A combined statistical-dynamical approach to modelling spatio-temporal variations of malaria risk

Rachel Lowe[1,3], James Chirombo[2], Adrian Tompkins[1], Xavier Rodo[3]

1. International Centre for Theoretical Physics (ICTP)
2. Ministry of Health, Lilongwe, Malawi
3. Catalan Institute for Climate Science (IC3)

rachel.lowe@ic3.cat

4th AMMA International Conference, 6 July 2012, Toulouse, France

Malaria in Malawi

- Malaria leading cause of morbidity/mortality (>6 million episodes per year), >85% *Plasmodium falciparum*.

- Direct costs: treatment. Indirect costs: workdays lost agriculture/industry, absenteeism school.

- RBM Objective: under 5 and pregnant women access to personal and community protective measures.

- National Malaria Control Programme established in 2002 to coordinate control measures.

–Insecticide-treated mosquito nets (ITNS)

–Effective case management (diagnosis and treatment of illness within 24 hours)

–Acesss to intermittent preventive treatment (IPT) for pregnant women.

Malaria transmission

- CLIMATE
- Temperature
- Precipitation
- Humidity

Mosquito biology and breeding sites

- NON-CLIMATE
- Urbanisation
- Poverty
- Level of education

Human vulnerability and vector habitat


Malawi tourism


CDC


National Geographic


UNICEF

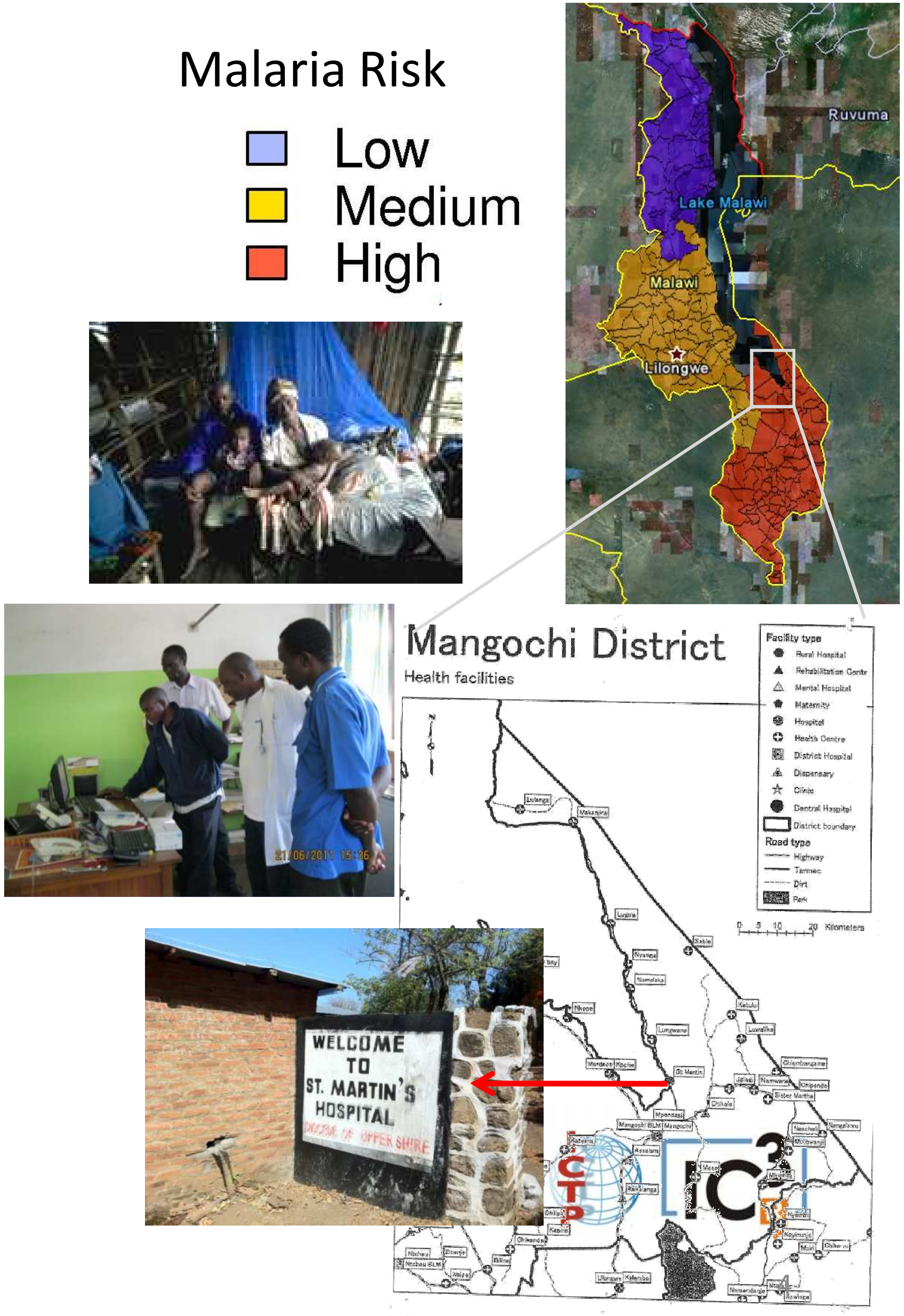
Research Questions

- To what extent can variations in malaria be account for by climate?

- Which non-climatic factors are important?

- Does inclusion of non-linear relationships between climate and the vector, captured by the dynamical model equations, improve model predictions in space and time?

