Changement climatique et nouveaux défis de la lutte contre le paludisme en Afrique

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The Abdus Salam International Centre for Theoretical Physics

Colloque paludisme, INSERM, Paris, 5 June 2026

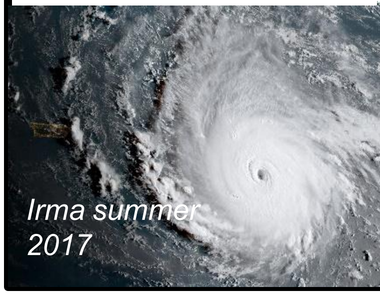
University of Liverpool

Climate change impact on health

Heatwaves


An Iraqi man shows a thermometer reading more than fifty degrees Celsius on **July 30, 2015** in Baghdad.

Hurricanes and floods

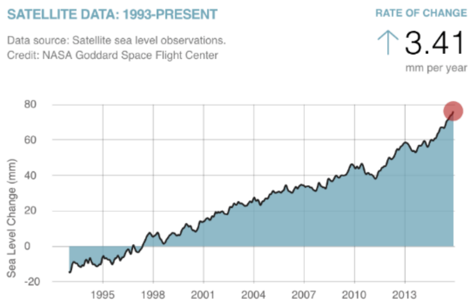

Irma summer 2017


Floods in Florida October 2015

Air pollution


Harbin, China

Sea level rise



Climate sensitive diseases


Arthropods are ectotherms

Vector, water and soil borne pathogens are impacted

Water, agriculture and biodiversity


Scientific American artwork


Starving polar bear National Geographic

Climate refugees and migration


Somali refugees flee flooding in Dabaab, Kenya (UNHCR)

Infrastructures


Genoa Morandi bridge collapsed in Aug 2018 due to heavy rainfall (ABC news)

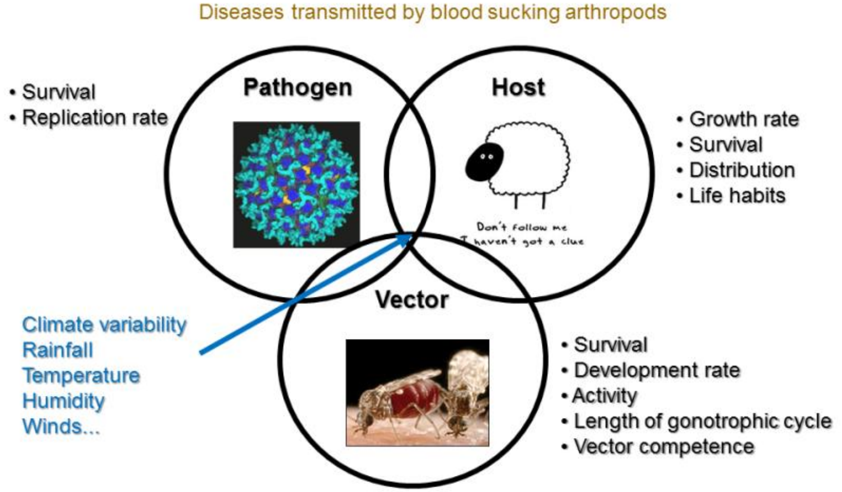
Forest fires


Forest fires in Gironde, France Aug 2022

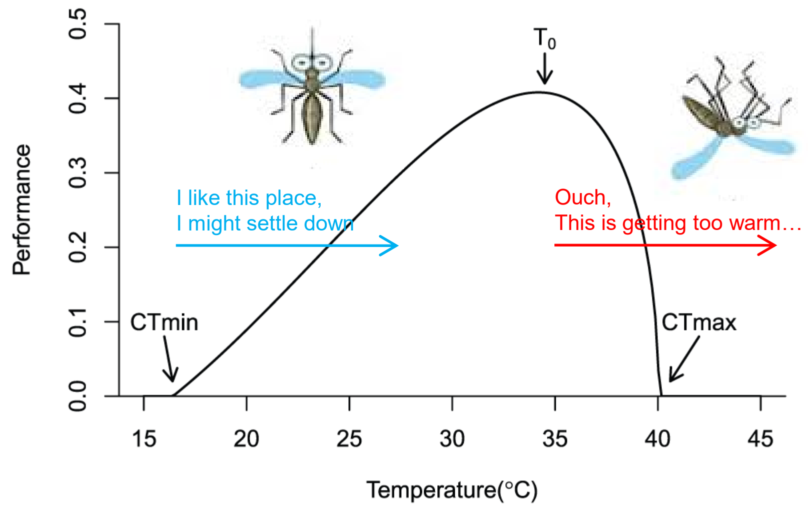
PART I:
DIRECT IMPACT OF CLIMATE CHANGE ON MALARIA

Climate & vector-borne diseases (VBDs)

VBDs are climate sensitive



Vectorial capacity = F(T°)

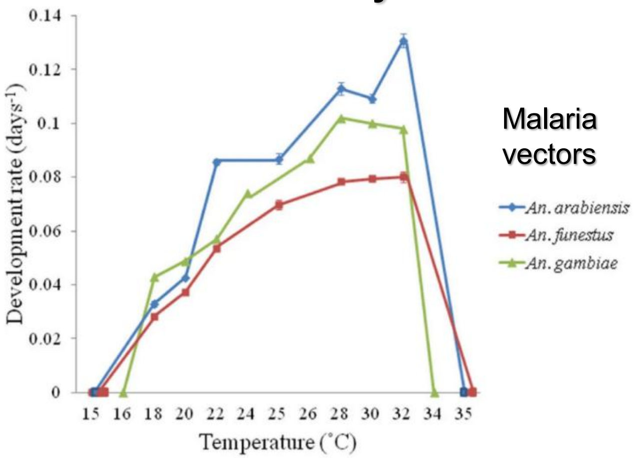


Lafferty KD and Mordecai EA 2016 - F1000Research 2016, 5:2040

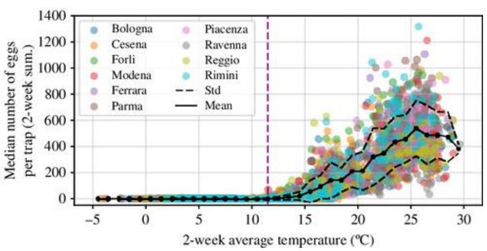
Modelling the impact of climate variability on VBD burden, development of early warning systems (seasonal to climate change time scales).

Entomological factors affected by climatic factors

Vector mortality & Tº



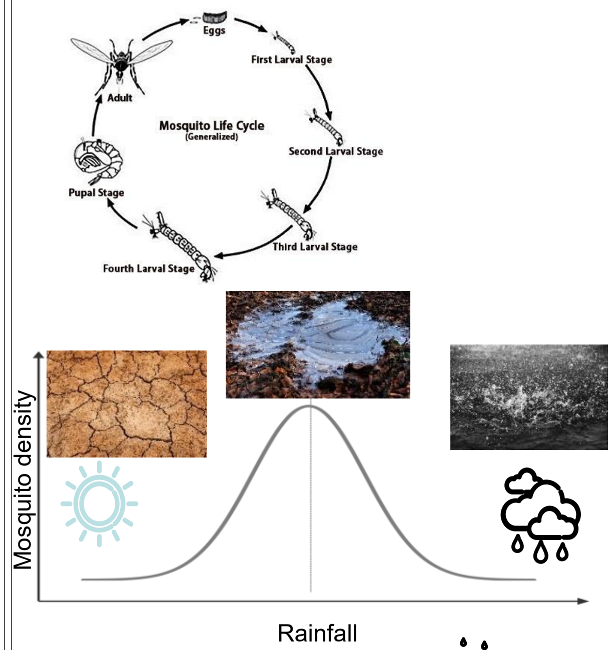
Lyons et al. 2013. *Parasites Vectors* **6**, 104



Asian tiger mosquito eggs trapped in Emilia Romagna, Italy (2010-23).

