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QWeCI

Quantifying Weather and Climate Impacts on Health in Developing Countries

D5.1.c: Formation of a Health Early Warning System

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Coordinator of deliverable: UoC
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PU	Public	PU
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Introduction

Work Package (WP) 5.1 of the QWeCI project developed integrated information and decision support systems based on the scientific output of various other WPs. One special aspect was the construction of a Health Early Warning System (HEWS). During the QWeCI project the most extensively studied disease was malaria. With regard to malaria the Liverpool Malaria Model (LMM; Hoshen and Morse 2004; Ermert et al. 2011a,b) and VECTRI (VECtor-borne disease community model of the ICTP, TRIest; Tompkins and Ermert 2012) were applied and developed.

The LMM was already available before the QWeCI project and VECTRI was newly developed within the project. Both models represent dynamical weather-driven malaria models and are driven by daily mean temperature values and daily rainfall amounts. They simulate key malaria variables including the Entomological Inoculation Rate (EIR; i.e. the number of infectious mosquito bites per human per time period) or the asexual Parasite Ratio (PR; i.e. the rate of humans being infected with the malaria parasite) with a daily resolution. Based on monthly EIR values the season of the malaria transmission can be reproduced by the models. The LMM was calibrated by entomological and parasitological malaria observations from West Africa and its results were compared to data from the Malaria Atlas Project (MAP; e.g. Hay et al. 2009). VECTRI was also compared to the observations from West Africa and to MAP data and is therefore roughly validated. However, both models lack a formal validation with malaria data, for example, from East Africa but LMM has been validated against a 20 year observed malaria index in Botswana (Jones and Morse, 2010).

The LMM and VECTRI neglect various factors of the malaria disease. For example, aspects like immunity or different characteristics of malaria vectors are not considered. In contrast to the LMM, VECTRI can distinguish the differential transmission conditions in urban, peri-urban, and urban locations since it also applies the population density of a given location. Furthermore, biting is considered as a Poisson process meaning that some humans are bitten more often or less frequently than others in the model. VECTRI has a physical based simple hydrological component that further includes permanent water bodies like rivers and lakes.

Other diseases such as Rift Valley fever or that of tick-borne diseases led within the QWeCI project so far not to the generation of disease models that could be operationally used for the prediction of the particular disease. IPD developed a statistical Rift Valley fever vector model, which is based on environmental observations. In the near future, this model could be further used to forecast the intra-seasonal variability and spatial distribution of the two Rift Valley fever vectors. This could advice stock farmers to join places with a low vector density. The model is based on fortnightly catches from the year 2005 of the two vectors *Aedes vexans* and *Culex poicilipes* and was calibrated to these observations. Lacking is the validation of the model with other field catches. A model of the same structure as LMM is being developed for RVF and will be completed within Healthy Futures. A climate based RVF risk model developed in FP6 AMMA and completed in QWeCI in Liverpool was also published (Caminade et al. 2011).

The Health Early Warning System consists of four different components. The first component consists of the online version of the LMM, the pilot system of the multi agency system. The second included system is VECTRI. The online versions of the two malaria models provide a simple access to these complex dynamical weather-driven malaria models. The third system consists of an information system with regard to exemplary malaria forecasts for the Kumasi region, Ghana. At the end of January 2013, the LMM and VECTRI models demonstrate how state-of-the-art weather-driven dynamical malaria models could be used for the local prediction of the malaria transmission season. Lastly, the Health Early Warning System includes operational seamless monthly-to-seasonal malaria forecasts. First prototype pan-African operational seamless forecasts are available from VECTRI and the LMM. Both dynamical weather-driven malaria models predict the potential transmission intensity with a lead-time of up to 120 days.

The Health Early Warning System therefore consists of the following online systems (see http://qweci.uni-koeln.de go to “HEWS”):

a) Liverpool Malaria Model (online version for point data)
b) VECTRI (online version for point data)
c) Malaria Early Warning System (Example malaria forecasts for the Kumasi region)
d) Operational monthly-to-seasonal malaria forecasts (link to the ECMWF web portal)

When the DoW was constructed it was planned that the HEWS would be based on disease impact model simulations of WP4.1 in terms of monthly-to-seasonal and decadal time scales. However, WP4.1 intended only to provide malaria hindcasts. For this reason, UoC set up a meeting at the General Assembly of the European Geophysical Union. It was decided that ICTP would set up VECTRI at the ECMWF server for the production of prototype monthly-to-seasonal malaria forecasts. UNILIV later decided also to include the LMM into the ECMWF system management software. Note that the set up of both VECTRI and LMM was supported by ECMWF and the ECMWF generated the online operational malaria forecasts web portal.

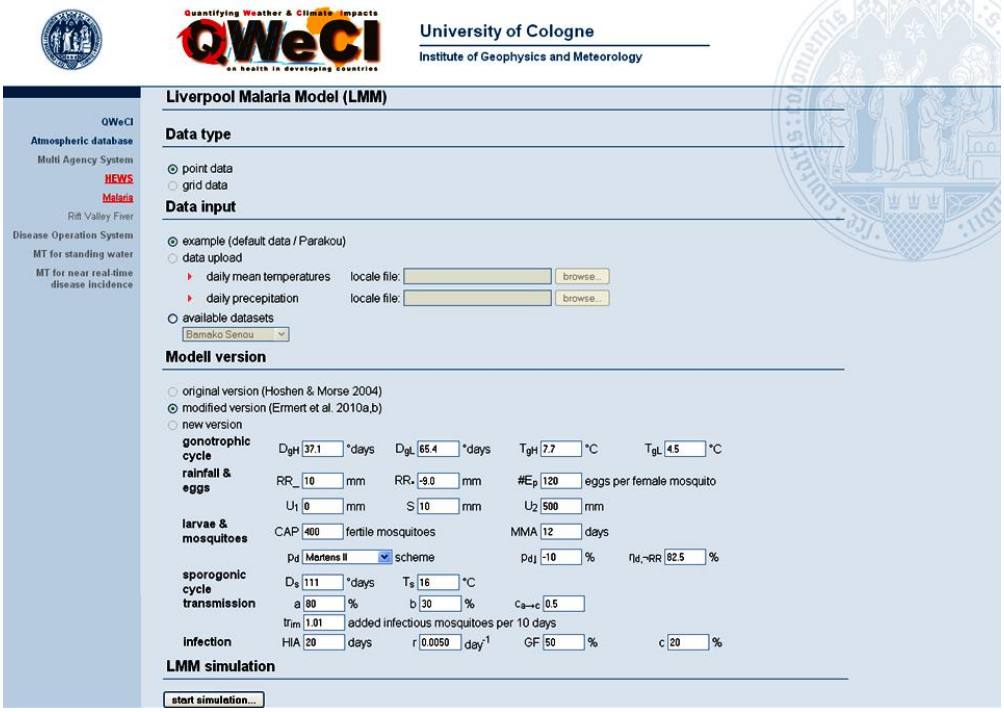
The Health Early Warning System

Included into the Health Early Warning System of the QWeCI project are the two weather-driven dynamical malaria models LMM and VECTRI. Both models can be used to interactively produce malaria simulations for a weather station or a grid point of a numerical weather prediction model. The users are able to run the models and to generate their own malaria simulations. They can produce their own model versions meaning that they are able to adapt the models to local malaria conditions.