- How can malaria early warnings be effectively disseminated to decision makers?



Malaria, demographic and socio-economic data

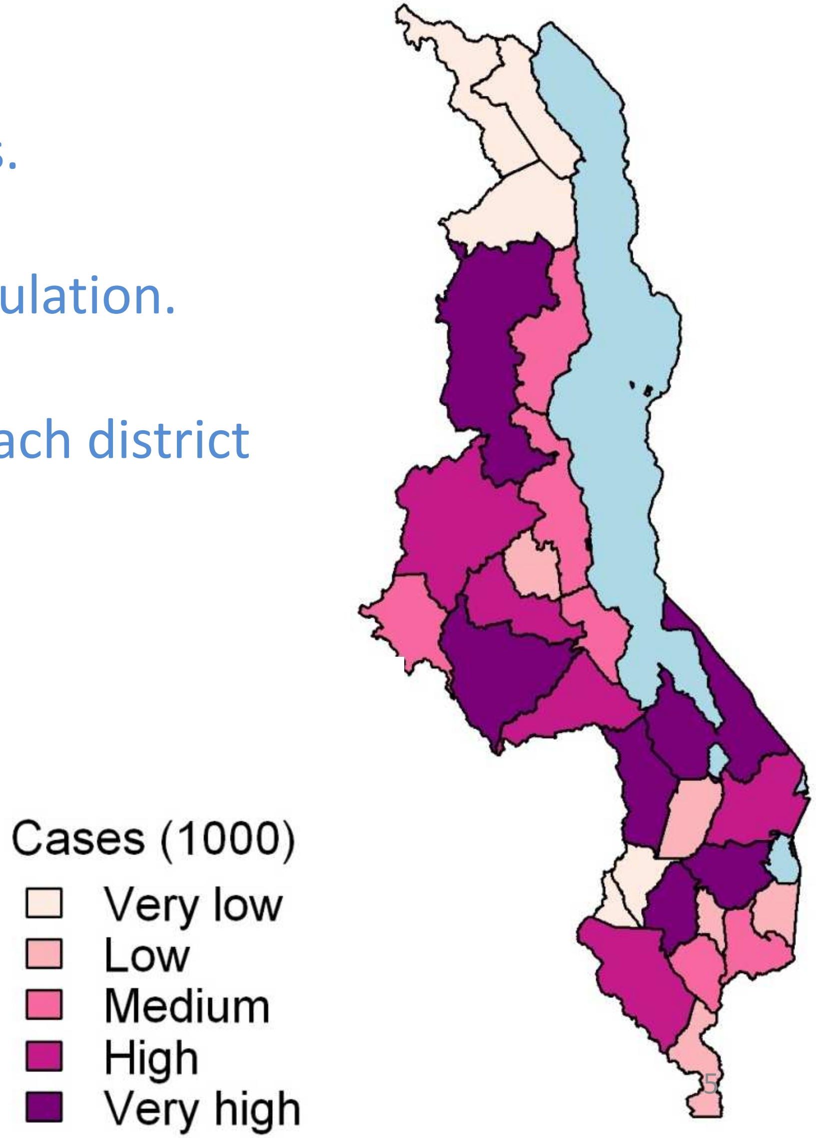
- Counts of malaria cases for under 5 and 5 years and over July 2004 – June 2011 (84 months).

- Annual population and density estimates.

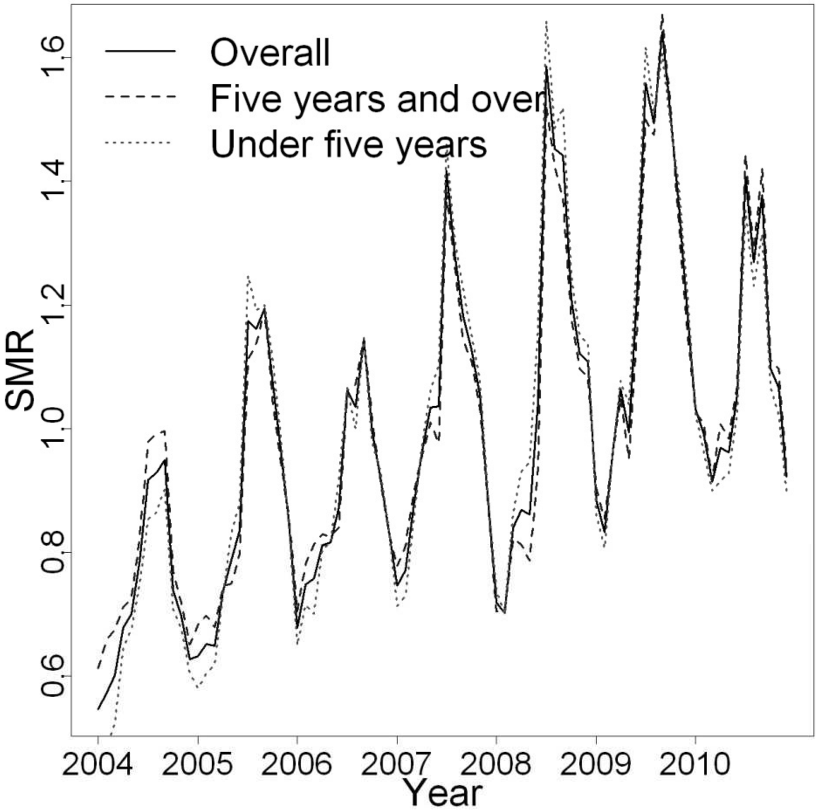
- Number of health facilities per 1000 population.