Garrido Zornoza et al. 2024. *J. Roy. Soc. Int., 21:20240319*

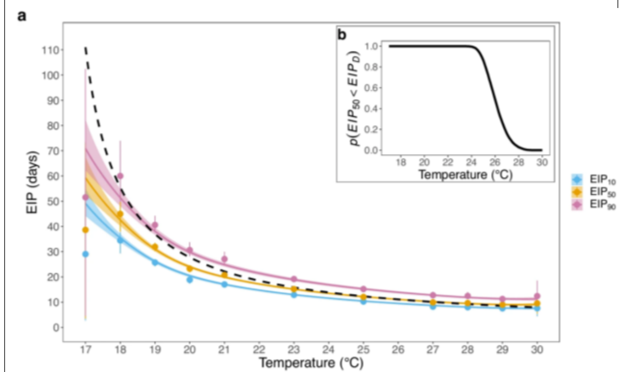
Rainfall & breeding sites



Too dry, no larvae – too wet, flushing of larvae with a rebound weeks later.

Bourgouin & Paul 2021. Med.Sci. 37(1):11-14.

Extrinsic Incubation period & Tº

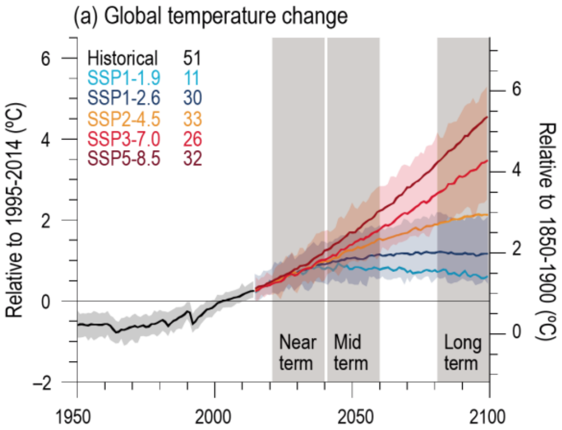


% of infected *An gambiae* at different temperatures

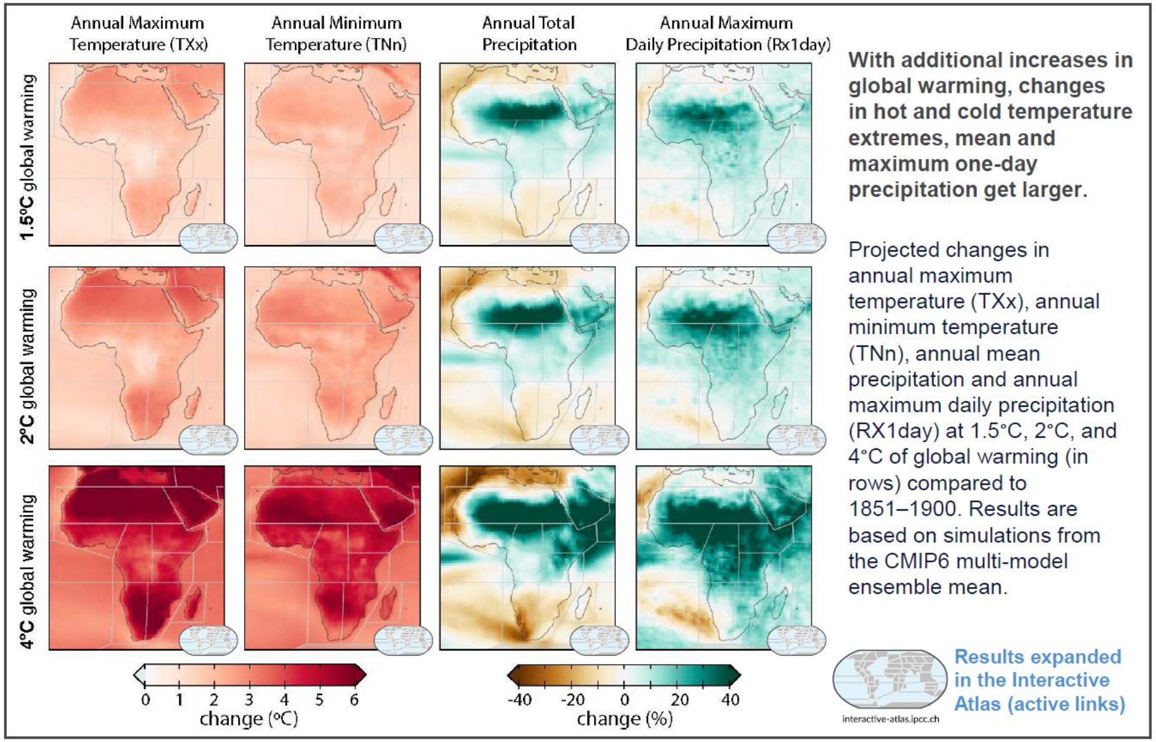
Suh, E. *et al* (2024). *Nat Commun* **15**, 3230

Temperature affects mosquito development rates, biting and oviposition rates, and their time for becoming infectious following an infected blood meal.

