Regional seasonal forecasting activities at ICTP: climate and malaria

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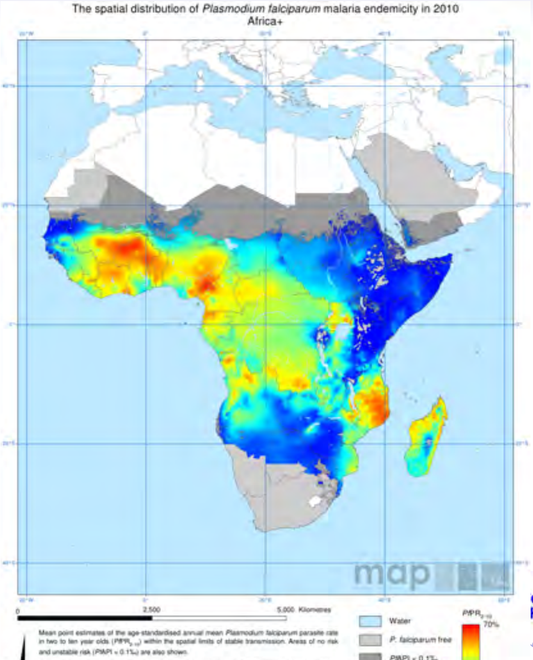
- Climate and malaria
- VECTRI: The new ICTP malaria model
- Projects: QWeCI, HEALTHY FUTURES and ISIMIP
- VECTRI/ECWMF Malaria monthly to seasonal forecasts

Malaria caused by the plasmodium parasite, of which 4 species are known to infect man. Two are wide-spread and particularly dangerous, falciparum and vivax. It is spread by the anopheles genus of mosquito (Fig. 1).

Figure: anopheles gambiae vector

Vivax can lie dormant in the liver for weeks to years and cause frequent relapses, while falciparum has wide-spread drug resistance and causes the most fatal cases due to the potential cerebral complications.

Many of these deaths occur in Africa where high parasite rates (PR) are observed over large regions (Fig. 2). Immunity is high in endemic regions, under 5s are most at risk.



- Epidemic regions are usually found on the transmission fringes and are associated with temperature and/or rainfall seasonality (Fig. 3).
- Epidemic areas - low immunity, whole population at risk - forecasts potentially very useful for early warning.
- Epidemic belt on the Sahel fridge is associated with rainfall variability, while cold temperatures reduce or eliminate malaria incidence at high altitudes over eastern Africa.

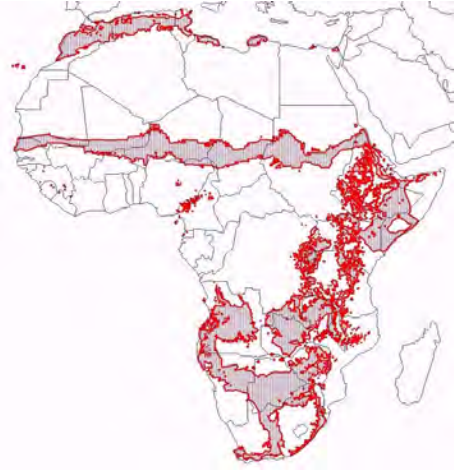


Figure: Malaria epidemic zones - from ?

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- Vector borne diseases such as malaria have a “climatic niche”
- Both the vector and parasite are influenced by weather

However many other factors can reduce the disease range:

- land use changes such drainage or wetland cultivation
- interventions: bed nets, spraying, treatment
- socio-economic factors: access to health facilities, population density, migration, poverty
- vector predators, competition and dispersion limits

Figure: pond spraying

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Climate variability may offer some potential predictability therefore to help planners:

- short-medium term: prediction of outbreaks in epidemic areas
- short-medium term: potential prediction of seasonal onset in endemic areas
- decadal timescales: potential shift of epidemic areas to higher altitudes [1,], shifts in response to rainfall, and associated changing epidemic and endemic patterns.

Climate variability may offer some potential predictability therefore to help planners:

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Role of climate change relative to socio-economic factors and interventions remains controversial.

Climate drivers of malaria

- Rainfall : provides breeding sites for larvae.
- Temperature: larvae growth, vector survival, egg development in vector, parasite development in vector.
- Relative Humidity : dessication of vector.
- Wind : Advection of vector, strong winds reduce CO_2 tracking.