The LMM and VECTRI are also used in the Malaria Early Warning System (MEWS) for Kumasi. Example malaria forecasts are provided for the Kumasi region in Ghana, where the LMM and VECTRI demonstrate the feasibility of local malaria forecasts. Both models predict the onset of the transmission season of malaria for the year 2013. Furthermore, a link is supplied for prototype operational seamless monthly-to-seasonal malaria forecasts, which are operated within the ECMWF's systems management software. Used are seamless monthly-to-seasonal weather forecasts from the ECMWF, which were bias-corrected for the malaria forecasts. The lead-time of the forecasts is up to 120 days (four months).

a) Liverpool Malaria Model (online version for point data)

In order to represent parts of the application spectrum of the web-based Java framework for scientists and stakeholders a pilot system was developed and is embedded in the multi agency system of the QWeCI project (Figure 1). Finally, the version 1.0 of the online LMM version was constructed. The system makes use of the LMM, which is a weather-driven malaria model that is driven by daily temperature and rainfall data (see Hoshen and Morse 2004; Ermert et al. 2011a,b). The system was primarily intended for the construction of specific sets of parameter settings for the QWeCI pilot regions (e.g. for rural and urban areas of Kumasi). Users can, for example, use this system to hindcast malaria epidemics for specific locations or they could forecast or project future malaria outbreaks via the upload of data from seasonal weather forecasts or regional climate projections. Due to the lack of calculating capacity of the QWeCI server, the model runs can only be performed for specific locations.



Liverpool Malaria Model (LMM)

Data type

● point data
○ grid data

Data input

● example (default data / Parakou)
○ data upload
daily mean temperatures locale file:
daily precepitation locale file:
○ available datasets
Bamako Senou

Modell version

○ original version (Hoshen & Morse 2004)
● modified version (Ermert et al. 2010a,b)
○ new version

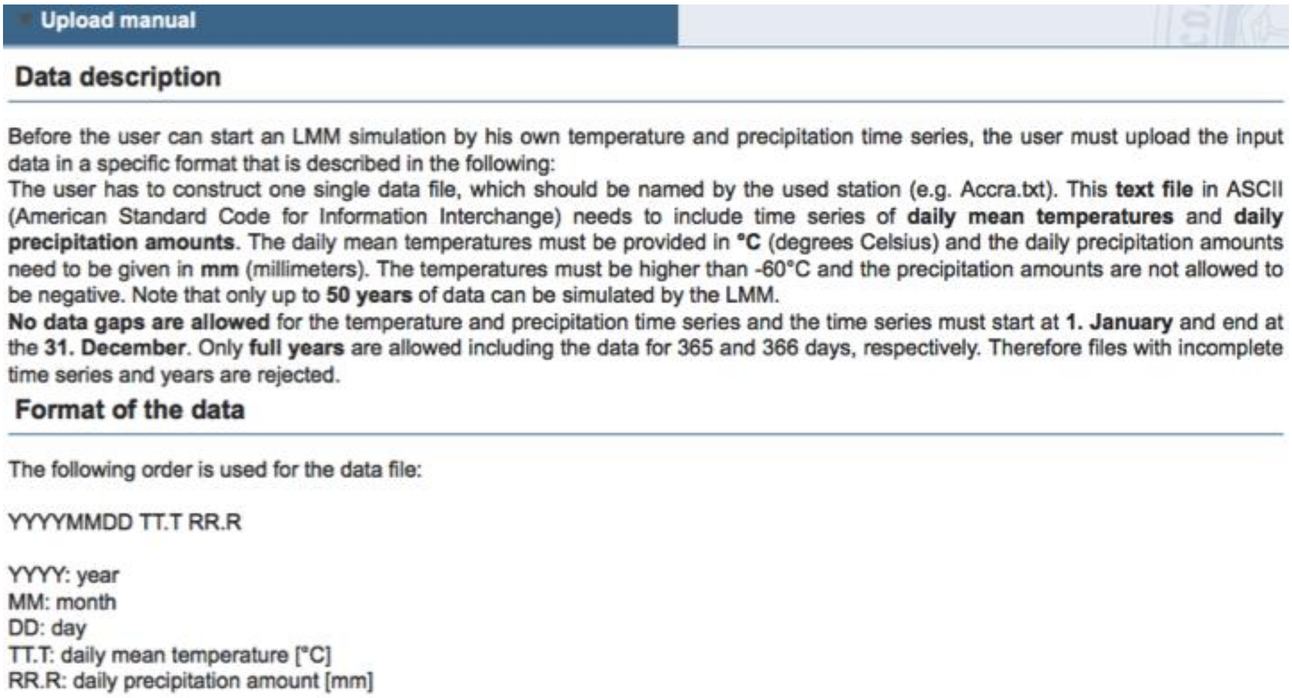
gonotrophic cycle D_{gH} 37.1 °days D_{gL} 65.4 °days T_{gH} 7.7 °C T_{gL} 4.5 °C
rainfall & eggs $RR\_$ 10 mm $RR_{\bullet}$ -9.0 mm $\#E_p$ 120 eggs per female mosquito
U_1 0 mm S 10 mm U_2 500 mm
larvae & mosquitoes CAP 400 fertile mosquitoes MMA 12 days
p_d Martens II scheme $p_{d\downarrow}$ -10 % $\eta_{d,\neg RR}$ 82.5 %
sporogonic cycle D_s 111 °days T_s 16 °C
transmission a 80 % b 30 % $c_{a\to c}$ 0.5
tr_{im} 1.01 added infectious mosquitoes per 10 days
infection HIA 20 days r 0.0050 day^{-1} GF 50 % c 20 %

LMM simulation

Figure 1. Start page of the pilot system including the configuration of the following LMM simulation.

The user can apply predefined temperature and precipitation time series between 1973 and 2006 from 34 synoptic weather stations in West Africa. The weather observations from Parakou/Benin are used as the default data set. However, the user can also upload his own temperature and rainfall time series for running the LMM. It allows scientists and stakeholders to see if the LMM is able to represent the malaria situation in their own area. In this case, the users need to construct daily temperature and rainfall time series in a certain data format to drive the online version of the LMM (see Figure 2 for the upload manual).

Before the user can start the LMM simulation with their own temperature and precipitation time series, the user must upload the input data. The user needs to construct one single data file, which should be named by the used station (e.g. Accra.txt). This text file in ASCII (American Standard Code for Information Interchange) needs to include time series of daily mean temperatures and daily precipitation amounts. The daily mean temperatures must be provided in °C (degrees Celsius) and the daily precipitation amounts need to be given in mm (millimetres). The temperatures must be higher than -60°C and the precipitation amounts are not allowed to be negative. Note that only up to 50 years of data can be simulated by the LMM version that is used by the online version. For future online versions, the LMM version will be updated meaning that there will be no more the limitation of 50 years of data.



