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QWeCI

Quantifying Weather and Climate Impacts on Health in Developing Countries

D1.3b – Scientific publication validating existing published climate-driver disease (malaria and RVF) incidence relationships in pilot target countries and appropriate modifications to these relationships in a future climate

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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)	

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1- Preamble

Malaria results in over one million deaths annually, with over 80% of these fatalities occurring in sub-Saharan Africa (WHO, 2005). Malaria is caused in humans by infection with the protozoan Plasmodium, and is transmitted between humans by female mosquito vectors from the *Anopheles spp*. The first symptoms are relatively similar to those of seasonal flu, with fever, sore throat, pain, chills and aches; and sometimes nausea and diarrhoea that can lead to more serious health issues. Infection with the most severe form of the parasite, *Plasmodium falciparum*, if not promptly treated, may lead to kidney failure, seizures, mental confusion, coma, and death. Epidemics of the disease can be triggered by factors affecting human, vector or parasite populations including abnormal meteorological conditions, changes in anti-malarial programs, population movement, and environmental changes (Nájera et al., 1998). The mosquitoes' breeding sites (ponds) and the lifecycle of the malaria parasite are both strongly connected to climatic variability, especially rainfall and temperature. Climate-driven models of malaria provide a quantitative method of considering the impact of one of these factors.

Rift valley fever (RVF) is a viral zoonosis that affects domestic animals and humans by causing an acute fever. This disease is caused by the RVF virus that belongs to the genus *Phlebovirus* in the family *Bunyaviridae*. The virus is transmitted to vertebrate hosts by the bite of infected mosquitoes, typically by the *Aedes* and *Culex* species. The RVF mainly affects domestic animals (cattle, goats, sheep and camels, among others). It generally causes high mortality and abortions in pregnant females. Human infections are mainly caused by direct or indirect contact with viraemic animal blood or infected organs (during butchering, slaughtering or veterinary procedures). The human symptoms are characterized by the onset of high fever, headache, generalised weakness and liver abnormalities. In a small percentage of the infected human population RVF can cause haemorrhagic fever, encephalitis and ocular disease and this can sometimes lead to death.

We here propose to review the recent scientific publications achieved (or in progress) within the QWeCI project framework, concerning the relationship existing between climate and infectious diseases (malaria and Rift Valley fever) for the project target countries (Senegal, Ghana and Malawi). Instead of a single publication as originally planned, one paper has been recently published in “Environmental Health Perspectives” for malaria, and two are actually under review concerning the link between climate and Rift Valley fever epidemics in Senegal and Mauritania, one in English in “Nature Scientific Reports”, and one in French in “La climatologie” (an English version will be submitted soon as well).

2- Malaria

Research

The Impact of Regional Climate Change on Malaria Risk due to Greenhouse Forcing and Land-Use Changes in Tropical Africa

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BACKGROUND: Climate change will probably alter the spread and transmission intensity of malaria in Africa.

OBJECTIVES: In this study, we assessed potential changes in the malaria transmission via an integrated weather–disease model.

METHODS: We simulated mosquito biting rates using the Liverpool Malaria Model (LMM). The input data for the LMM were bias-corrected temperature and precipitation data from the regional model (REMO) on a 0.5° latitude–longitude grid. A *Plasmodium falciparum* infection model expands the LMM simulations to incorporate information on the infection rate among children. Malaria projections were carried out with this integrated weather–disease model for 2001 to 2050 according to two climate scenarios that include the effect of anthropogenic land-use and land-cover changes on climate.

RESULTS: Model-based estimates for the present climate (1960 to 2000) are consistent with observed data for the spread of malaria in Africa. In the model domain, the regions where malaria is epidemic are located in the Sahel as well as in various highland territories. A decreased spread of malaria over most parts of tropical Africa is projected because of simulated increased surface temperatures and a significant reduction in annual rainfall. However, the likelihood of malaria epidemics is projected to increase in the southern part of the Sahel. In most of East Africa, the intensity of malaria transmission is expected to increase. Projections indicate that highland areas that were formerly unsuitable for malaria will become epidemic, whereas in the lower-altitude regions of the East African highlands, epidemic risk will decrease.

CONCLUSIONS: We project that climate changes driven by greenhouse-gas and land-use changes will significantly affect the spread of malaria in tropical Africa well before 2050. The geographic distribution of areas where malaria is epidemic might have to be significantly altered in the coming decades.