Climate change in Africa

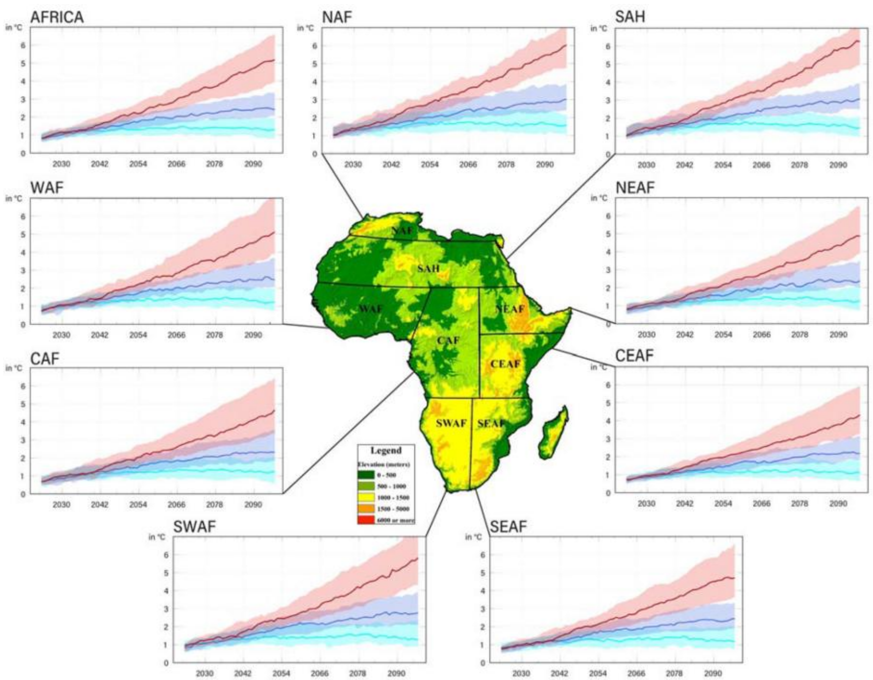


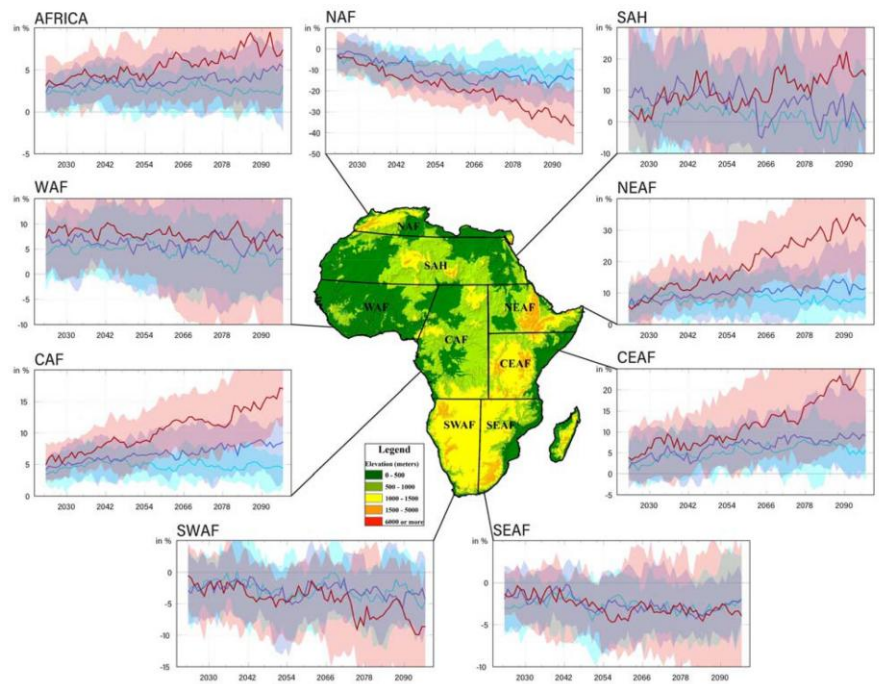
https://www.ipcc.ch/report/ar6/wg1/figures/



https://www.ipcc.ch/report/ar6/wg1/downloads/factsheets/IPCC_AR6_WGI_Regional_Fact_Sheet_Africa.pdf

Climate change in Africa





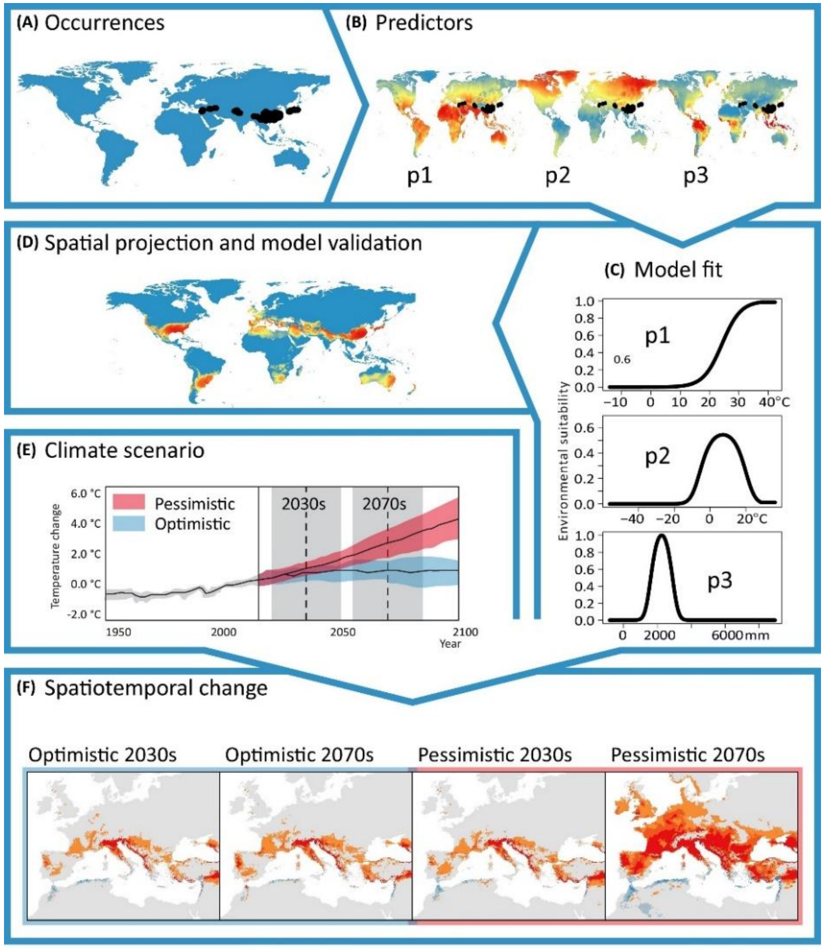
Area-averaged changes in **temperature** (°C) for the eight regions and for the entire Africa during the twenty-first century. Green, blue, and red curves represent the median values for SSP1-2.6, SSP2-4.5, and SSP5-8.5, respectively

Same as Left Fig., except showing **precipitation** change (%) for the twenty-first century

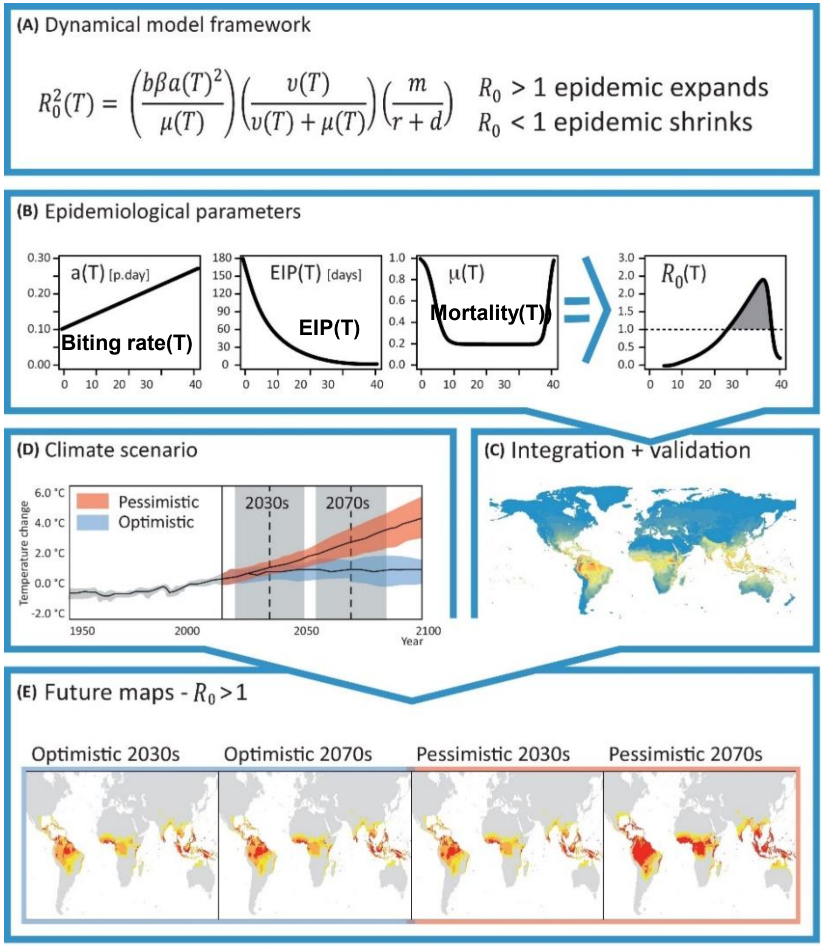
Almazroui, M et al. *Earth Syst Environ* **4**, 455–475 (2020).