Upload manual

Data description

Before the user can start an LMM simulation by his own temperature and precipitation time series, the user must upload the input data in a specific format that is described in the following:
The user has to construct one single data file, which should be named by the used station (e.g. Accra.txt). This **text file** in ASCII (American Standard Code for Information Interchange) needs to include time series of **daily mean temperatures** and **daily precipitation amounts.** The daily mean temperatures must be provided in **°C** (degrees Celsius) and the daily precipitation amounts need to be given in **mm** (millimeters). The temperatures must be higher than -60°C and the precipitation amounts are not allowed to be negative. Note that only up to **50 years** of data can be simulated by the LMM.
No data gaps are allowed for the temperature and precipitation time series and the time series must start at **1. January** and end at the **31. December**. Only **full years** are allowed including the data for 365 and 366 days, respectively. Therefore files with incomplete time series and years are rejected.

Format of the data

The following order is used for the data file:

YYYYMMDD TT.T RR.R

YYYY: year
MM: month
DD: day
TT.T: daily mean temperature [°C]
RR.R: daily precipitation amount [mm]

Figure 2. The upload manual of the online LMM version.

No data gaps are permitted for the temperature and precipitation time series and the time series must start at 1st January and end at the 31st December. Only full years are allowed including the data for 365 and 366 days, respectively. Therefore files with incomplete time series and years are rejected. This detailed information is also provided via an “Upload manual” for the web version of the LMM. Moreover, the key references in terms of the LMM are provided in the “Manual”, here the user can get background information, for example, with regard to the model parameters of the LMM.

In version 1.0 of the pilot system, the user is able to run the *LMM parameter and settings version of 2004* (LMM_{2004}; Hoshen and Morse 2004), *that of 2010* (LMM_{2010}; Ermert et al. 2011a,b), as well as by a self-defined set of parameter setting. The user first needs to select a particular version of the LMM. Simultaneously, the parameter settings will be adapted to the choice of the user. In case, that the user defines his own set of parameter settings, the configuration of the parameters starts either with the setting of the LMM_{2004} or LMM_{2010} (default). Now, the user can change single values. For example, the malaria transmission will be significantly reduced when the user decreases the number of laid eggs per female mosquito or when the human-to-mosquito transmission efficiency is reduced. The parameter choice is limited to realistic values mostly taken if possible from the literature. For example, the user is not able to insert negative values for the survival of mosquito larvae. After setting the values of the model run, the user starts the simulation, which needs about 15 seconds to be performed.

Finally, the output of the model run is presented to the user (cf. Figure 3). Provided are three pre-defined figures, which are visualizing eleven entomological and parasitological malaria variables as well as ASCII files that contain the output of the simulation.

In the first figure, the input data as well as the simulated entomological and parasitological values are presented. In the upper panel the input data of the model simulation is displayed in terms of the annual mean temperatures and the annual precipitation amounts. The middle panel of the figure visualizes the annual Entomological Inoculation Rate (EIR_a; i.e. the number of infectious mosquito bites per human per year), annual Human Biting Rate (HBR_a; i.e. the number of mosquito bites per human per year), and annual CircumSporozoite Protein Rate ($CSPR_a$; i.e. the fraction of infectious mosquito bites). The bottom panel displays the annual mean (PR_a), annual minimum ($PR_{min,a}$) and annual maximum ($PR_{max,a}$) asexual parasite ratio. In addition, the malaria seasonality is illustrated. The transmission season is defined by the months with an Entomological Inoculation Rate of at least 0.01 infectious mosquito bites per human per month. The month with the maximum transmission is marked moreover. The second figure is equal to the middle and lower panel of the first figure but also includes, if available, field malaria observations. Therefore, this figure can be used to study the performance of that particular model run. The comparison with observed data enable to estimate if the model simulations are realistic. However, malaria observations are not available for the area of all 34 synoptic weather stations. The third figure displays monthly composites of key malaria variables, which are displayed as box-and-whisker plots.

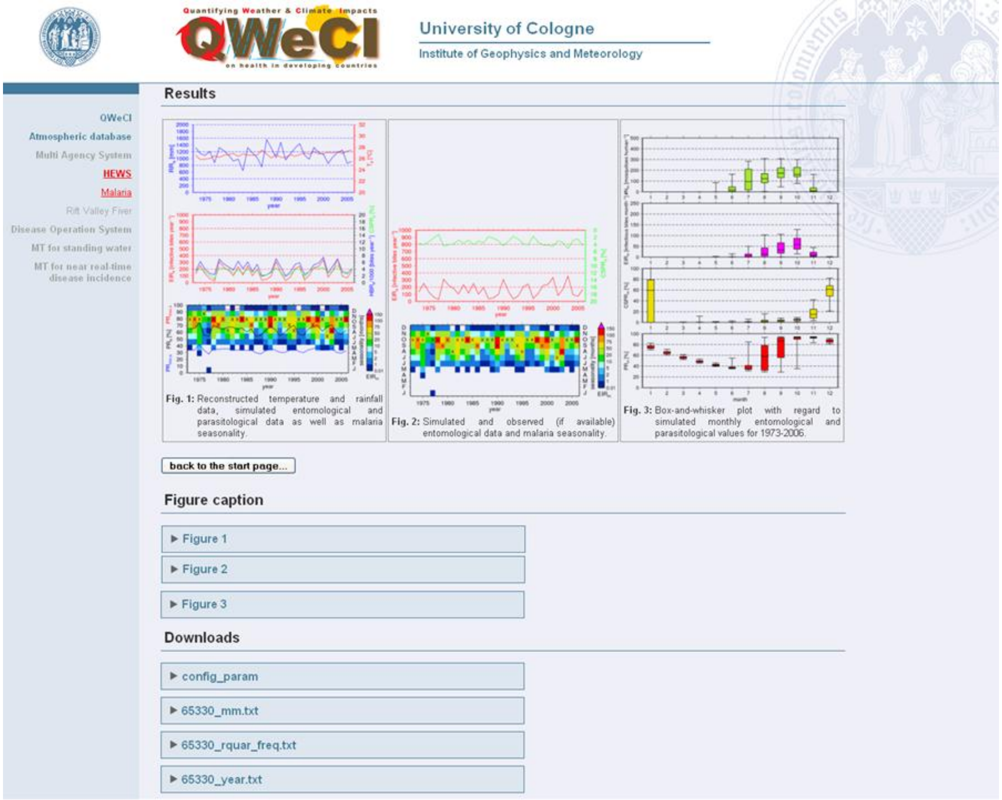


Fig. 1: Reconstructed temperature and rainfall data, simulated entomological and parasitological data as well as malaria seasonality.

Fig. 2: Simulated and observed (if available) entomological data and malaria seasonality.

Fig. 3: Box-and-whisker plot with regard to simulated monthly entomological and parasitological values for 1973-2006.

Figure 3. Final page of the web-version of the LMM that includes the output data as well as pre-defined figures of the LMM simulation.