Two bites are required to pass on the disease (Fig. 5:)

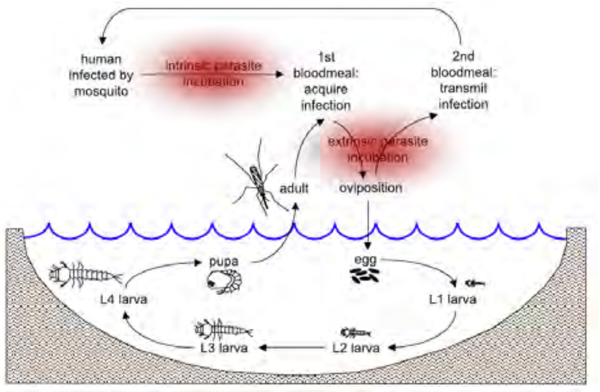
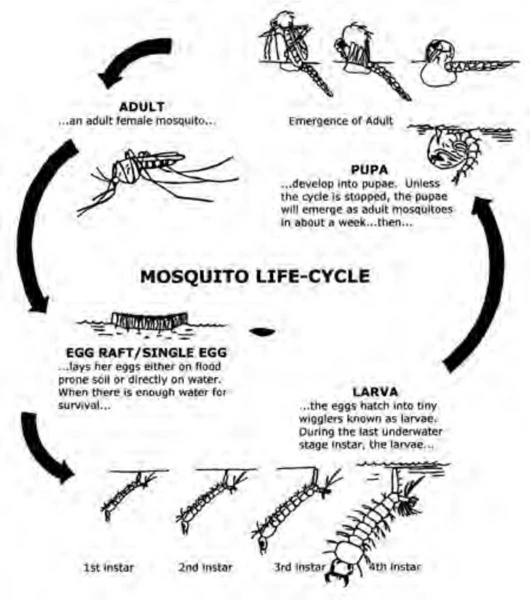


Figure: schematic of transmission cycle from [2]

What came first: the mosquito or the egg?



As temperature increases

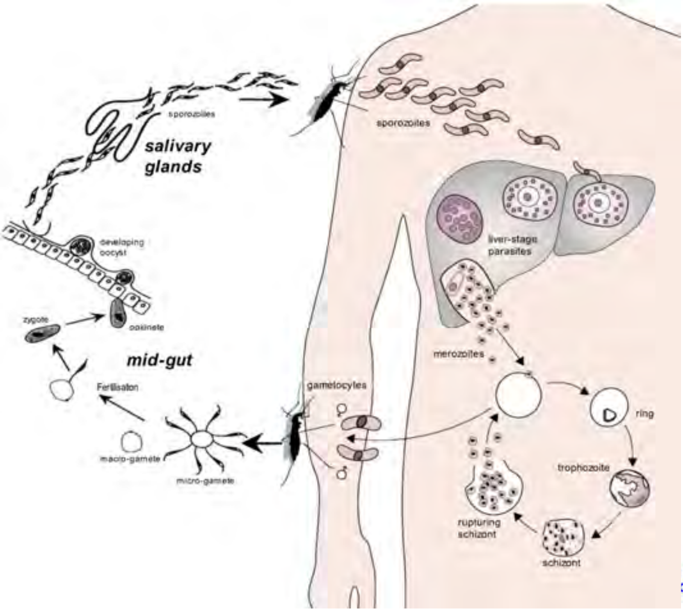
- Larvae development speeds up in warmer ponds
- Gonotrophic cycle: Eggs development in vector speeds up (Degree days concept)
- But high temperatures $> 39C$ kill vector
- And high water temperature $> 35C$ kill larvae

Cycle in host takes 10-26 days

Sporogonic cycle

Cycle in vector is temperature dependent (threshold 16-18C, 111 degree days)

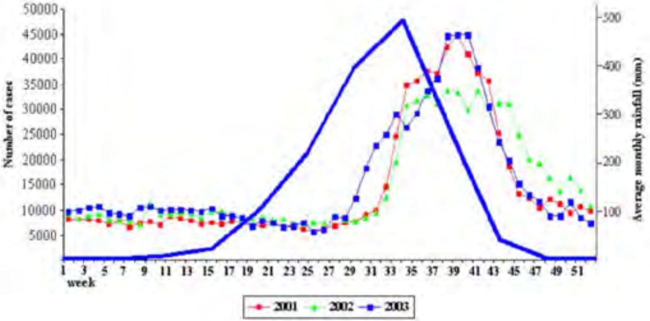
Not all bites on infective host or by infected vector lead to transmission (probability estimated at 20-30%)