Methods to model risk

Statistical models



Mechanistic models



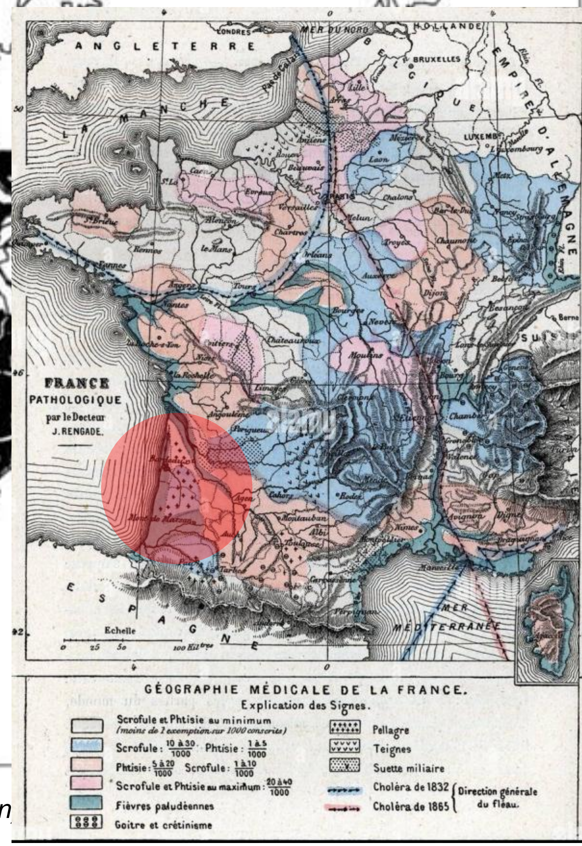
Stat models: Maxent, BRTs, Bayesian models, Mahalanobis distance…

Mechanistic models: SEIR/SIR, R0, Fuzzy logic, climate envelope…

***Fig. 1 &2** Tjaden et al. (2018). Trends in Parasitology 34(3): 227-245. http://dx.doi.org/10.1016/j.pt.2017.11.006*

Malaria distribution 1946

1946 map by kind permission of the World Health Organisation



Top: Carta della Malaria, Luigi Torelli (Florence: 1882)

Left: "La nature et l'homme" de Rengade 1881 Private collection.

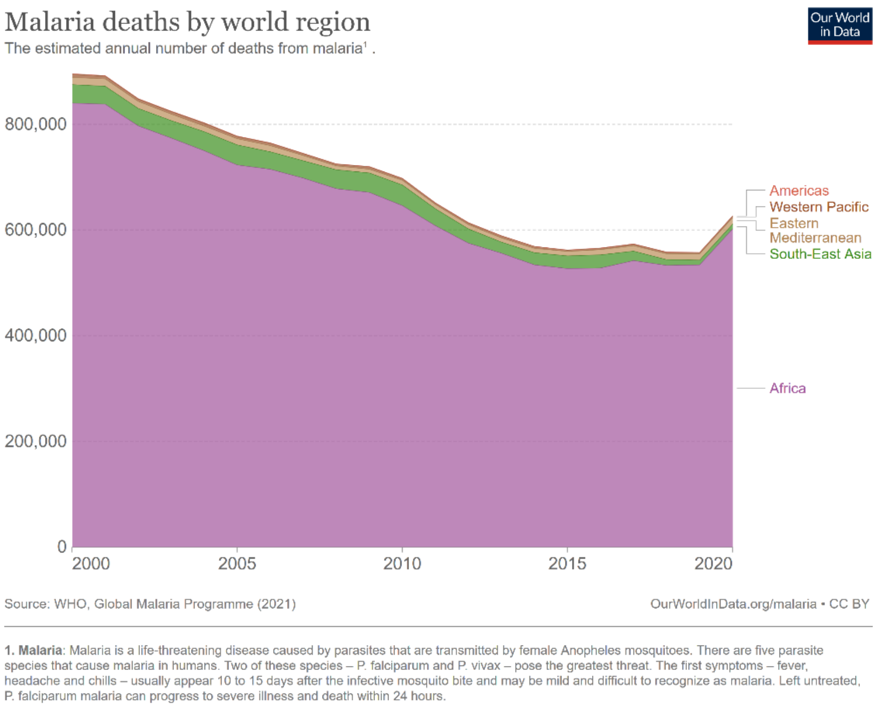
P. vivax & Temperature Limits

- "Even before the discovery of the agent and vector of malaria, the great Russian physician and medical geographer **N. I. Toropov** (**1864**) noted the following in his monograph "The experience of medical geography in the Caucasus with regard to intermittent fevers": **"Fevers do not exist in places where the average summer temperature is lower than 16.2˚C**. A little while later, but also before the discovery of the malaria agent, the German medical geographer **Hirsch** came to **a similar conclusion (1881)."**

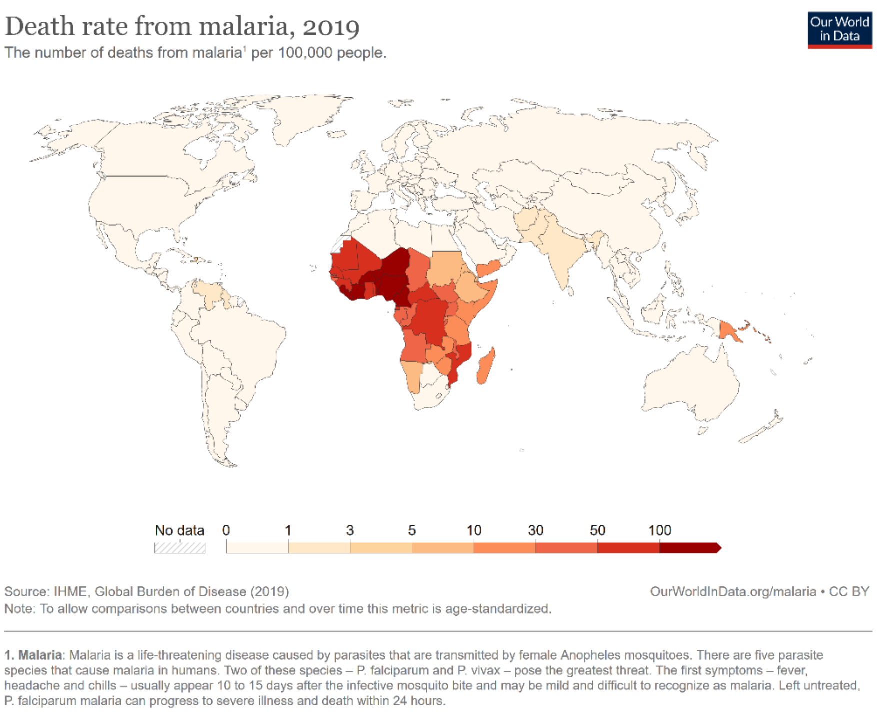
- "The explanation for why the borders of the distribution area of local malaria are governed by temperature came later, when Grassi and Jancsó (1903-04, post Ross discovery in 1897) ascertained through experiments that ***P. vivax* does not develop in mosquitoes in temperatures below 15.5 - 16˚C."**

Lysenko, A. J. & Semashko, I. N. in Itogi Nauki: Medicinskaja Geografija (ed. Lebedew, A. W.) 25–146 (Academy of Sciences, Moscow, 1968). English translation available at https://endmalaria.org/sites/default/files/lysenko.pdf

Malaria: recent trends



https://ourworldindata.org/malaria

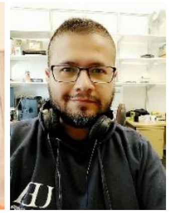
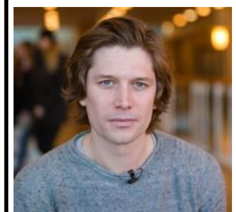
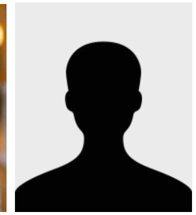


- Malaria cases and deaths primarily affect the African continent
- Number of cases and deaths significantly decreased from 2000 due to vector control, bednet distribution, rapid diagnostic tests
- Small rebound over the past few years (side effect of COVID19 pandemic on control efforts?)

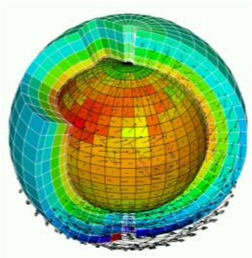
ISI-MIP1: climate change and malaria project, 2014

Overall aim: model the impact of climate change on malaria risk using a multi-model method

The malaria modelling team:

Liverpool Uni.	ICTP	Umea Uni.	LSHTM	Maastricht Uni.
 	 	 	 	