- Yearly estimates of ITN distribution for each district by different agencies: UNICEF, PMI

- Proportion of population in district
  - –Urban areas
  - –One room for sleeping
  - –No toilet
  - –Living in traditional housing
  - –Literate
  - –Do not attend school



Standardised Morbidity Ratio (SMR)

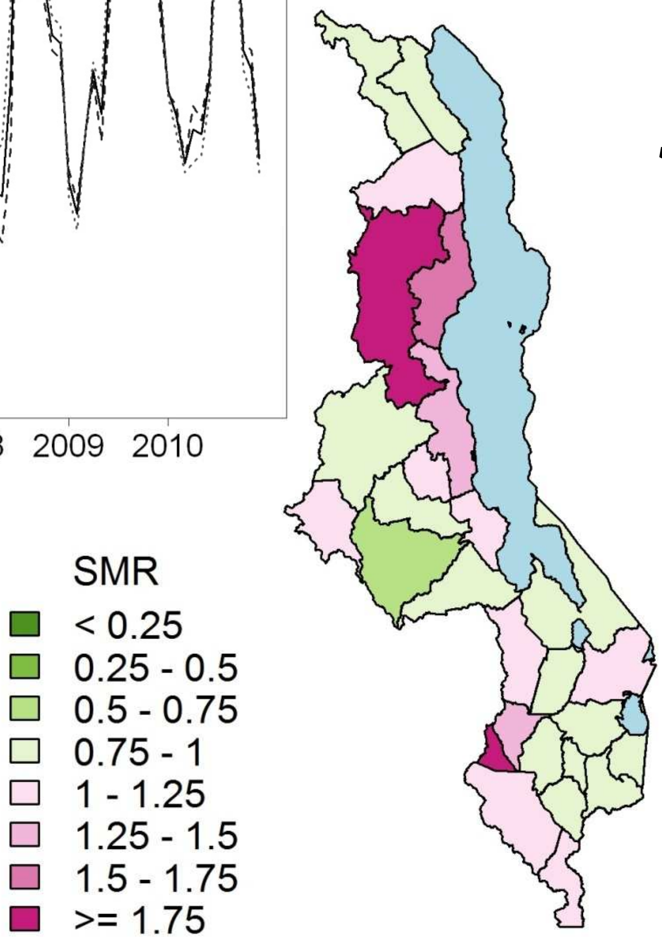


- SMR ratio of observed to expected cases
- Excess risk when SMR>1