Rainfall

- Water required for breeding.
- Anopheles Gambiae prefers natural sunlit puddles.
- highly nonlinear relationship (flushing)

Example from village in SW Niger from Bomblies et al. (2008)



Blue - Rainfall

Dots - Malaria cases in 3 seasons

Modelling malaria: Some existing dynamical models

Some models have divided the categories into many sub-categories, or *bins*, or order to try and model delays in e.g. adult emergence, and have been applied to spatial modelling. Two examples of existing models: represent the 'bounds', run on coarse (100km) and very fine (10m) resolutions.

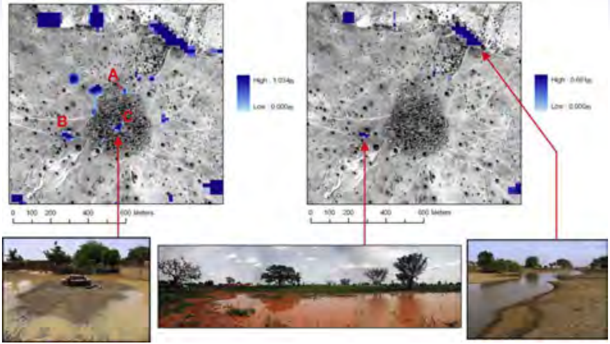
Liverpool Malaria Model LMM

- Rainfall affects larvae birth/death rate
- Temperature affects sporogonic/gonotrophic cycles and vector death rate
- 100 humans per grid cell, tuned for rural locations on coarse grid-cells

Bomblies model

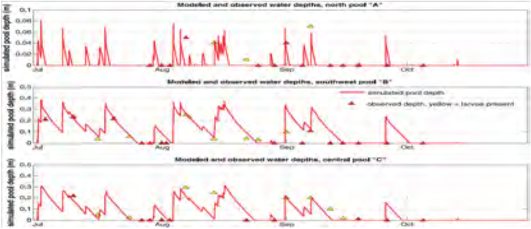
- Similar temperature and rainfall relationships
- Runs on village scale with 10m resolutions
- tracks every human and mosquito!

[3, 4, 5, 2]



Modelled pond behaviour - However the aggregated effect of these small water bodies could be represented by a pond parametrization in a coarser scale model

Bomblies et al. 2008



VECTRI: VECtor-borne disease community model of ICTP, TRIeste

http://www.ictp.it/~tompkins/vectri

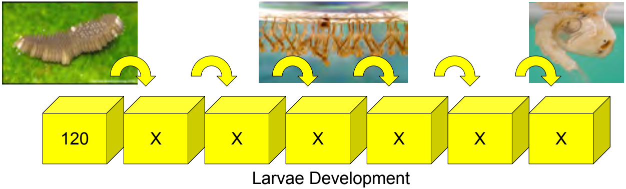
A model that incorporates the impact of weather on malaria with

- a reasonable surface hydrology, running at over regional scales with resolution down to 1km
- That incorporates population interactions (migration, immunity) and interventions (spraying, drugs, bednets).