Furthermore, the user is able to download the processed output files of the LMM including the monthly and yearly values of the temperature and rainfall input and of eleven simulated entomological and parasitological variables. A file is provided as well for quartile statistics in terms of the simulated and observed (if available) annual values of the simulation period. In addition, a file is provided that includes the setting of the model parameters of that particular model run.

b) VECTRI (online version for point data)

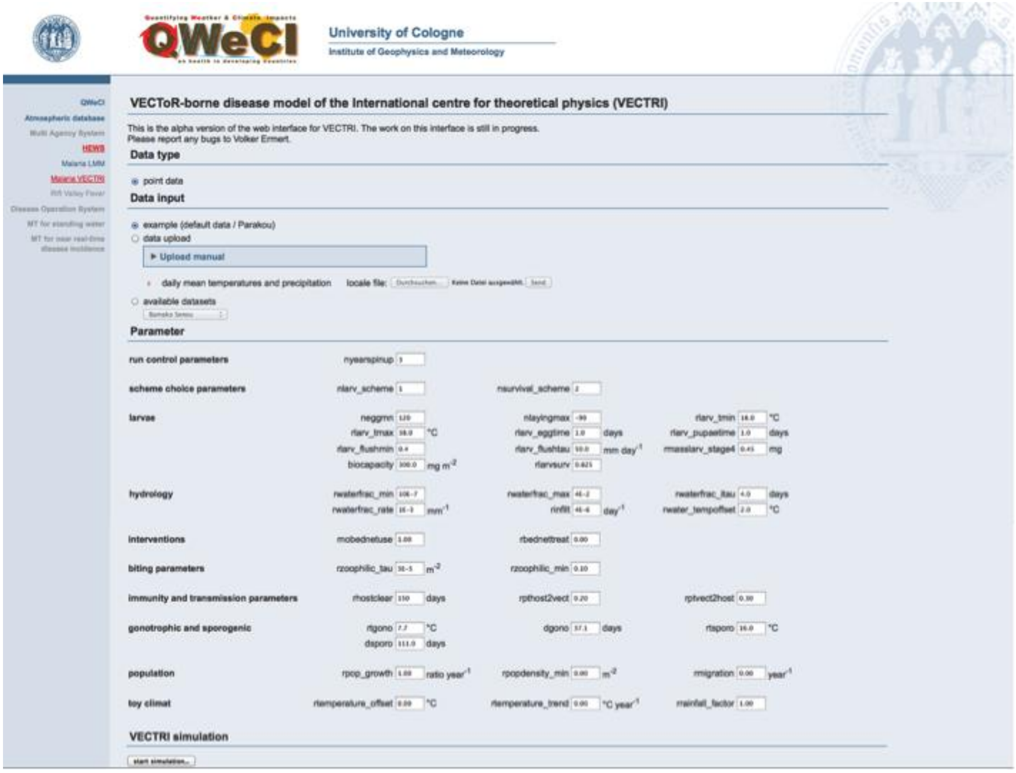
VECTRI is a high-resolution dynamical weather-driven malaria model, which accounts for population density and surface hydrology (Figure 4). This model can run on a two-dimensional grid or for a single point.

Figure 4. The logo of VECTRI (preliminary version).

To set up the model skills in terms of Linux and shell scripting are required. For this reason, an online version of VECTRI was included into the web-based Java framework (Figure 5). The alpha version of the online tool is available for the user meaning that some bugs need to be fixed in the near future.

As for the LMM, due to the lack of calculating capacity of the QWeCI server, the model can only be performed for specific locations. The user can again use observed data from the past to study the performance of VECTRI for their location. Moreover, the online VECTRI version can be used to forecast or project future malaria conditions if the user uploads such data. It is recommended to run both malaria models for the comparison of the results. VECTRI reveals a much smaller year-to-year variability than the LMM meaning that the LMM is much more sensitive to the input data (i.e. temperatures and rainfall amounts). Only VECTRI can be used to study the impact of the population density on the model simulations. Note that the LMM_{2010} was only calibrated with rural field malaria observations and not with urban data. Also the LMM_{2004} is not designed to account for various population densities.

Comparable to the online version of the LMM, the users can use the temperature and precipitation data from 34 West African synoptic weather stations to run the model. In addition, the user can upload his own data to drive VECTRI with other than the provided atmospheric conditions. The same regulations are used for the format of the data as for the online LMM version. The users are again able to set up their own set of parameter settings of the model or can use the default setting of VECTRI. Also here the set up of the single parameters is limited to realistic values. Note that the user needs to know the population density of the area of interest. By default, the model is driven for a rural area. The model runs are strongly sensitive to the setting of the population density. The increase in the population density for urban areas, for example, strongly reduces the transmission intensity. Like for the LMM, a manual was generated for the users. The manual is especially helpful when the users like to upload their own input data (these are daily temperature and precipitation time series).



VECToR-borne disease model of the International centre for theoretical physics (VECTRI)

This is the alpha version of the web interface for VECTRI. The work on this interface is still in progress.
Please report any bugs to Volker Ermert.

Data type

● point data

Data input

● example (default data / Parakou)
○ data upload
daily mean temperatures and precipitation locale file:
○ available datasets

Parameter

run control parameters: nyearspinup 1
scheme choice parameters: nlarv_scheme 1; nsurvival_scheme 2
larvae: neggmn 120; nlayingmax -99; rlarv_tmin 18.0 °C; rlarv_tmax 38.0 °C; rlarv_eggtime 1.0 days; rlarv_pupaetime 1.0 days; rlarv_flushmin 0.4; rlarv_flushtau 10.0 mm day⁻¹; rmasslarv_stage4 0.45 mg; biocapacity 300.0 mg m⁻²; rlarvsurv 0.825
hydrology: rwaterfrac_min [illegible]; rwaterfrac_max [illegible]; rwaterfrac_tau 4.0 days; rwaterfrac_rate [illegible] mm⁻¹; rinfilt [illegible] day⁻¹; rwater_tempoffset 2.0 °C
interventions: rnobednetuse 1.00; rbednettreat 0.00
biting parameters: rzoophilic_tau [illegible] m⁻²; rzoophilic_min 0.10
immunity and transmission parameters: rhostclear 150 days; rpthost2vect 0.20; rptvect2host 0.30
gonotrophic and sporogenic: rtgono 7.7 °C; dgono 37.1 days; rtsporo 16.0 °C; dsporo 111.0 days
population: rpop_growth 1.00 ratio year⁻¹; rpopdensity_min 0.00 m⁻²; rmigration 0.00 year⁻¹
toy climat: rtemperature_offset 0.00 °C; rtemperature_trend 0.00 °C year⁻¹; rrainfall_factor 1.00

VECTRI simulation

Figure 4. First page of the online VECTRI version. The user is able to change the parameter setting of VECTRI.

After running the model, the results of the model runs are again visualized by three graphics (see the online LMM version). Illustrated are entomological and parasitological malaria variables. Moreover, the user can download the output of the model simulation.

c) Malaria Early Warning System

In order to show the feasibility of local malaria forecasts, the Health Early Warning System includes further demonstrative malaria seamless monthly-to-seasonal malaria forecasts for the Kumasi region (see Task 5.2.e of the QWeCI project). Here we illustrated the seamless malaria forecasts from January 2013. The results of these example malaria forecasts are included into the multi agency system. In contrast to the forecasts from the ECMWF, the local forecasts focus on the generation of time series of one entomological and parasitological malaria variable, respectively. In January 2013, the lead-time of 120 days includes the start of the main malaria transmission season, for which the forecast is provided by VECTRI and LMM.