KEY WORDS: climate change, highland malaria, malaria, malaria model, malaria projection, Sahel. *Environ Health Perspect* 120:77–84 (2012). http://dx.doi.org/10.1289/ehp.1103681 [Online 7 September 2011]

controversial. Various researchers have argued that observed increases in malaria in the East African highlands were caused by increased temperatures (e.g., Alonso et al. 2011; Bonora et al. 2001; Loevinsohn 1994; Omumbo et al. 2011; Pascual et al. 2006), whereas others have concluded that the increase in malaria in the highlands was caused by other factors (e.g., Hay et al. 2002). Pascual et al. (2008) reported that disease and meteorological factors might complement each other and interact at different time scales. Therefore, the assessment of the potential change in malaria risk caused by climate change and climate variability remains an important topic.

Most studies that have assessed the future of malaria used output from coarse spatial resolution of general circulation models (GCMs), and some were limited to comparatively small regions (e.g., Ebi et al. 2005; Peterson 2009; Tanser et al. 2003; Thomas et al. 2004; van Lieshout et al. 2004). From a meteorological point of view, the direct use of output from coarse global

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Ermert V., Fink A.H., Morse A.P., Paeth H., 2011. The Impact of Regional Climate Change on Malaria Risk due to Greenhouse Forcing and Land-Use Changes in Tropical Africa. *Environ. Health Perspect.* **120**:77-84. http://dx.doi.org/10.1289/ehp.1103681

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Abstract:

Background: Climate change will probably alter the spread and transmission intensity of malaria in Africa.

Objectives: In this study, we assessed potential changes in the malaria transmission via an integrated weather–disease model.

Method: Mosquito biting rates have been simulated using the Liverpool Malaria Model (LMM). The input data for the LMM were bias-corrected temperature and precipitation data from the regional model (REMO) on a 0.5° latitude–longitude grid. A *Plasmodium falciparum* infection model expands the LMM simulations to incorporate information on the infection rate among children. Malaria projections were carried out with this integrated weather–disease model for

2001 to 2050 according to two climate scenarios that include the effect of anthropogenic land-use and land-cover changes on climate.

Results: Model-based estimates for the present climate (1960 to 2000) are consistent with observed data for the spread of malaria in Africa. In the model domain, the regions where malaria is epidemic are located in the Sahel as well as in various highland territories. A decreased spread of malaria over most parts of tropical Africa is projected because of simulated increased surface temperatures and a significant reduction in annual rainfall. However, the likelihood of malaria epidemics is projected to increase in the southern part of the Sahel. In most of East Africa, the intensity of malaria transmission is expected to increase. Projections indicate that highland areas that were formerly unsuitable for malaria will become epidemic, whereas in the lower-altitude regions of the East African highlands, epidemic risk will decrease.

Conclusions: We project that climate changes driven by greenhouse-gas and land-use changes will significantly affect the spread of malaria in tropical Africa well before 2050. The geographic distribution of areas where malaria is epidemic might have to be significantly altered in the coming decades.

For the Sahel:

1) The Liverpool malaria model driven by rainfall and temperature from the REMO regional climate model reproduces a realistic malaria prevalence pattern over West Africa, with the endemic areas located at the northern fringe of the Sahel (north of 15°N) for the recent time period (1961-2000).
2) Significant southward shift of the future epidemic belt over the Sahel (2020s-2040s). The decrease in rainfall causes a reduction of the mean malaria transmission (between 15°N and 18°N). As the simulated epidemic belt shift southward, the frequency of epidemics is expected to increase further south in currently more densely populated territories (13°N to 15°N).
3) South of the Sahel the decline in precipitation is beneficial for the growth of the mosquito population. Under these modified climatic conditions, the LMM simulates a reduced flushing of breeding habitats. The start of the malaria season is delayed and ceases earlier under the malaria projections, except for areas between Liberia and Ghana.

These results are consistent with former findings based on an ensemble of Regional Climate Models scenario produced within the ENSEMBLES and AMMA projects (Caminade *et al*., 2011).