Cyril Caminade *Andy Morse*	*Adrian Tompkins* *Felipe C. González*	*Joacim Rocklov* *Hans Stenlund*	*Sari Kovatz* *Simon Lloyd*	*Pim Martens*
LMM_Ro, MARA	VECTRI	UMEA	POP AT RISK	MIASMA

The framework:



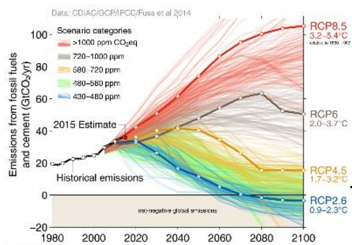
5 GCMs

HadGem2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, GFDL-ESM2M, and NorESM1-M

X

Climate obs

CRUTS3.21, TRMM rainfall, ERAINTERIM reanalysis



5 future GHG scenarios

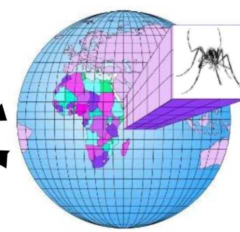
RCP2.6, RCP4.5, RCP6.0, RCP8.5

X

Pop obs

GPWv3 – NASA-SEDAC

SSP2 pop scenario



5 malaria models (MM)

LMM_Ro, MARA, MIASMA, VECTRI, UMEA

Common outputs:

Length of the malaria transmission – LTS (months)

Population at risk (millions)

Validation

Malaria 1900s (Lysenko et al. 1968) – pre intervention – *all Plasmodium*

MAP 2007 (Hay et al., 2009) – *Plasmodium falciparum* (tropical form of malaria)

Future LTS scenarios & pop at risk

5 x 5 x 5(space, time) matrix -> uncertainty – signal and noise

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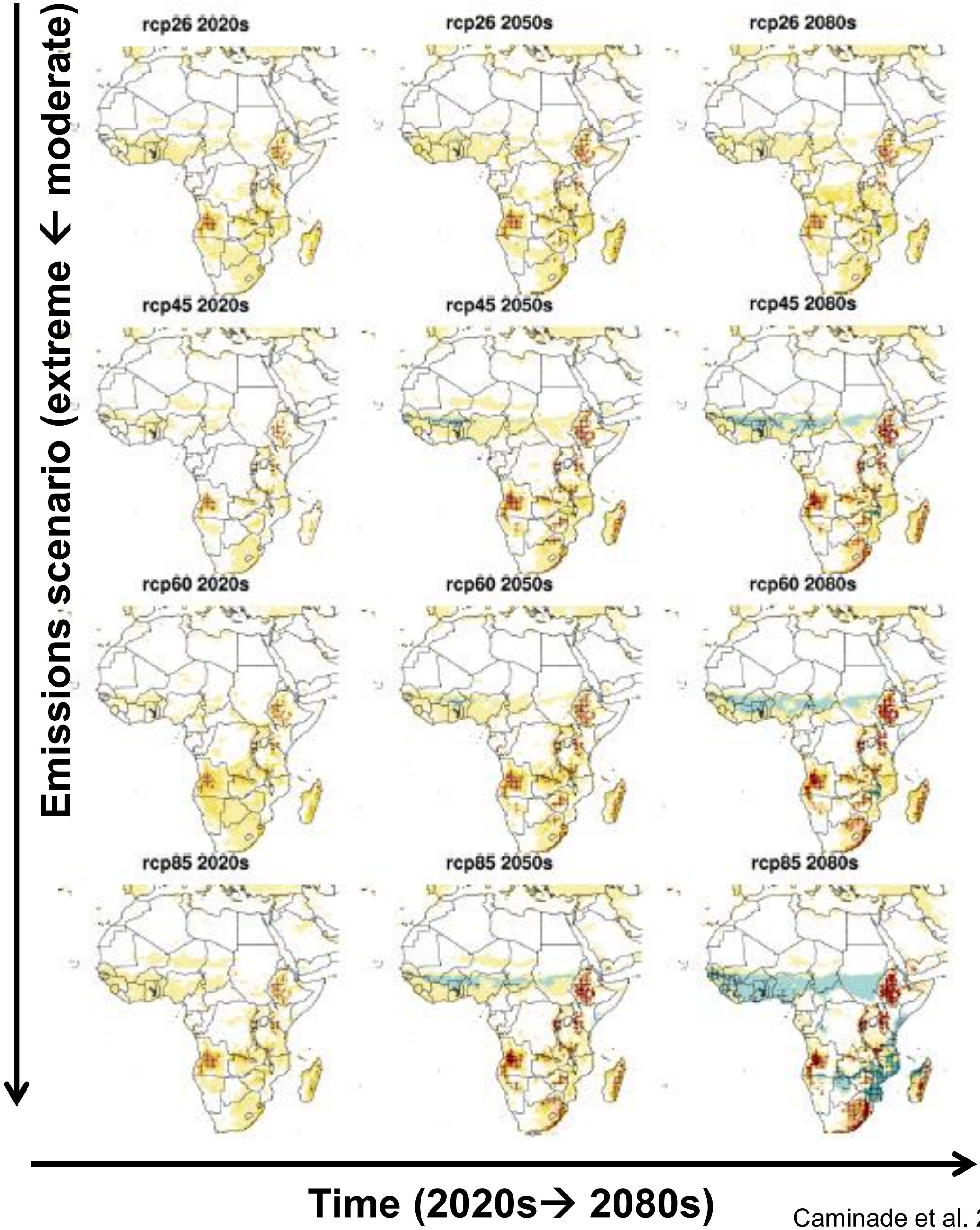
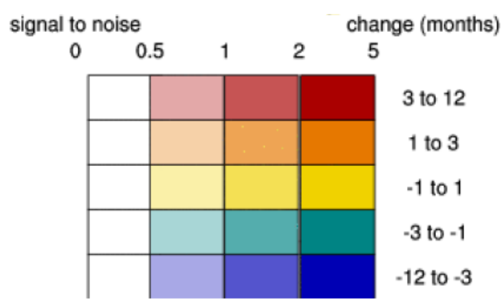
Climate change & malaria - ISI-MIP project



The effect of climate scenarios on future malaria distribution: changes in length of the malaria season.

Each map shows the results for a different emissions scenario (RCP). The different hues represent changes in the length of the transmission season for the mean of CMIP5 sub-ensemble (with respect to the 1980-2010 historical mean). The different saturations represent signal-to-noise (μ/Sigma) across the super ensemble (noise is defined as one standard deviation within the multi-GCM and multi-malaria model ensemble). The stippled area shows the multi-malaria multi GCM agreement (60% of the models agree on the sign of changes if the simulated absolute changes are above one month of malaria transmission).