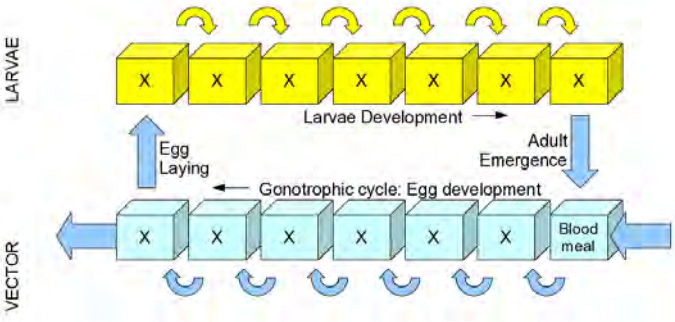
to attempt to address such questions as

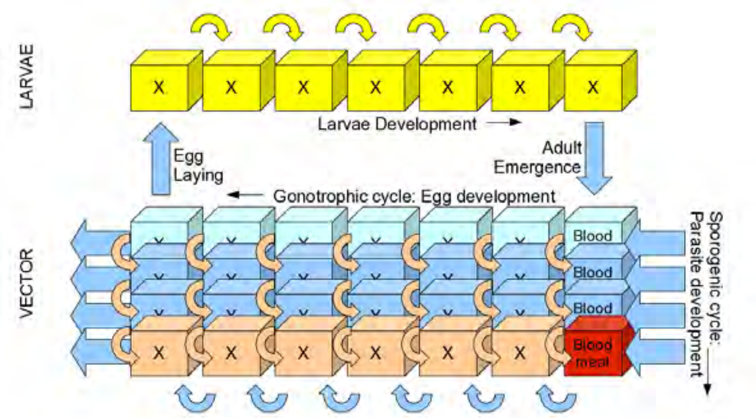
- Can malaria epidemics be predicted in advance?
- Is there useful information that can be derived in endemic areas (e.g. earlier than usual onset)?
- Does a model need to know about microclimates in temperature and humidity in order to predict regional scale malaria intensity?

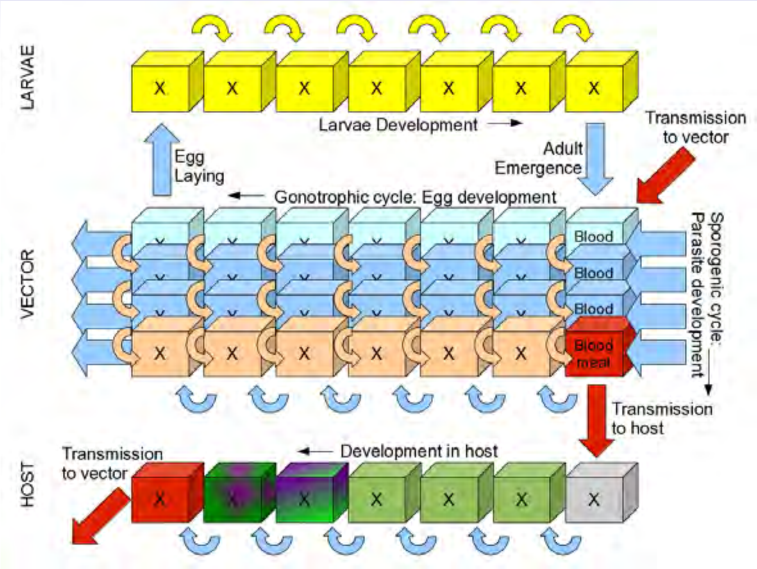
The larvae lifecycle is divided into stages or “bins”. Each model timestep, larvae ’progress’ from left to right, with the rate determined by temperature.



We now add the subclasses for the vector gonotrophic cycle.



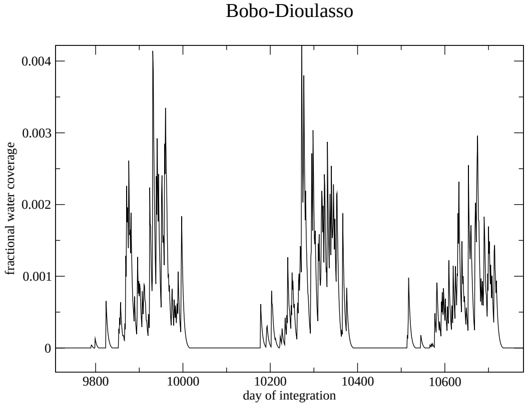

LARVAE
X
Larvae Development
Egg Laying
Adult Emergence
Gonotrophic cycle: Egg development
VECTOR
Blood
Blood
Blood
Blood meal
Sporogenic cycle: Parasite development


LARVAE
VECTOR
HOST
Larvae Development
Transmission to vector
Adult Emergence
Egg Laying
Gonotrophic cycle: Egg development
Blood
Blood
Blood
Blood meal
Sporogenic cycle: Parasite development
Transmission to host
Development in host
Transmission to vector

The rate of change of fractional pond coverage a is given by

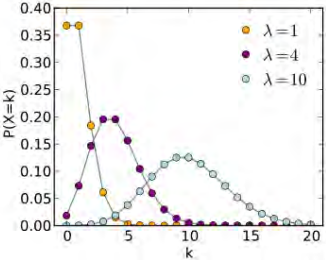
$$\frac{da}{dt} = KP - I - E - \frac{a}{\tau_r} \quad (1)$$