For Senegal:

1) The simulated present-day malaria patterns (1960-2000) are realistic with respect to former observations. The malaria season extends ranges for about 2 months at the northern boundary of the country and extends for about 6 months at the southern boundary. Low malaria prevalence is simulated in the North (about 10%) and large malaria prevalence is simulated over the south-eastern part of the country (about 70%). The epidemic fringe (where large year to year variability in malaria prevalence is simulated) is located north of 15°N.
2) In the future, the simulated malaria season shortens by about one month, especially in the

northern half of the country (2041-2050). The mean malaria prevalence (for people under 15) decreases in the north by about 10 to 20% while it slightly increases in the south (south of Gambia). The epidemic belt is shifted southward, leading to higher year to year variability in malaria transmission in the central western part of the country.

For Ghana:

1) The simulated present-day malaria patterns (1960-2000) depict a high endemic profile for Ghana. The malaria season extends ranges for about 2 months at the northern boundary of the country and extends for about 10 months at the southern boundary to 7 months in the North. High malaria prevalence is simulated in the South, about 90%, and about 70% in the northern half of the country. As an endemic risk of malaria is simulated, the year to year malaria prevalence variability is relatively low over Ghana.
2) In the future, the simulated malaria season slightly extends by about two weeks in the south-west, while it shortens by about 2 weeks elsewhere (2041-2050). The mean malaria prevalence (for people under 15) slightly increases (1-5%) over the whole country, excepting the southern coasts.

For Malawi:

1) The malaria season extends ranges for about 5-6 months in the western part of the country. The simulated malaria prevalence is about 30%.
2) In the future, the mean malaria prevalence (for people under 15) significantly increases (10-20%) over the whole country, likely due to a simulated temperature increase.

3- Rift Valley Fever

Using weather forecasts to anticipate Rift Valley Fever outbreaks in Senegal and Mauritania

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A large outbreak of Rift Valley Fever (RVF) occurred in late 2010 in the northern Sahelian region of Mauritania which caused several animal and human deaths. Like four other large RVF outbreaks that occurred in northern Senegal, the Mauritanian outbreak was preceded by anomalous abundant rainfall that occurred at the end of the rainy season in October 2010, leading to a large mosquito hatching. Using operational weather prediction system, we showed the potential to forecast such an event and to anticipate the first reported animal cases infected by RVF ten days in advance. Using operational weather forecasts, an early warning system might then be developed in Senegal and Mauritania to warn decision makers and health services about the upcoming RVF risk.

C. Caminade, J.A. Ndione, M. Diallo, D.A. McLeod, O. Faye, Y. Ba, I. Dia, A.P. Morse, 2012. Forecasting Rift Valley fever risk in sub-Saharan Africa: the example of the 2010 outbreak in northern Mauritania. Submitted to Nature Scientific Reports (under review).

Abstract:

Background: A large outbreak of Rift Valley Fever (RVF) occurred in late 2010 in the northern Sahelian region of Mauritania which caused several animal and human deaths. The RVF risk has previously been related to extreme climatic conditions, but this has not been fully quantified and detailed.

Objectives: We estimated the environmental risk factors related to the RVF outbreak that occurred in Mauritania in 2010. We also investigated the predictability of such environmental risk using operational weather forecasts.

Methods: We used observed satellite and rain gauge estimates and animal host densities data for the year 2010. We also employed operational weather forecasts based on the Global Forecast System developed at the NCEP in the USA.

Results: Like four other large RVF outbreaks that occurred in northern Senegal, the Mauritanian outbreak was related to anomalous abundant rainfall that followed a dry spell at the end of the rainy season in September-October, leading to a large mosquito hatching. Using the GFS numerical weather prediction system, we showed the potential to forecast such an event and to anticipate the start of the RVF outbreak ten days in advance.

Conclusion: Using operational weather forecasts, an early warning system might be developed in Senegal and Mauritania to warn decision makers and health services about the upcoming RVF risk.

Pluviométrie et émergence de la fièvre de la vallée du Rift (FVR) au Sénégal : au-delà de 20 années de recherche, où en sommes-nous ?

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Résumé

Depuis l'épidémie de la Fièvre de la vallée du Rift (FVR) survenue à la frontière sénégalo-mauritanienne en 1987, les équipes scientifiques impliquées dans les investigations se sont diversifiées au fil des années ; de nouvelles idées et approches méthodologiques ont vu le jour. L'émergence de cette zoonose a toujours été associée à la pluviométrie. Cet article revient sur l'évolution des idées qui ont alimenté ces recherches entre pluviométrie et émergence de la FVR voilà déjà plus vingt ans ; il présente une analyse rétrospective des travaux qui ont porté sur le bassin inférieur du fleuve Sénégal. Au regard des derniers résultats, d'importants acquis scientifiques ont été réalisés, de nouveaux partenariats se sont développés et les perspectives sont de bon augure pour le futur.
Mots clés : Pluviométrie, émergence, fièvre de la vallée du Rift, Sénégal

J.A. Ndione, I. Dia, Y. Ba, M. Diallo, J.P. Lacaux, C. Caminade, A.P. Morse, A.T. Gaye, 2012. Pluviométrie et émergence de la fièvre de la vallée du Rift (FVR) au Sénégal : au-delà de 20 années de recherche, où en sommes-nous ? To be submitted to "La climatologie".