Simulated Increase in transmission over the highlands of Africa (east Africa, Madagascar, Angola, southern Africa) / decrease over the Sahel (extreme scenario / long term)



Caminade et al. 2014. PNAS, 111(9): 3286-3291. https://doi.org/10.1073/pnas.1302089111

Future population at risk

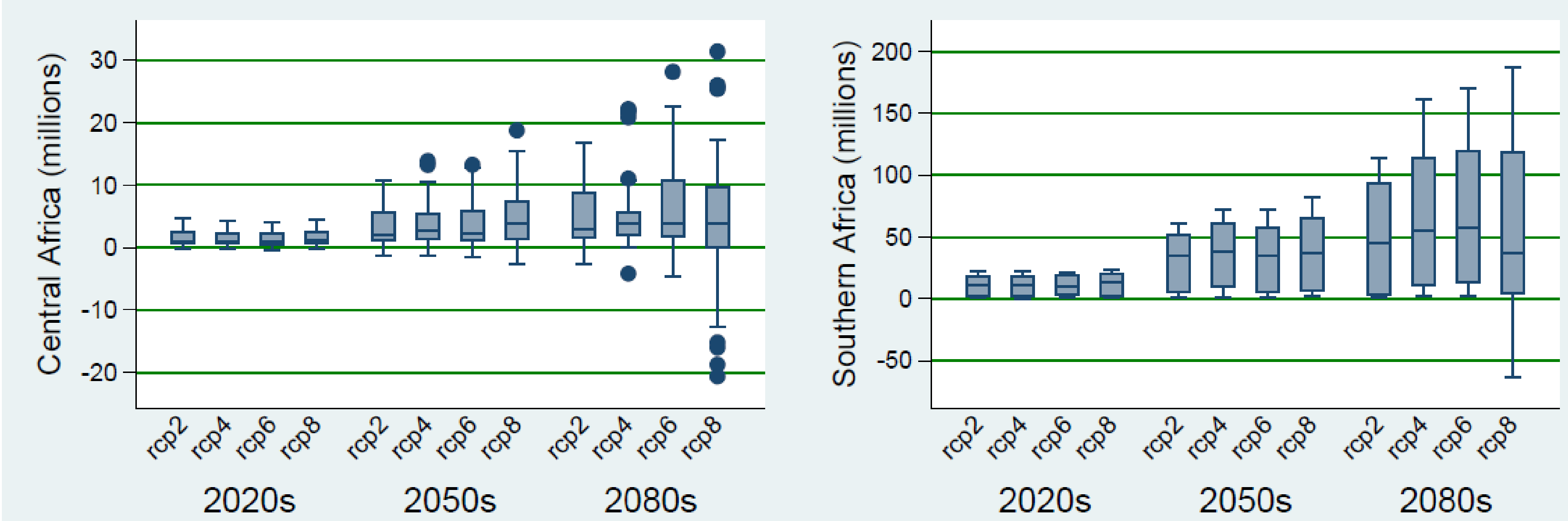
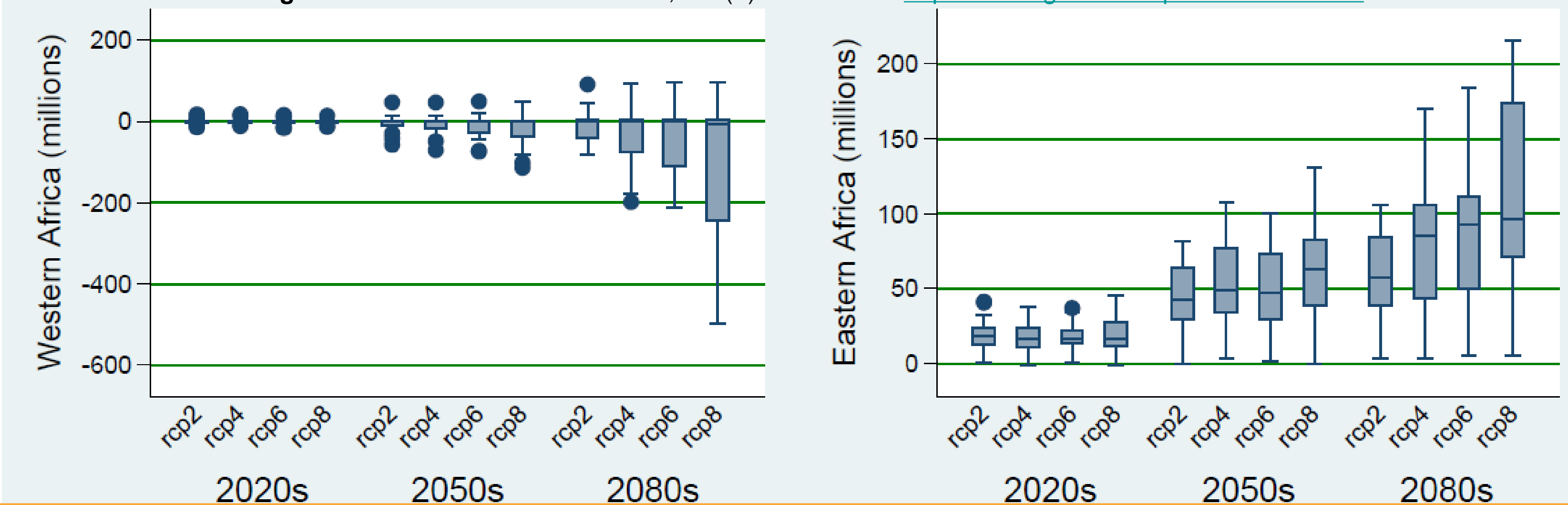
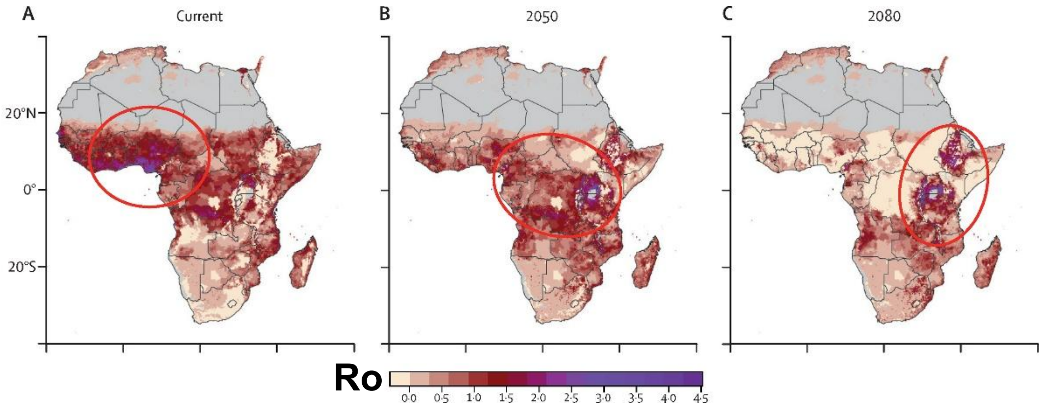


Fig. 3 - Caminade et al. 2014. PNAS, 111(9): 3286-3291. https://doi.org/10.1073/pnas.1302089111



Other modelling studies

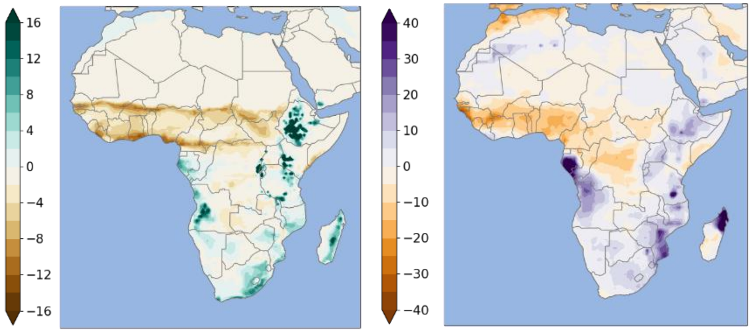
Standard IPCC scenario (RCP8.5)



Similar results but larger decrease in risk over the Sahel

Mordecai, Erin A et al. [The Lancet Planetary Health](https://), 4(9): e416-423

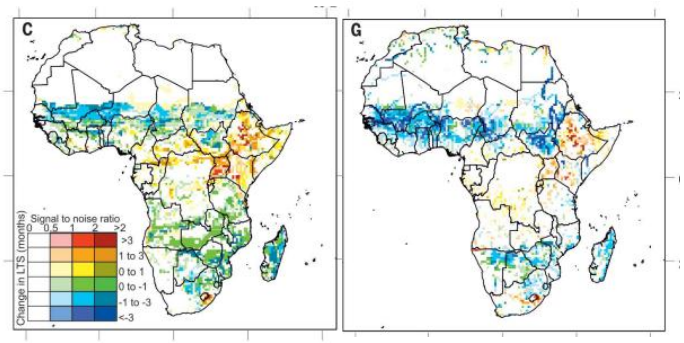
Rapid ice melting scenario



Incidence difference Rainfall difference

Southward shift of the rainbelt and the malaria belt when considering a rapid melting of Greenland (equivalent to a +3m SLR)