Forecasts and hindcasts from the LMM_{2010}

The malaria forecast for Kumasi/Ghana starts at the beginning of February (week 5) and is finished at the end of May 2013 (week 21). The forecast includes entomological and parasitological malaria variables such as the simulated weekly EIR (EIR_W) values. According to the LMM_{2010} monthly-to-seasonal prediction malaria transmission is ongoing throughout the forecasting period. The model runs indicate that the transmission of the malaria disease is predicted to be significant high enough to enable the infection of humans but partly low during the four forecasted months. The lowest malaria risk is simulated to occur between the end of February and beginning of March (week 7 and 9). The weekly EIR median value of the 51 ensemble members of the malaria forecasts is always higher than 0.25 infectious bites per 100 people (see the blue line in Figure 6) meaning that malaria transmission is ongoing also during the driest period of the year (see the definition above). However, the risk of a malaria infection is fairly low during this time. Some ensemble members forecast lower and higher transmission levels, respectively. During week 7 and 9 the EIR$_w$ values range between 0.0002 and 0.02 infectious bites per human per week. After the beginning of March, the simulated EIR$_w$ value increases significantly due to the start of the main rainy season in the Kumasi area. At the end of April (week 16), every human receives already about one infectious mosquito bite per week. The malaria risk further increases toward the end of the forecast period at the end of May (week 21), when the EIR$_w$ value reaches about 10-20 infectious bites per human per week.

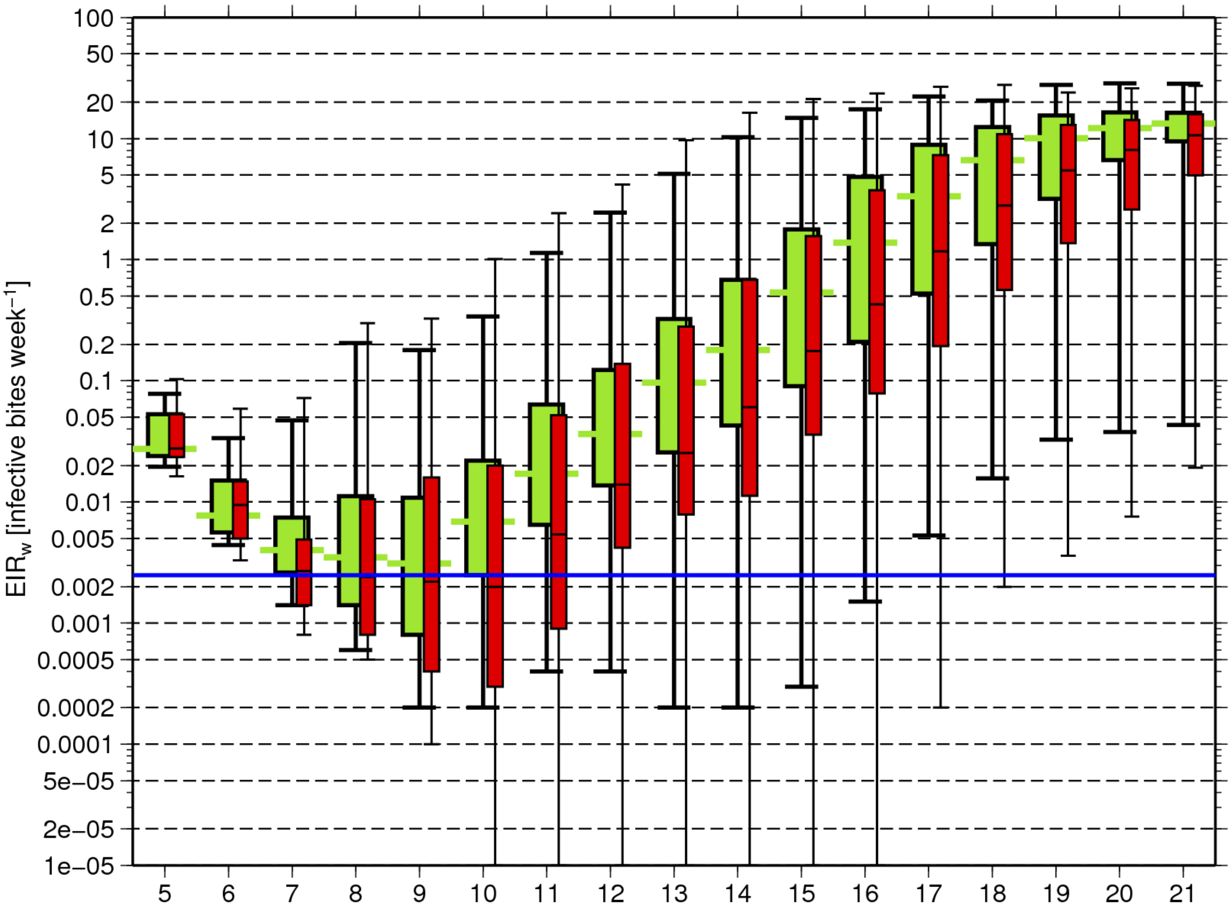


Figure 5. Demonstrative monthly-to-seamless malaria forecast (starting from 31 January 2013) of the Liverpool Malaria Model (LMM) for the Kumasi region in Ghana. Illustrated is the weekly Entomological Inoculation Rate (EIR$_w$; i.e. the number of infectious mosquito bites per person per week) on a log scale between the beginning of February (week 5) and the end of May 2013 (week 21) from 51 forecast ensemble members (green box-and-

whisker plots) for 2013 and from 90 hindcast ensemble members between 1995 and 2012 (red box-and-whisker plots). The blue horizontal line indicates the status when the LMM simulates 0.0025 infectious bites per human per week (i.e. about 0.01 infectious bites per human per month, which is the defined level of on-going malaria transmission).

Malaria transmission is predicted to be in general above the average as compared with the seasonal hindcasts (period: 1995-2012). The EIR_w median value of the 51 ensemble forecasts for 2013 is mostly higher than that for the hindcasts. It also seems that the malaria transmission increase starts in March 2013 about one week earlier than usual. Some hindcasts reveal a very low malaria transmission between week 10 and week 16 meaning that some years reveal a break in malaria transmission during this time interval. However, this is predicted to be not the case for 2013.