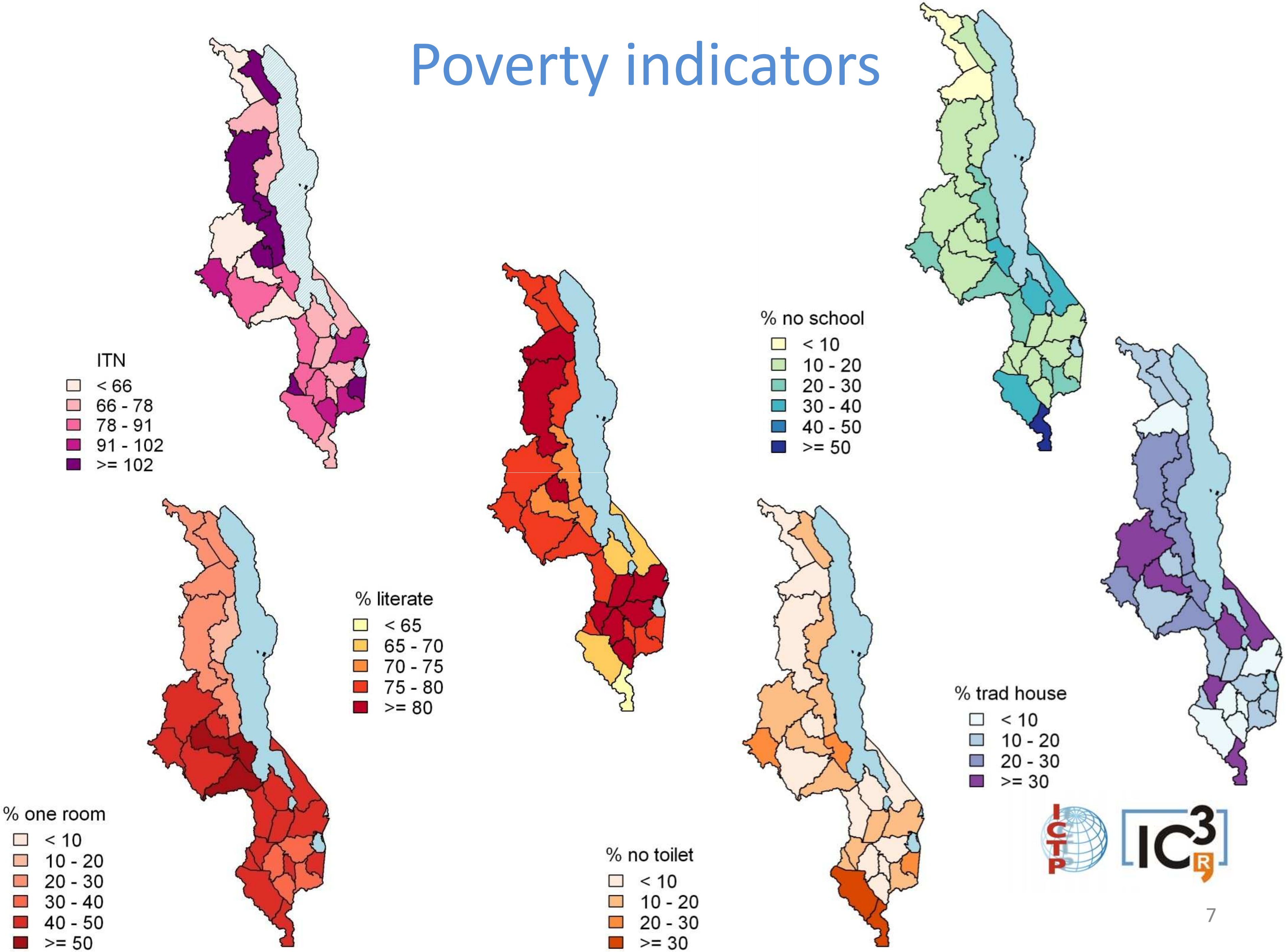
$$SMR_{st} = \frac{y_{st}}{e_{st}},$$

$$e_{st} = p_{st}\pi,$$

$$\pi = \frac{\sum y_{st}}{\sum p_{st}}.$$



Poverty indicators

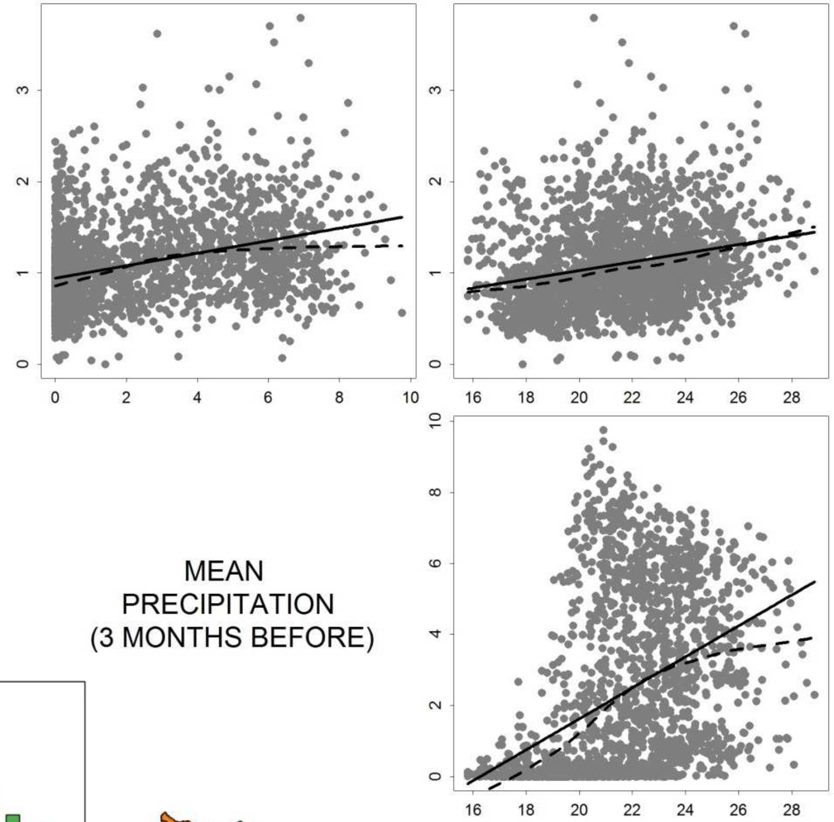


Climate information

- CPC FEWS-Net rainfall estimates based on satellite and rain gauge data

- ERA-Interim Reanalysis temperature data

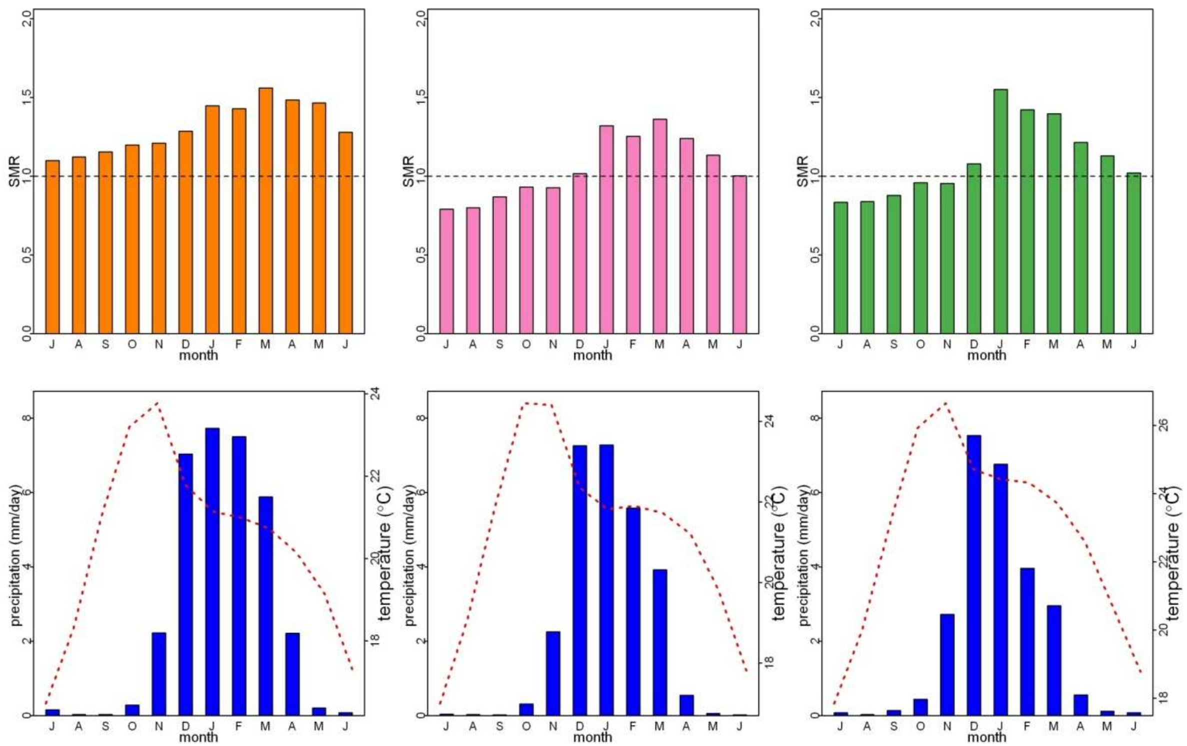
log(SMR)