- P is the precipitation rate
- K is related to the aggregate pond/coconut geometry - the puddle parametrization!
- I Infiltration should be related to soil type (coconut=0).
- E Evaporation should be related to meteorology



VECTRI: biting rate

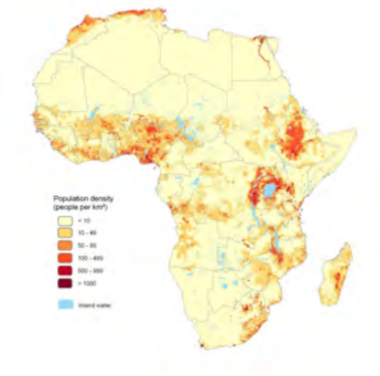
- Mean number of bites per human $B = V_b/D$ biting vectors density/population density
- Assume random distribution (no tastier people!)
- bednet (BN) use can be accounted for $B^* = \frac{V_b}{D(1-BN)}$
- single-bite malaria transmission probability is integrated over Poisson distribution to give transmission probability



$$P_{vh} = (1 - P_{bednet}) \sum_{n=1}^{\infty} G_{B^*}(n) P^n_{v_i h} \qquad (2)$$

where G_B is the Poisson distribution for a mean bite rate B^*

VECTRI: biting rate



- AFRIPOP data used on a 1km grid (thanks Dr. Catherine Linard) or GRUMP on 5km grid (global)
- Present day maps for seasonal forecasting purposes
- For future scenarios, GRUMP/AFRIPOP scaled by AR5 SSP country growth scenarios (no urbanisation trends).
- Data on migration will be extremely important for incorporation in VECTRI (in-country records, lights, mobile phone statistics)

Multiple year gridded runs

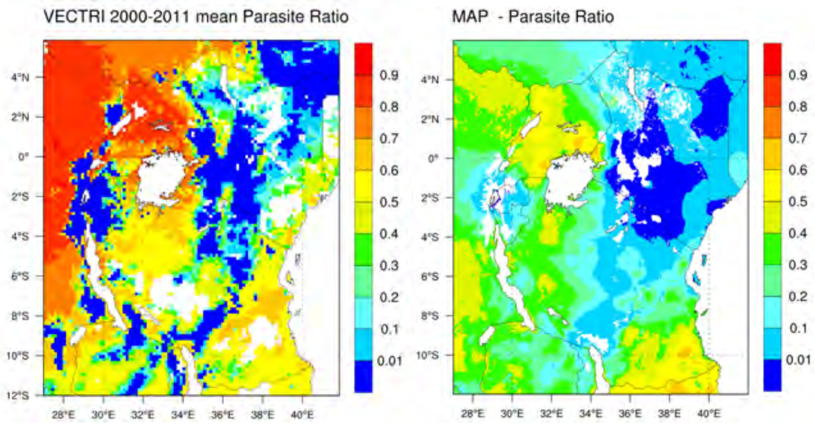
Testing has been conducted in equilibrium modes, and point-wise integrations driven by daily station data compared to a large number of research field studies measuring parasite rate (PR), infectious biting rate (EIR). See Tompkins and Ermert 2012 for details.

As a move towards the forecast system, VECTRI also run in a gridded mode for different regions of Africa.

Basic Set up:

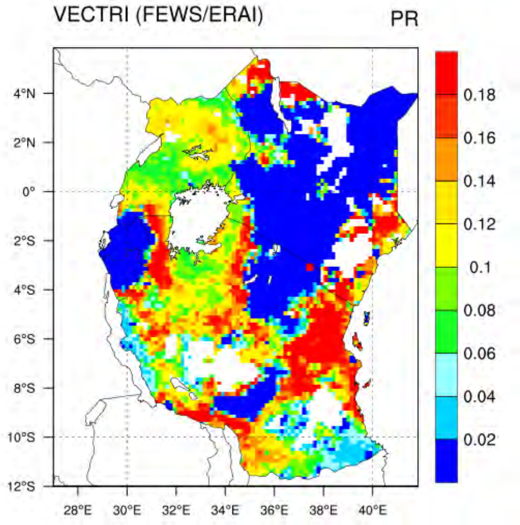
- Integration 10 years, 10-20km spatial resolution.
- Rainfall data: FEWS RFE 2.0v (10km)
- Temperature data: ERA-Interim T2m (80km) - downscaled using lapse-rate based topography adjustment.