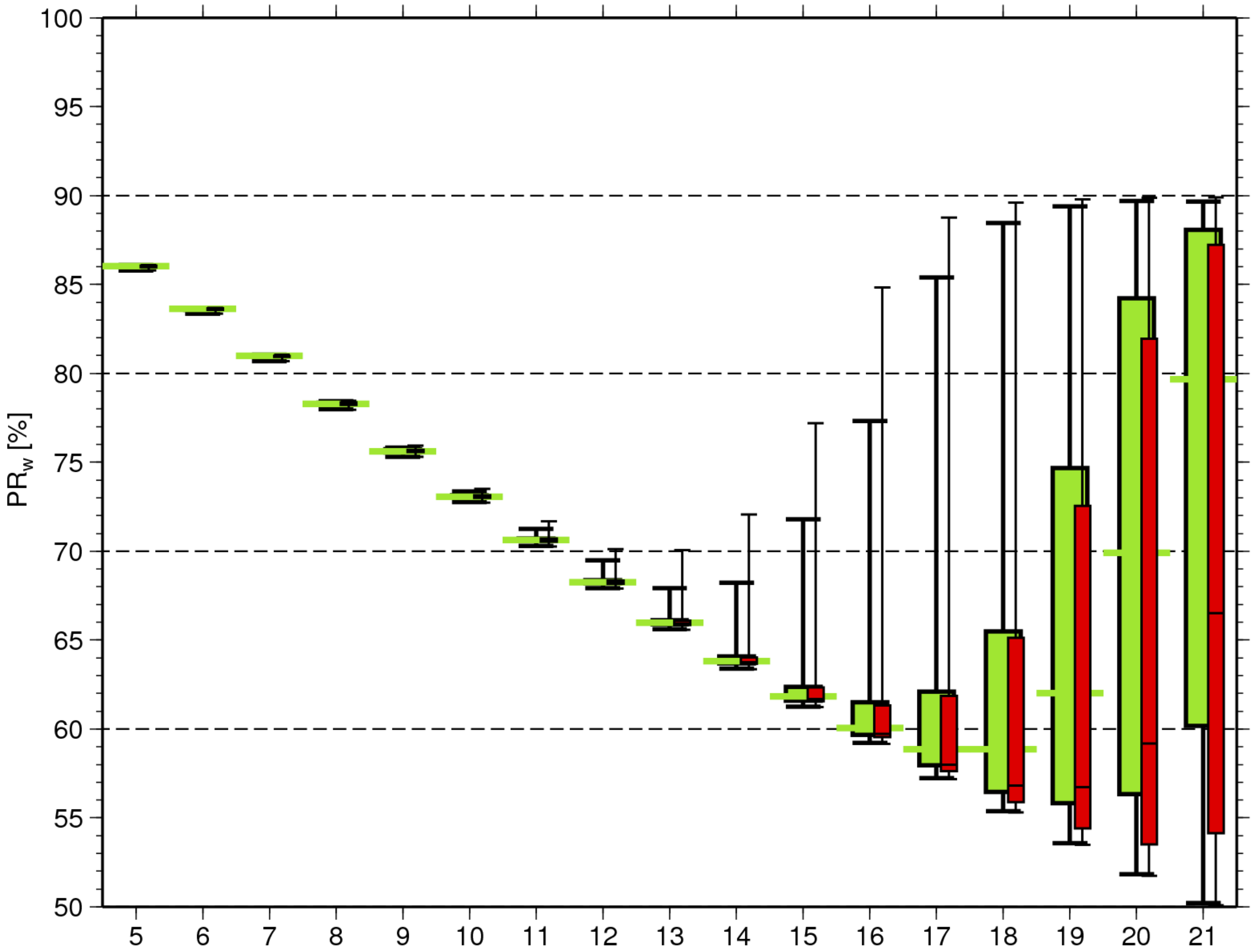


Figure 6. Same as Figure 5 but here for the weekly averaged asexual Parasite Ratio (PR_w; in %).

In general, the malaria infectiousness is predicted to decrease during the first part of the forecasting period (Figure 7). That is due to the fact that most humans in the model got infected during the minor rainy season between September and December. At the start of the forecast period, the weekly asexual Parasite Ratio (PR_w) is about 86% both in the forecasts for 2013 and the hindcasts. In the follow-up of the second rainy season the humans recover in the model during the dry season, when the malaria transmission is very low (see Figure 6). The recovery rate is about 1.7% per week and leads to a steady decrease of the infectiousness of the population until about the beginning of May (week 18). At that time, the asexual parasite ratio reveals a minimum value below 60%. However, due to the spread of the ensemble members there is a strong uncertainty with regard to the timing and the magnitude of this minimum value.

The confined values of the ensemble members during the first half of the forecast period show that there is a low uncertainty within the simulation of the LMM_{2010} (Figure 7). However, this does not indicate an accuracy of the model in terms of the simulation of the asexual parasite ratio. Ermert et al. (2011b) found a low skill of the LMM_{2010} with regard of the simulation of parasitological values. That is mainly because of neglecting aspects like immunity or a missing age distribution of the disease in the model framework. As previously mentioned, there is also no differentiation between asymptomatic and symptomatic malaria infections. This means that the forecast of the infectiousness needs to be treated with caution and should not be over-interpreted.

After April a strong increase in the malaria infectiousness is simulated (Figure 7). Forecasted is a significant increase of the PR_w values within May 2013. However, there is a large uncertainty in terms of the strength of this increase due to the large spread of the ensemble members. The same spread is also found for the hindcasts that reveal a somewhat lower infection rate than the actual forecast. The last is due to the stronger predicted malaria transmission of 2013 (see Figure 6).

Forecasts and hindcasts from VECTRI

Similar to the LMM_{2010}, VECTRI generates a malaria transmission forecast for the same period for Kumasi/Ghana. Throughout the four months of the forecasts, VECTRI predicts a relative high malaria transmission risk between about 0.5 and 15 infectious bites per person per week (Figure 8). The lowest predicted risk of a malaria infection occurs at the beginning of the forecast period in February (week 5 of Figure 8). The model however indicates an increase of malaria transmission during the following weeks. In contrast to the LMM_{2010} forecasts, the ensemble spread is quite low (quartile range). The EIR_w values of the 51 ensemble members of the malaria forecasts are all higher than 0.25 infectious bites per 100 people (see the blue line of Figure 8), which is considered as the malaria transmission limit. This means that VECTRI is not simulating a transmission break within the dry season of the Kumasi area.

The hindcasts (period: 1995-2012) follow a similar fashion to the forecasted malaria transmission as elaborated above. Comparing the hindcasts with the forecasts, the actual predicted malaria transmission is in general above that of the hindcasts. Therefore, the forecasts indicate a higher transmission risk than the hindcasts. The hindcasts reveal a much high variability with regard to the malaria transmission rates than the forecasted values.

Comparing the EIR_w simulations of the two models (Figures 6 & 8), they both reveal a similar pattern of low to high transmission rates in the dry to wet period, respectively. In comparison to the hindcasts both models reveal above average EIR_w values. Malaria transmission is ongoing in the dry season both in the LMM_{2010} and VECTRI. However, there are some disparities in the simulations of the models. VECTRI simulates much higher transmission values in the dry season than the LMM_{2010}. While both models simulate an increasing malaria risk during the forecast period, the LMM_{2010} produces a transmission minimum at the end of February. Unlike VECTRI the LMM_{2010} reveals a much stronger variability of the EIR_w values in both the forecasts and hindcasts runs.