Chemison, A. *et al (2021)* *Nat Commun* **12**, 3971



Modèle piloté par P et T° ***Effet additional de l'hydrologie***

Decrease in transmission risk more pronounced over the Sahel when considering hydrological conditions

M.W. Smith *et al. (2024)*. *Science* **384**, 697-703

Recent modelling study

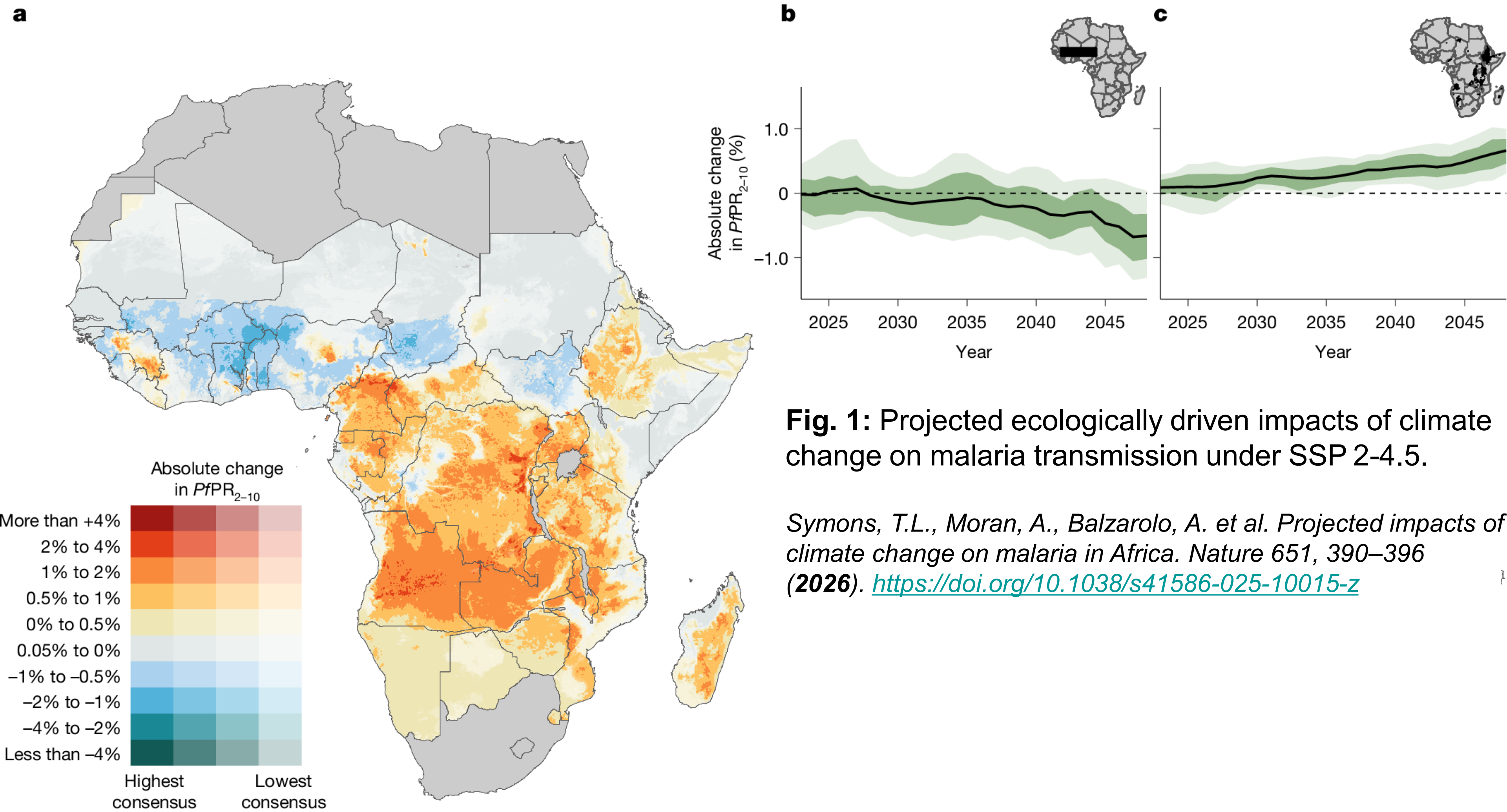
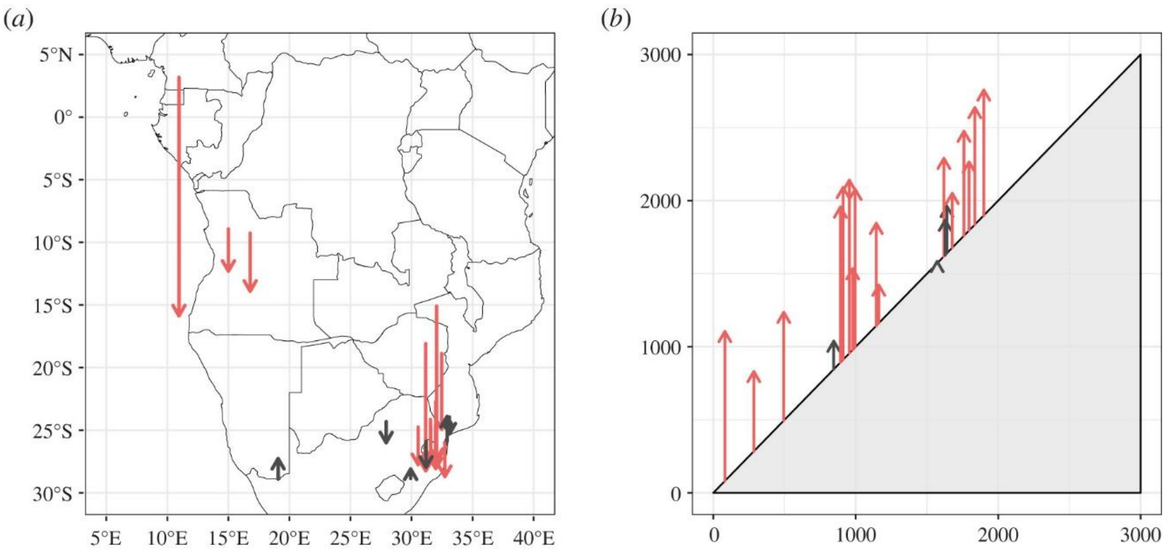


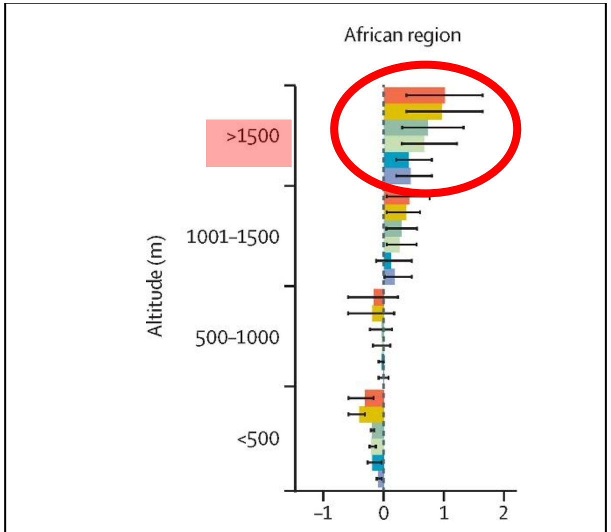
Fig. 1: Projected ecologically driven impacts of climate change on malaria transmission under SSP 2-4.5.