MEAN PRECIPITATION (3 MONTHS BEFORE)

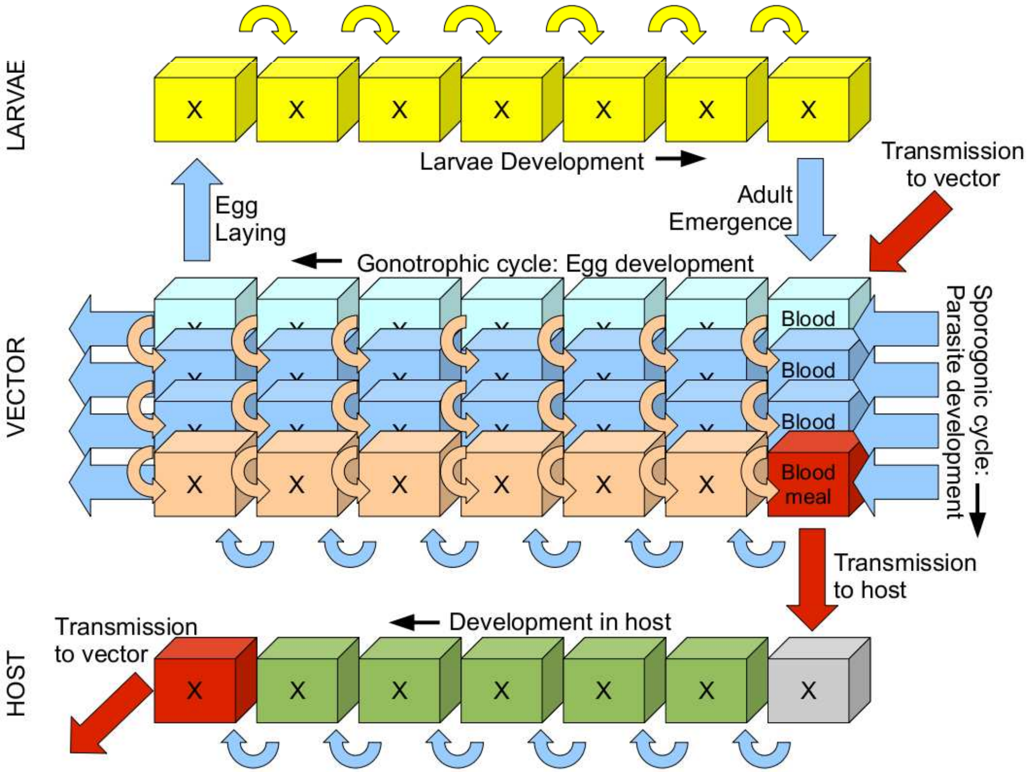
MEAN TEMPERATURE (3 MONTHS BEFORE)