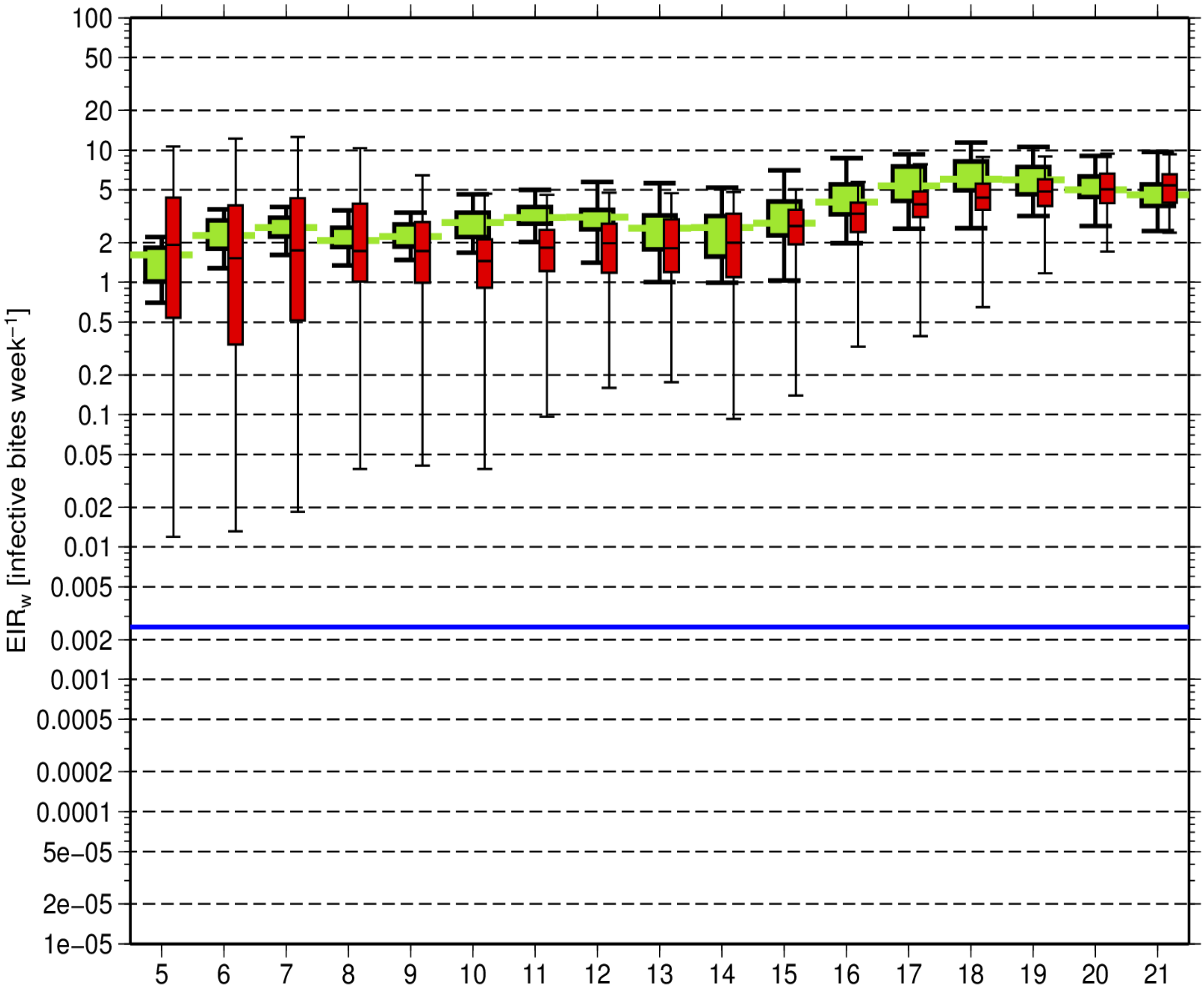


Figure 7. Same as Figure 5 but here for VECTRI forecasts and hindcasts.

In contrast to the LMM_{2010} simulations, the VECTRI forecasted malaria infectiousness is high throughout the period (Figure 9) ranging only between a minimum and maximum values of about 85 and 93%, respectively. The variability of the infectiousness is generally weak throughout the forecast period. A strong PR_w variability is only found for the hindcasts indicating that the forecasted abnormal high transmission rates lead to the high infectiousness of the population. However, also for most hindcast runs the malaria prevalence remains at a very high level above about 80%. Therefore, VECTRI reveals in most model simulations even during the dry period no significant recovery of the population from the malaria parasite. Dissimilar to VECTRI (see Figures 7 & 9), the LMM_{2010} indicates a steady decrease in malaria infectiousness of the population both in the forecasts for 2013 and hindcasts from the first half of the period.