VECTRI vs MAP Parasite Rates (PR)



MAP data from http://www.map.ox.ac.uk/

Standard deviation of parasite rate for July



- Variations high in epidemic zones as expected
- “border regions” between lowland endemic and highland epidemic also highlighted; susceptible to climate change?

Force of infection and EIR

Generally the division between epidemic and endemic regions is governed by the force of infection.

entomological inoculation rate

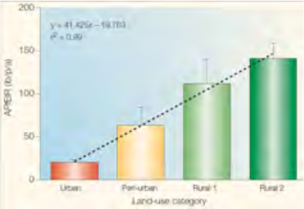
A good measure of the force of infection is the entomological inoculation rate (EIR) which is the number of infected bites per person per unit time.

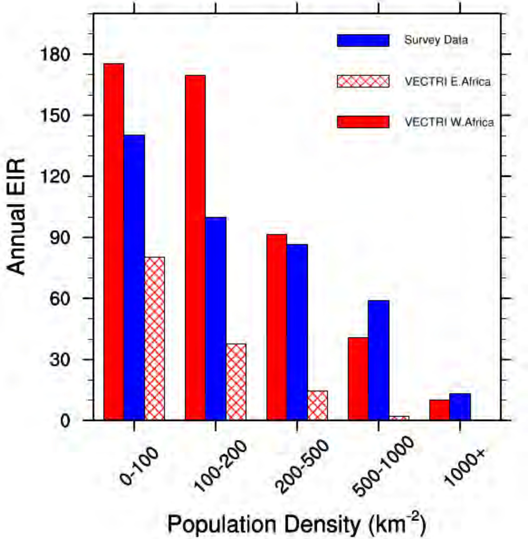
An EIR of around 10 infected bites per year marks the division between epidemic and endemic areas.

EIR - infective bite rates

VECTRI run for E/W Africa compared to Kelly-hope and McKensie (2009)

Hay et al. (2005)

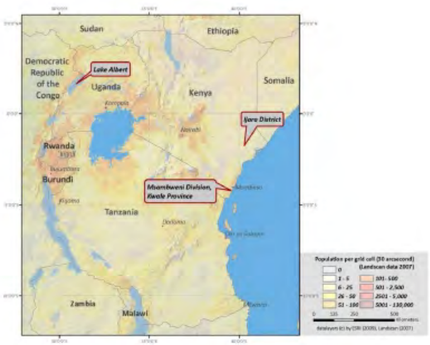




Healthy Futures

Coordinated by David Taylor (formally TCD, now at Singapore national university).

- Runs 2011-2015 (4 year), equal partition between European and African partners
- Examining decadal to century climate-change timescales
- Focussed in Eastern Africa: Tanzania, Rwanda, Uganda, Kenya
- Three target diseases
  - Malaria
  - RVF
  - Schistosomiasis



Has permitted ICTP to build close links to ministry of health in Rwanda and Uganda

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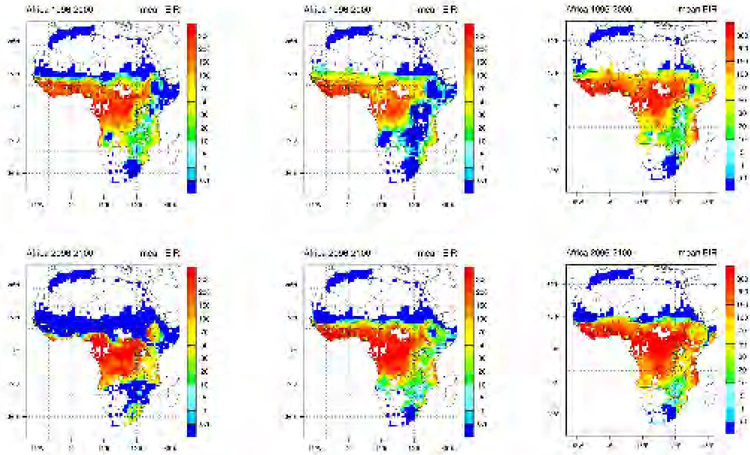
AR4 climate change example

Caveat: only the climate signal from 3 sample models... malaria model is deterministic. Shows highlands becoming endemic - large variation between models.



