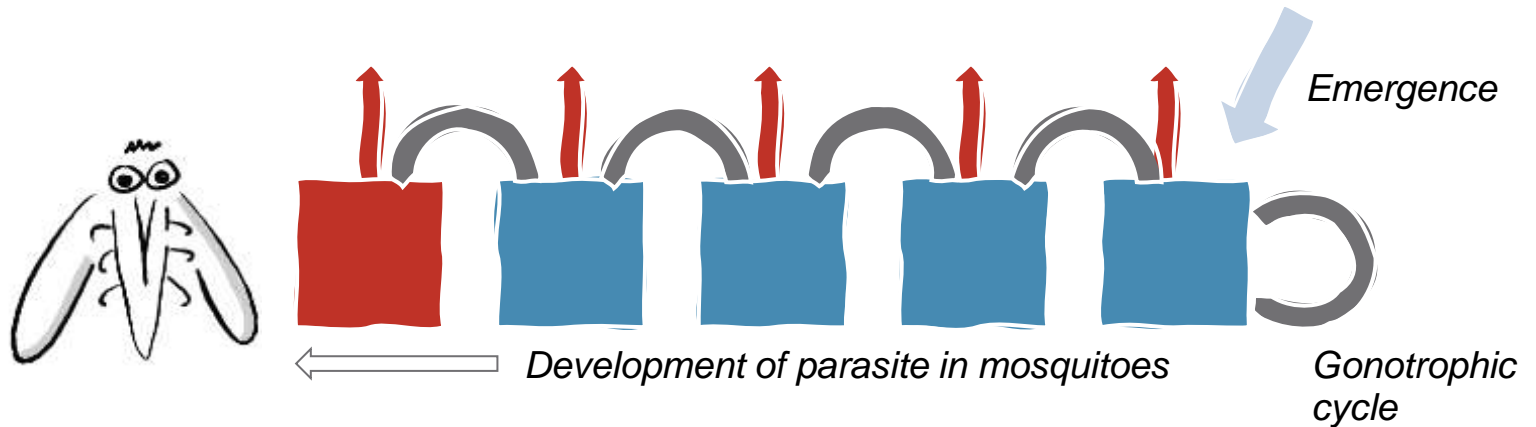
$$P_{L,surv} = \left(1 - \frac{M_L}{wM_{L,max}}\right) K_{flush} P_{L,surv0}$$

Availability of breeding sites

VECTRI: larval stage



VECTRI: adult stage



- Mosquito survival rate and parasite development is **(air) temperature-dependent**.
- Successful gonotrophic cycles rely on **human population** and spatial heterogeneity.

VECTRI: parasite in humans