Rainfall and Rift Valley Fever emergence in Senegal: beyond twenty years of investigation, where do we stand?

Abstract

Since the Rift valley fever epidemic occurred at the border line between Senegal and Mauritania in 1987, the scientific teams involved in these investigations have been widen along the years; new ideas and methodological approaches have been setup… The emergence of this zoonosis has always been associated with rainfall. This article give an overview of the ideas history related to *more than twenty years of research, focusing on Senegal River basin in this analysis. Having a look of the last results, important scientific achievements have been accomplished and perspectives are good premonition for the future.*

Key words: Rainfall, emergence, Rift valley fever, Senegal

<u>For Senegal and Mauritania:</u>

Both publications demonstrate the relationship with a large rainy event that occurs late at the end of the rainy season (October-November) and RVF epidemics in Senegal and Mauritania. This late rainfall event causes a large hatching in the female *Aedes* mosquito population that should have hatched the following rainy season leading to increased RVF risk.

This risky rainfall profile has been observed during the major epidemics that occurred in northern Senegal in 1993, 1994, 1999 and 2002.

During the QWeCI project, a large outbreak of RVF occurred in northern Mauritania in 2010. The same climatic risk profile was observed over this area, namely a large convective system caused significant rainfall on the 17th of October 2010 (by about a third of the annual precipitation for the area, e.g. 60mm were observed from the 16th to the 18th of October). This was followed by a large RVF outbreak that started in the first affected Mauritanian village eight days after.

These findings further confirm this climate-disease epidemic relationship. We also demonstrate that we can use operational weather forecast to anticipate such a disease risk, 11 days in advance. This is a valuable result for planners and policy makers.

Given the chaotic nature of the climate system, and the large climate models uncertainties in simulating rainfall intra-seasonal features (like a dry spell followed by a peak in rainfall within the rainy season), we cannot use this method to look at future changes (this is far too uncertain in the “climate model world”). This is why we mainly focused on the use of short term forecast (initial condition models) which is far more appropriate to forecast such a rainfall event at the end of the rainy season in West Africa.

Other methodologies are actually investigated, such as developing a dynamical Rift Valley Fever model, a R0 model (basic reproduction number) for RVF transmission that might be more appropriate tools to look at such modifications in a future climate.

4- Summary and Perspectives

	Current climate	Future climate
Malaria in Senegal	Large rainfall control on malaria transmission. The LMM driven by rainfall and temperature from the REMO Regional Climate Model (RCM) realistically reproduces the observed epidemic areas in Senegal.	Rainfall decrease at the northern boundary of the country. Decrease in malaria prevalence in the North, slight increase in the South. The epidemic fringe is significantly shifted southward (to more populated areas), more variability in malaria transmission in the central western part of Senegal
Malaria in Ghana	Rainfall – temperature control. The LMM driven by rainfall and temperature from the REMO RCM depict a high endemic profile for Ghana as observed.	Slight Extension of the malaria season in the south west and contraction elsewhere. Malaria prevalence slightly increases over the whole country, more related to a temperature increase.
Malaria in Malawi	The LMM driven by rainfall and temperature from the REMO RCM realistically reproduces the malaria patterns.	The mean malaria prevalence significantly increases (10-20%) over the whole country, likely due to a simulated temperature increase.
Rift Valley Fever in Senegal and Mauritania	The RVF risk is related to anomalous large rainfall following a dry spell at the end of the rainy season. This leads to a massive hatching of infected *Aedes* mosquito eggs that should have hatched the following rainy season.	None attributed. Impossible to assess changes in intra-seasonal rainfall features in current state of the art climate models (too many uncertainties).