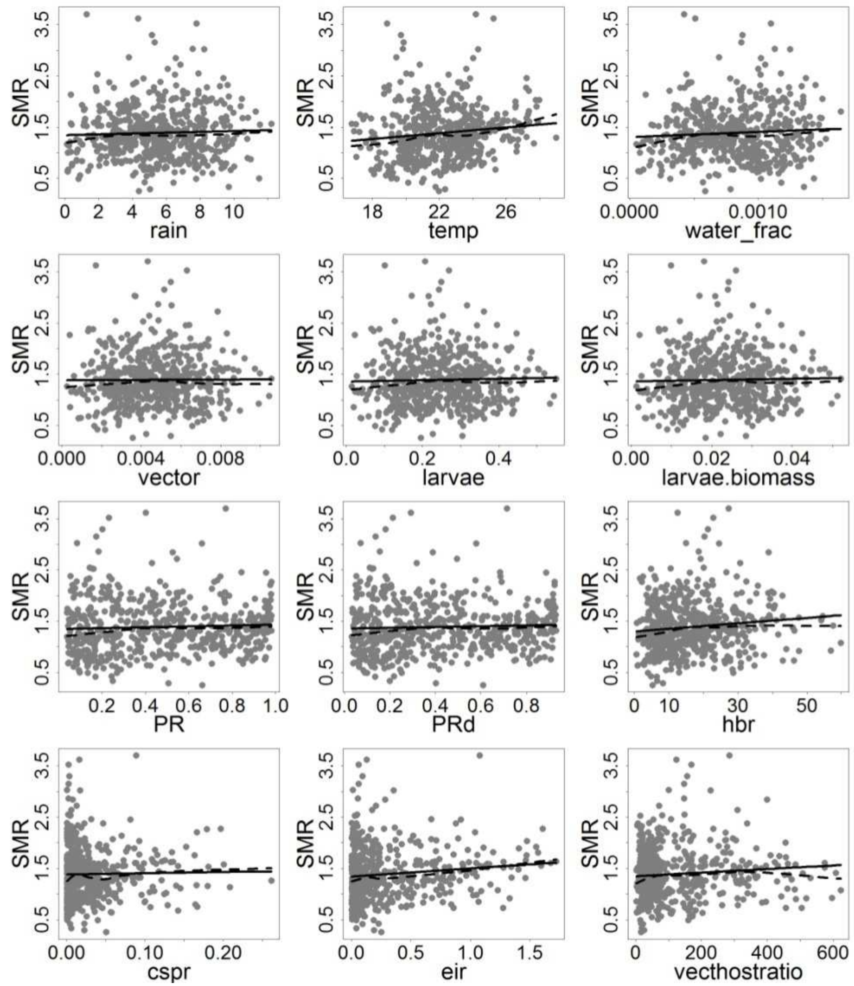
North **Central** **South**



How does climate impact malaria?

- VECTRI: VECToR-borne disease community model of ICTP.
- Incorporation of VECTRI output into model framework. Does this better represent climate influence on *Anopheles* mosquitoes than raw climate data?
- Model output: water fraction, vector-host ratio, larvae, human bite rate, parasite ratio, Entomological Inoculation Rate,…





Model framework

- Negative Binomial Generalised linear model framework used to test and select spatial, temporal variables, factors, interactions and polynomial terms.

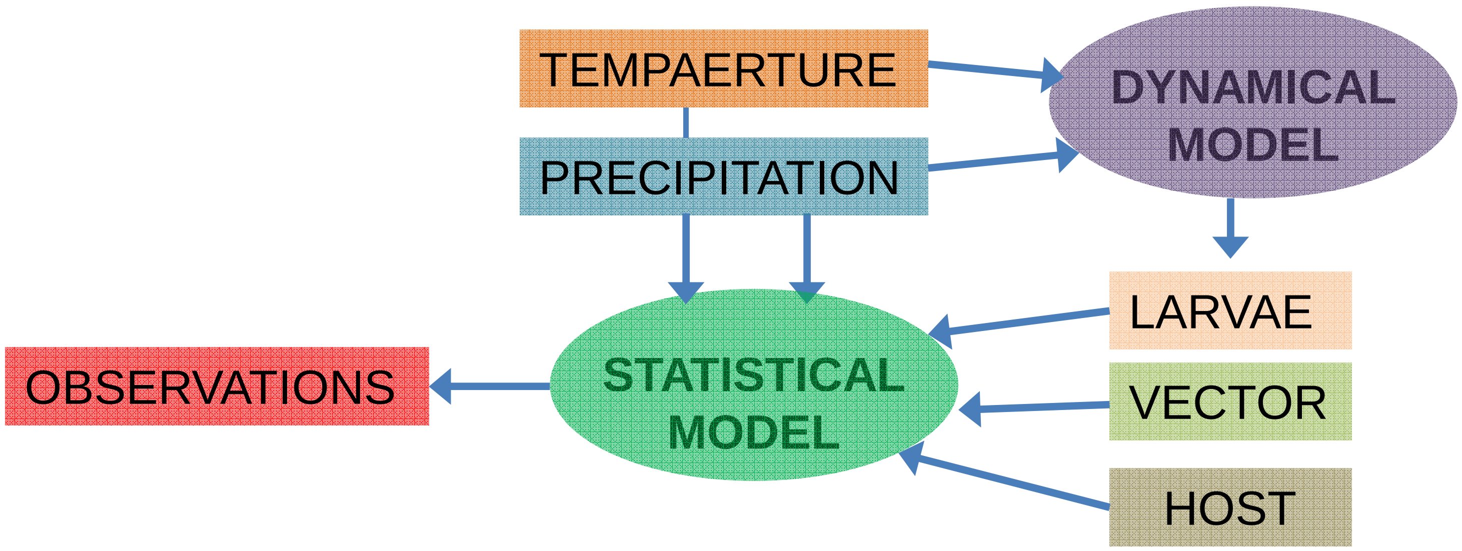
$$y_{stj} \sim NegBin(\mu_{stj}, \kappa)$$

$$\log \mu_{stj} = \log e_{stj} + \log \rho_{stj}$$

- Stepwise model selection using Akaike Information Criterion (AIC).
- **Categorical variables**: age group (under and over 5),region (north, central, south), zone (lowland, lake shore, highland and combinations), annual cycle.
- **Non-climate information**: Altitude, longitude and latitude (quadratic), demographic: urbanisation, population density, housing condition: one room for sleeping, no toilet, health facilities per population, education level.
- **Climate information**: temperature and precipitation (averaged over previous 3 months – precipitation: quadratic association).
- **Dynamical model output**: vector density, larvae density, human bite ratio, proportion of infective vectors, Entomological Innoculation Rate, vector to host ratio