ISIMIP

Impacts model intercomparison project led by PIK

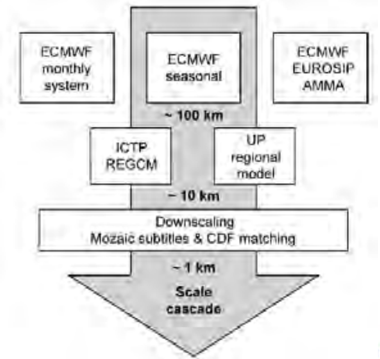
- Aims to feed directly into IPCC 5th assessment report.
- Covers several sectors: water, agriculture, health.
- Health only concerns falciparum malaria and contains 3 statistical malaria models, a monthly means version of LMM, and VECTRI.

VECTRI is the only dynamical model with a daily timestep contributing to the project and the only one that accounts for population density in transmission rates.

QWeCI

Coordinated by Andy Morse, University of Liverpool.

- 13 partners, 6 Europe, 7 Africa.
- Concentrates on the ECMWF forecast system for investigating potential for monthly to seasonal prediction and beyond.
- Three pilot project countries:
  - Senegal: extending disease models to RVF
  - Ghana: contrasting rural and peri-urban malaria
  - Malawi: Potential for operational forecasting and dissemination via long-range Wifi to rural clinics



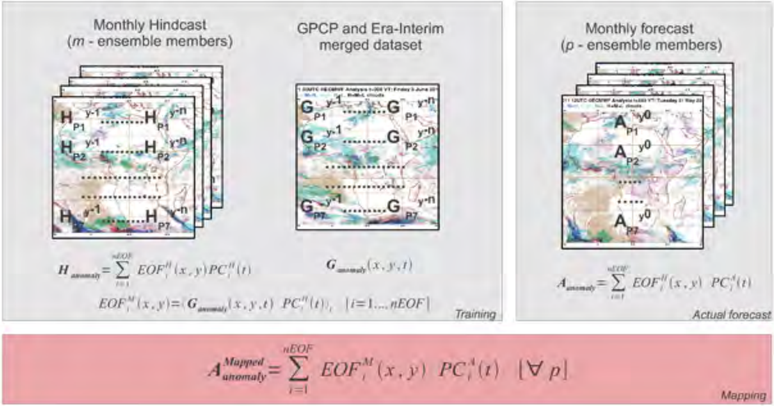
Why develop a coupled dynamical seasonal forecast system for malaria now?

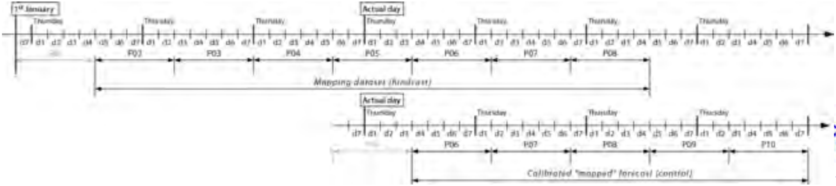
- Latest monthly and seasonal forecast systems now have skill in some tropical areas in temperature and precipitation prediction
- Dynamical malaria models are available that can be run over regional scales (more testing required)
- Several African states have put health monitoring systems into place over the past decade that provide monthly incidences of malaria on the district scale
- Availability of new diagnostic methods (rapid diagnostic testing) greatly improve the accuracy and reduce uncertainty of malaria data

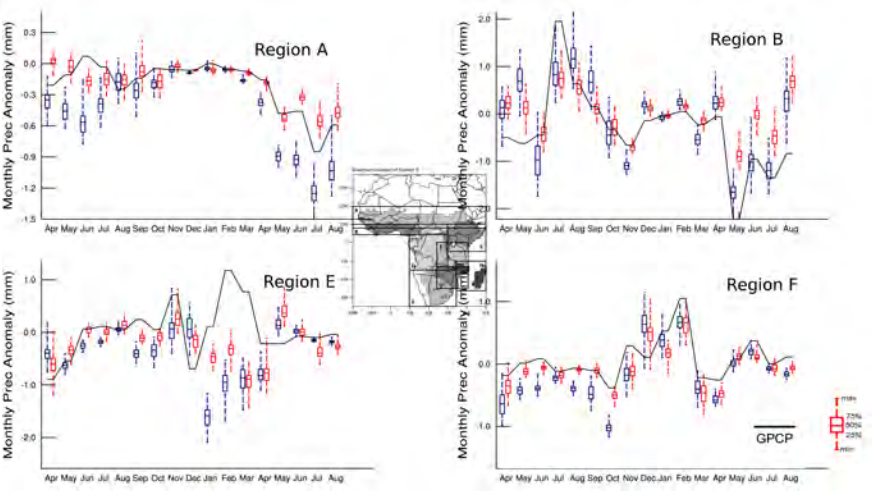
bias correction approach for seamless system