Achievements of Deliverable objectives:

- Three publications instead of one originally planned (QWeCI acknowledged three times)
- Environmental Health Perspectives is a high impact journal

- Need more research on the links existing between current climate conditions and malaria for the target countries, and also good parameter settings for the LMM at the country level

- Need more focus on looking at future changes for RVF risk in Senegal (new methods to develop)

Rift Valley Fever work, perspectives:

We mainly focused on RVF in Senegal and Mauritania, as no outbreaks have been reported yet over the other project target countries (Ghana and Malawi, see fig S1). Furthermore, we did not look at changes in RVF risk for the future because the related climatic risk (unusual peak in rainfall at the end of the rainy season) is poorly simulated by the actual state of the art climate models which are employed to simulate future scenarios.

Future research will focus on developing a dynamical disease model for RVF (ongoing in Liverpool University) and/or using simple R0 model (basic reproduction number). These models will be driven by state of the art climate models to look at RVF risk scenario for the future.

Malaria work, perspectives:

A lot has already been achieved in the papers by Ermert et al., 2011 and Caminade et al., 2011.

Concerning the relationship between climate parameters and malaria in Senegal, we will use the entomological work carried out in IPD (Institut Pasteur, Dakar) to refine the parameter settings for the Liverpool Malaria Model for Senegal (already in progress). This new parameter settings will then be employed (in conjunction with WP2.1 and WP5.3) to assess malaria transmission changes in Senegal.

For the future projections, we will also use bias corrected rainfall and temperature from an ensemble of regional climate models from the ENSEMBLES EU project. Different malaria model (including the standard version of the LMM, the LMM version used by Ermert et al., 2011, and Vectri; a malaria model developed at ICTP; a publication about this new model is actually in progress) will be ultimately run by this ensemble of Regional climate Models. This is carried out in conjunction with WP2.1. The output results will be submitted to a high impact peer reviewed journal (Nature / Science).

References and figures

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C. Caminade, J.A. Ndione, M. Diallo, D.A. McLeod, O. Faye, Y. Ba, I. Dia, A.P. Morse, 2012. Forecasting Rift Valley fever risk in sub-Saharan Africa: the example of the 2010 outbreak in northern Mauritania. Submitted to Nature Scientific Reports (under review).

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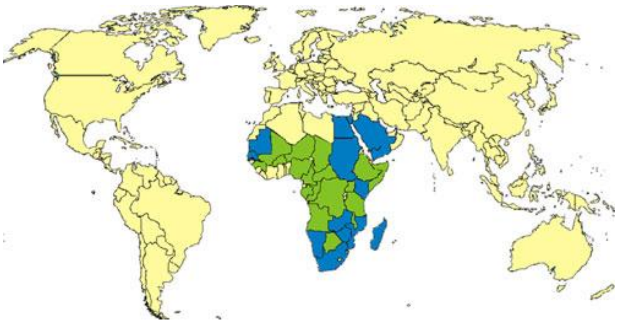
J.A. Ndione, I. Dia, Y. Ba, M. Diallo, J.P. Lacaux, C. Caminade, A.P. Morse, A.T. Gaye, 2012. Pluviométrie et émergence de la fièvre de la vallée du Rift (FVR) au Sénégal : au-delà de 20 années de recherche, où en sommes-nous ? To be submitted to "La climatologie".



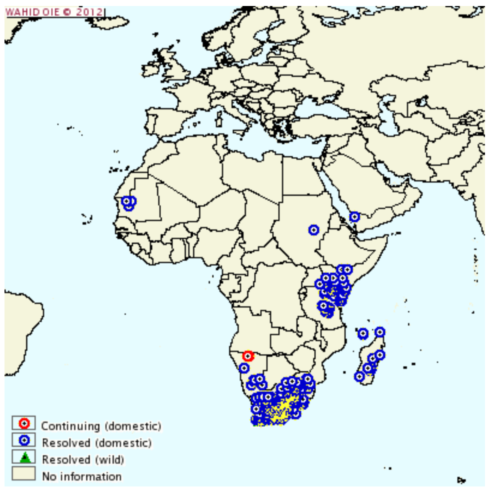


Fig S1: **Left**: Blue: Countries with endemic disease and substantial outbreaks of RVF, Green: Countries known to have some cases, periodic isolation of virus, or serologic evidence of RVF. Adapted from CDC (Centre for disease Control). **Right**: Resolved and continuing domestic outbreak of RVF (animals) based on the period 2005-2011. Adapted from OIE (World Organisation for Animal Health).