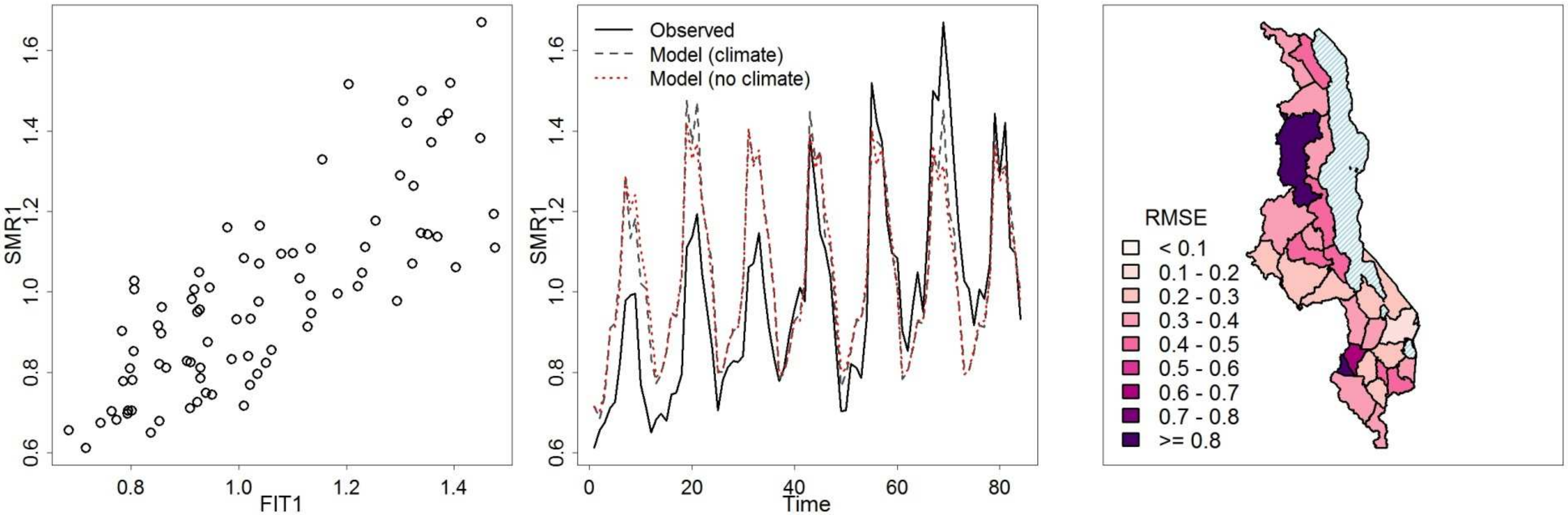
Does the use of a physically based non-linear operator for climate information improve model?

Model	AIC	R^2_{ad}
non-climate	82501	0.395
+climate	82450	0.402
+dynamical	82434	0.404
combined	82384	0.411