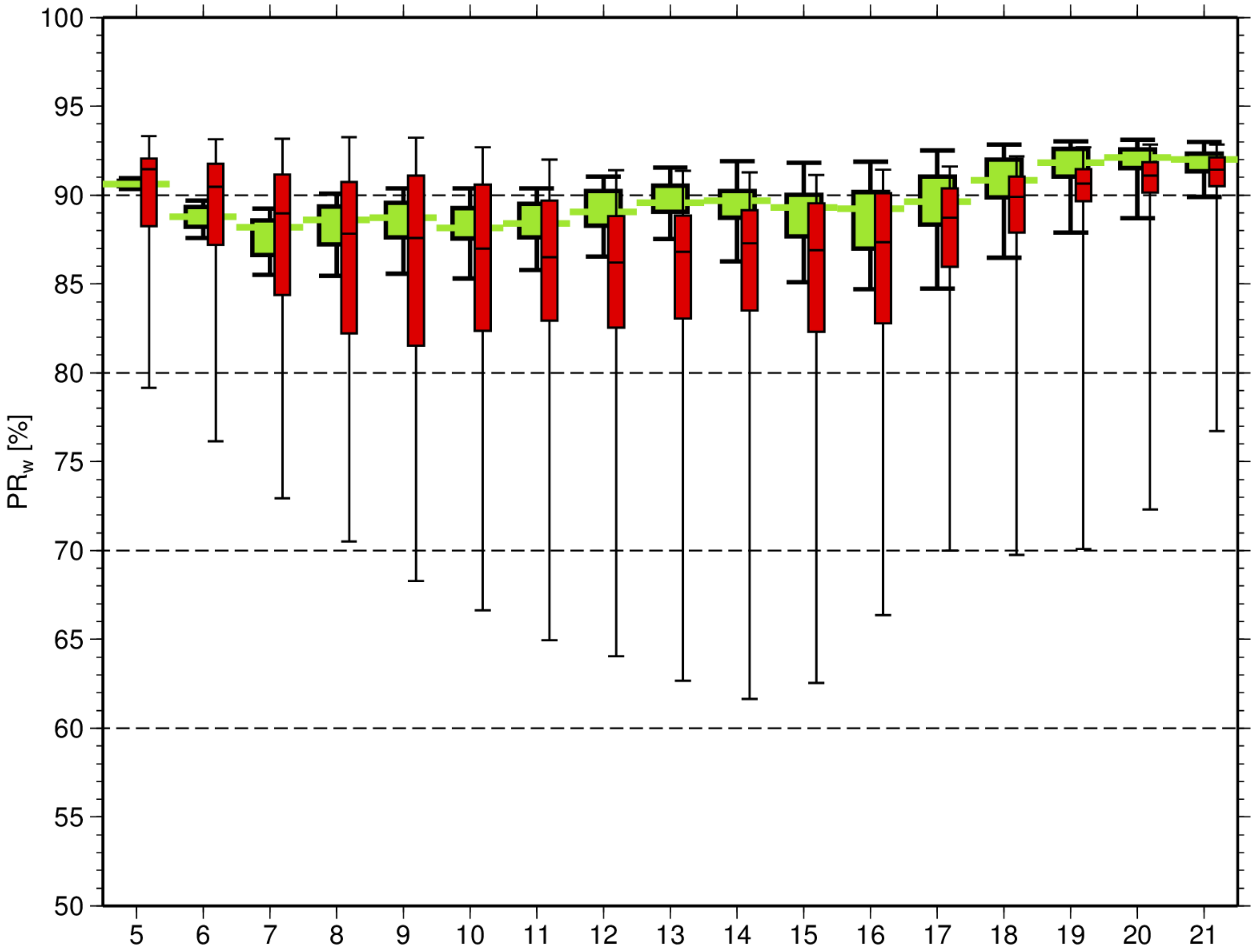


Figure 8. Same as Figure 7 but here for the weekly averaged asexual Parasite Ratio (PR_w; in %).

Discussion

The monthly-to-seasonal malaria forecast for Kumasi demonstrates the possibility of local disease forecasts. Ermert et al. (2011b) worked out that the simulation of entomological variables like the EIR is much more reliable than the reproduction of parasitological data. For this reason, it is noted that the EIR_w forecasts should provide more skill than the prediction of the PR_w values. The comparison between the LMM2010 and VECTRI forecasts strongly disagree in the prediction of the infectiousness of the population. Nevertheless, the forecast with regard to PR_w can be used by decision makers to figure out the likely time period when more and more people get infected with the malaria parasite.

That notwithstanding, both models show some level of similarities in their forecasting patterns. The LMM_{2010} and VECTRI reveal low but above average transmission rates. However, malaria transmission is in general higher in VECTRI during the dry season resulting in the high infection rates of the human population. As the forecast progresses into the rainy season, as expected both models forecast a higher malaria transmission.

Malaria transmission is known to be ongoing but low in dry and high in the wet period, respectively. This suggests that the modelled forecasts might depict a good representative picture of the malaria transmission in the region. However, the models need to be improved with regard to the presence and characteristics of different vector species. In terms of the forecast of the infectiousness of the population, immunity and age aspects need to be considered. It is unclear if transmission was really above average in the Kumasi region during the dry season of 2013. No entomological observations are available from the past and for 2013 to verify this modelling result. Neither the models nor the monthly-to-seasonal forecasts or hindcasts can be validated.

Conclusions

This study demonstrates the feasibility of local monthly-to-seasonal malaria forecasts. The LMM_{2010} and VECTRI were used to assess the near future malaria conditions within the Kumasi region. The LMM_{2010} and VECTRI runs reveal ongoing malaria transmission during the dry season and a transmission increase at the beginning of the mayor rainfall season. A strong increase in the transmission and infection rates is predicted to occur in May 2013. The comparison with the hindcasts reveals that the malaria risk is above average. Decision makers like health planners can use the entomological information of the forecast to set up tailored disease control measures. However, the forecasts and hindcasts lack a validation procedure due to missing entomological and parasitological malaria observations.

d) Operational monthly-to-seasonal malaria forecasts

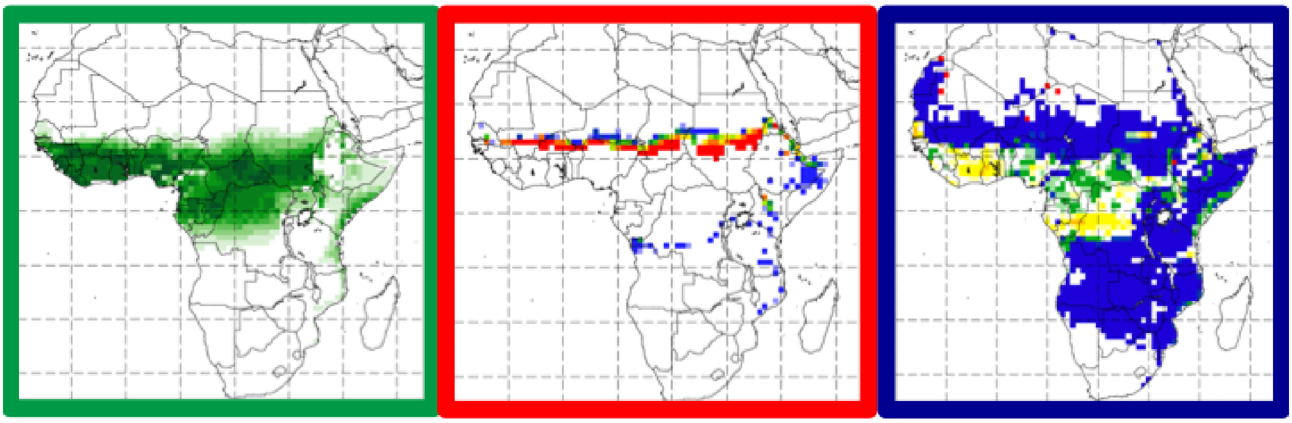
Prototype malaria forecasts were developed by the QWeCI project. The first pan-African operational seamless monthly-to-seasonal malaria forecasts are available from dynamical weather-driven malaria models.

The project partners ICTP and UNILIV with ECMWF implemented the malaria model VECTRI and LMM into the ECMWF system management software. In summer 2012, VECTRI and LMM were finally integrated into the ECMWF forecasting system and uses a calibrated seamless monthly-to-seasonal weather forecast from the ECMWF. The malaria forecasts are generated on a weekly basis (every Thursday) with a lead-time of 120 days (i.e. four months) and are available at a ECMWF web portal:

http://nwmstest.ecmwf.int/products/forecasts/d/inspect/catalog/research/qweci/

Available are precipitation and temperature maps from the calibrated and non-calibrated monthly-to-seasonal weather forecasts. This data is used for the malaria forecasts in terms of the Entomological Inoculation Rate (i.e. the number of infectious mosquito bits per human) and the parasite ratio (i.e. the proportion of the population that is infected by the malaria parasite). Maps are provided for the hindcast period and a probability map represents the probability that transmission is below, normal, or above the average value.

Malaria Forecasts @ECMWF



The prototype seamless monthly-to-seasonal meteorological and malaria forecast system provides entomological and parasitological malaria forecast maps.

Note that the forecasts need to be verified against reality. At present, no real-time malaria observations are available for this task. This will be a possible follow-up investigation of the QWeCI project.

Therefore the prototype real time malaria forecasting system is developing into a pilot operational multi malaria model ensemble malaria prediction system. Of course, this system needs to be verified against malaria observations to show if the prediction system is able to provide forecast skills for this disease.

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