- Initial plan was to implement CDF pointwise rainfall bias correction
- After investigation of Feudale and Tompkins (2011) [6] pattern based (EOF) correction preferred
- Taken further by new idea of Molteni to appear in Di giuseppe, Molteni and Tompkins(2012) using pseudo-EOFs

This is used to correct rainfall and seamlessly join the monthly and seasonal forecast systems.
Temperature is statistically downscaled using a simple pointwise methodology based on topography.


Monthly Hindcast
(m - ensemble members)
GPCP and Era-Interim
merged dataset
Monthly forecast
(p - ensemble members)
$H_{anomaly} = \sum_{i=1}^{nEOF} EOF_i^H(x,y) PC_i^H(t)$
$G_{anomaly}(x,y,t)$
$A_{anomaly} = \sum_{i=1}^{nEOF} EOF_i^H(x,y) \; PC_i^A(t)$
$EOF_i^M(x,y) = \langle G_{anomaly}(x,y,t) \; PC_i^H(t) \rangle_t \quad [i=1 \ldots nEOF]$
Training
Actual forecast
$A_{anomaly}^{Mapped} = \sum_{i=1}^{nEOF} EOF_i^M(x,y) \; PC_i^A(t) \quad [\forall p]$
Mapping


1st January
Actual day
Thursday
Mapping dataset (hindcast)
Actual day
Calibrated "mapped" forecast (control)

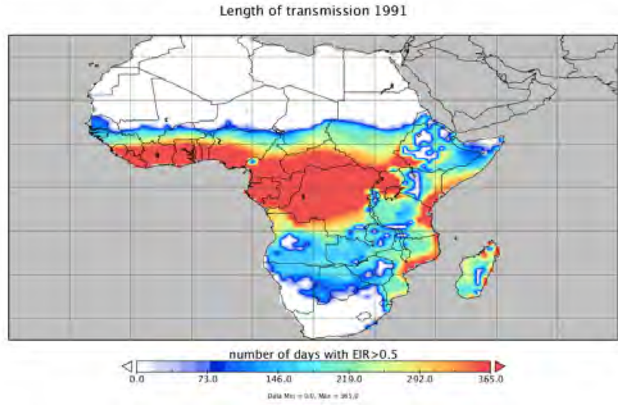


red corrected

blue raw forecast

Coupled ECMWF-VECTRI malaria forecast system

- VECTRI now fully coupled with monthly-seasonal forecast system
- malaria model initialized from a malaria "reanalysis"
- hindcast suite consists on previous 18 years (as in EPS ensemble system)



ECMWF-ICTP IFS-VECTRI coupled system: next steps and timeframe

- Reanalysis to finish by mid-October
- First test hindcast/forecast integration by November
- Evaluate malaria hindcast "climatology" of EIR and PR against field studies and MAP (as in Tompkins and Ermert, 2012)
- Evaluate hindcast products in collaboration with ministries of health in Malawi, Uganda and Rwanda (Jan/Feb 2013)
- Beta launch of IFS-VECTRI at the workshop and colloquium to be held at ICTP in April 2013 (jointly with Healthy Futures and co-sponsored by WMO)
- Extension to multimodel system:
  - Perturbed parameters/parametrizations in VECTRI
  - Extension of seasonal timescales to EUROSIP (4 models)
  - Addition of LMM/LMM2010

Reaching end users

ICTP investigates the potential of low-cost, long-range WIFI to **collect health data realtime** and **disseminate health forecasts** in a malaria early warning system (EWS) from/to local clinics with (long-term) partners from Blantyre.

Work of the group of Prof. S. Radicella

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FUTURE developments of VECTRI

- Hydrology: Currently very *ah hoc*, but uses framework that allows further development - will include permanent water bodies.
- Population: Migration very simply treated (trickle source), but work on a full migration model underway.
- Immunity: differences between adult and child? Is blocking immunity well understood? Simple SEIR model as a first step.
- Interventions: Bednets are included in a simple way, other interventions to be added.
- DATA
- Open source: model is a community model, already used in Ethiopia.

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