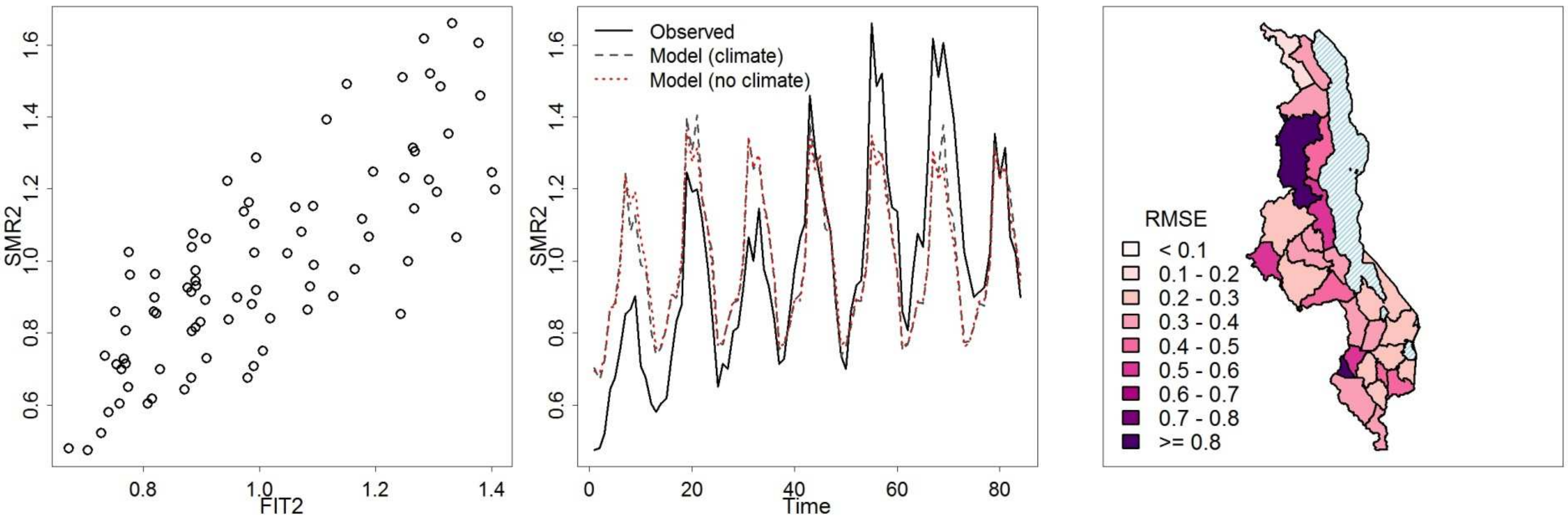


Model results

Over five



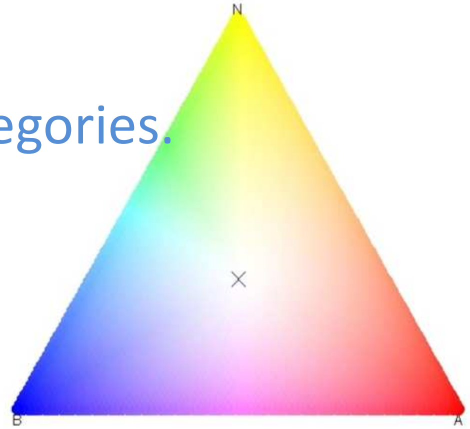
Under five



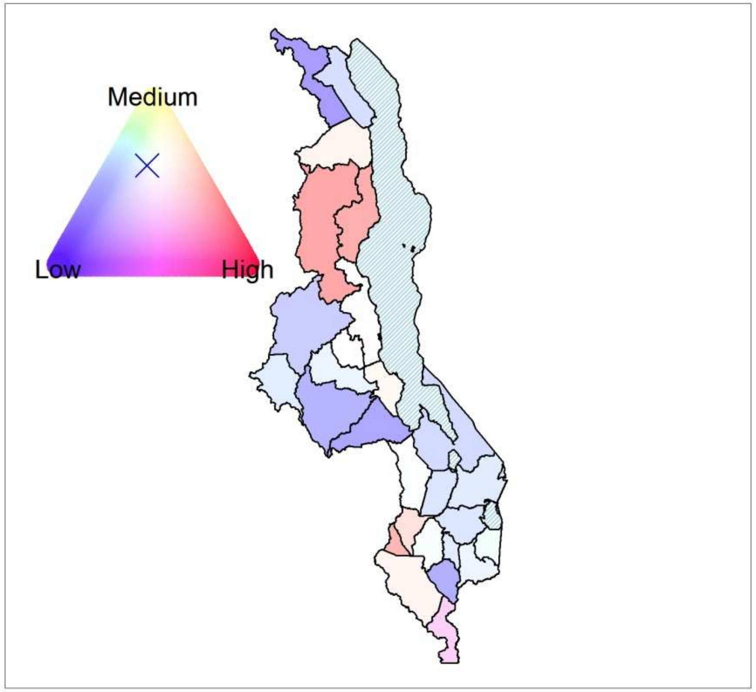
Communicating probabilistic predictions to decision makers

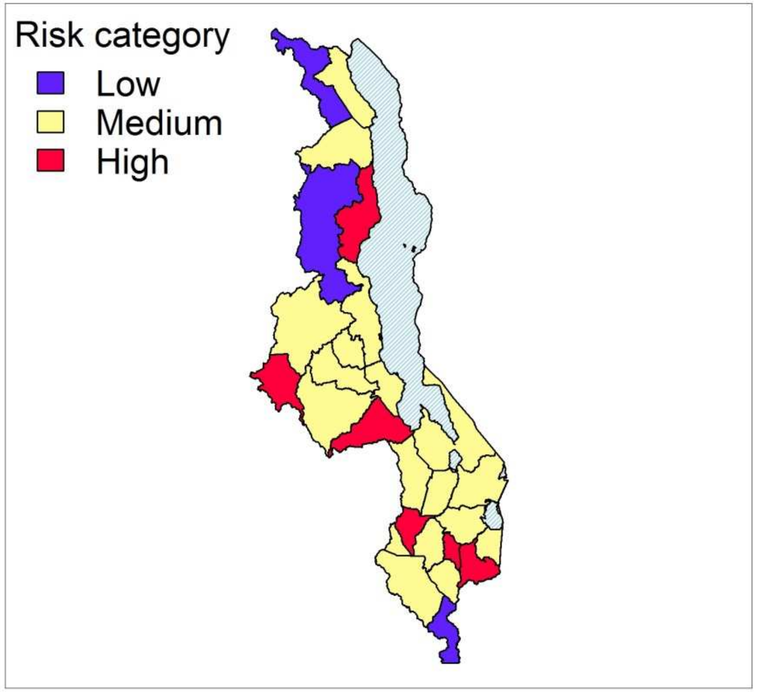
- Visualisisation technique (Jupp et al., 2012) to convey probability of malaria risk falling within pre-defined risk categories.
- NEW: R package ‘ternvis’

http://cran.r-project.org/web/packages/ternvis/ternvis.pdf



Probability map January 2010, category boundaries: SMR=1 and SMR=2





Conclusions

- Climate significant predictor of malaria in space and time, explains very small % inter-annual variability.
- Important consider other spatio-temporal factors that influence malaria.
- Incorporating dynamical model input, to capture non-linear effects of climate on the vector and disease marginally improves the model fit.

Further work

- Continue test usefulness dynamical model output in statistical models.
- Identify missing information using structure of random effects.
- Bayesian framework: provide probabilistic predictions of malaria risk (Lowe *et al*., 2011, Lowe *et al*,. in press).
- Extent to which climate forecasts extend predictive lead time.
- Integrate ensemble of QWeCI disease models to predict malaria.
- Test model framework more fully in other locations.

Merci beaucoup