*Symons, T.L., Moran, A., Balzarolo, A. et al. Projected impacts of climate change on malaria in Africa. Nature 651, 390–396 (**2026**). https://doi.org/10.1038/s41586-025-10015-z*

20th century Trend in *Anopheles* mosquitoes



RCP2.6-SSP1 RCP2.6-SSP2 RCP4.5-SSP2 RCP6.0-SSP2 RCP8.5-SSP2 RCP8.5-SSP5



*Estimated shifts in Anopheles species' observed latitudinal and elevational maxima over the twentieth century, where each arrow gives one species' estimate (see electronic supplementary material, table S1). **(a)** Species' estimated southern maxima, where starting points are given at the longitude of the southmost point in the first half of the century (1900–1950), and the arrow shows the **estimated latitudinal shift from 1900 to 2000** (chosen as a standardized unit for visualization, rather than the entire observation period, given that some species are sampled over slightly different intervals). **(b) Estimated elevational gain, 1900–2000** (y-axis), on a 1:1 elevational 'gradient' (x-axis gives initial estimated elevational position). Red arrows indicate species for which temporal trends were statistically significant ($p < 0.05$).*

Colon-Gonzalez et al. 2021. Lancet Plan. Health 5(7): E404-414
https://doi.org/10.1016/S2542-5196(21)00132-7

Anopheles have moved by **6.5m in altitude per year** and southward by **4.7km/year**

Carlson C.J. et al. (2023) Rapid range shifts in African Anopheles mosquitoes over the last century Biol. Lett.1920220365 20220365
https://doi.org/10.1098/rsbl.2022.0365

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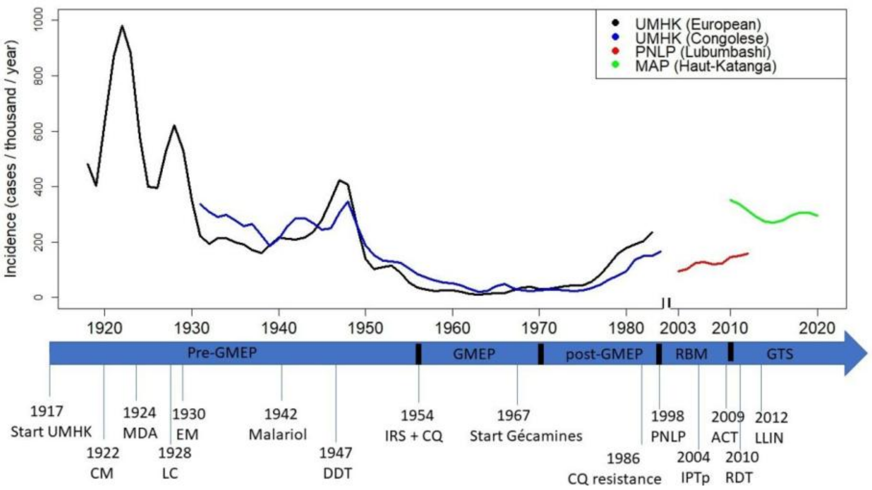
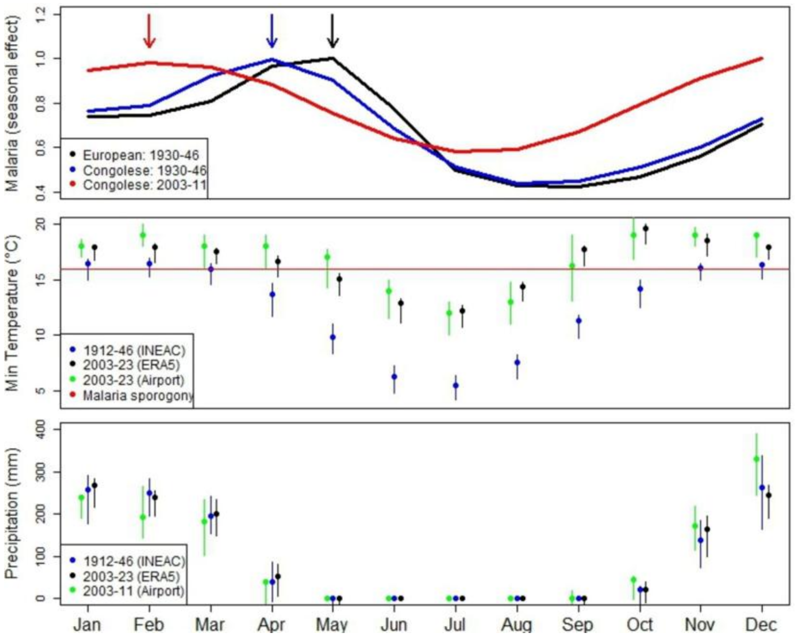
Changes in malaria seasonality – Katanga (DRC)



Annual malaria incidence in Haut-Katanga (RDC, 1200-1300m) for the various data sets encompassing distinct time periods and control strategies.

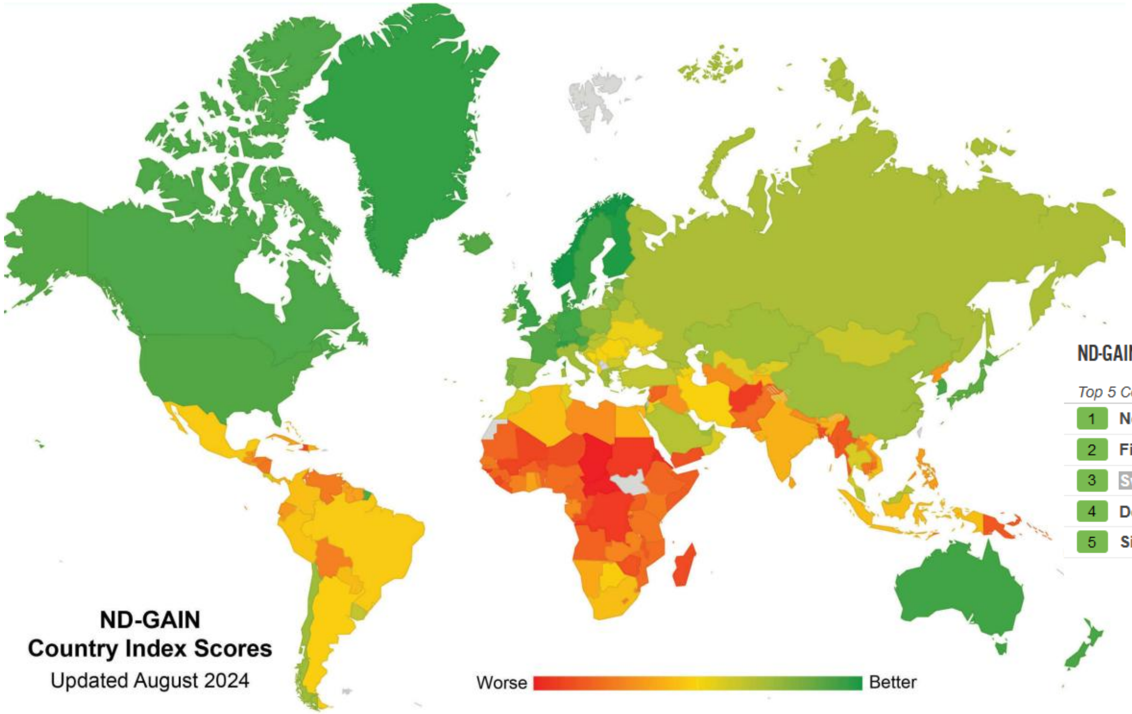


Mariën et al. (2024) BMJ Global Health, 9:e015375.

"A notable **decrease in cases followed the introduction of DDT**, while a surge occurred after the civil wars ended at the beginning of the new millennium. **Recently**, the malaria season **began 1–2 months earlier** than historically observed, **likely due to a 2–5° C increase in mean minimum temperatures**, which enables the **sporogonic cycle of the parasite**."

PART II:
INDIRECT IMPACTS OF CLIMATE CHANGE ON MALARIA

Vulnerability



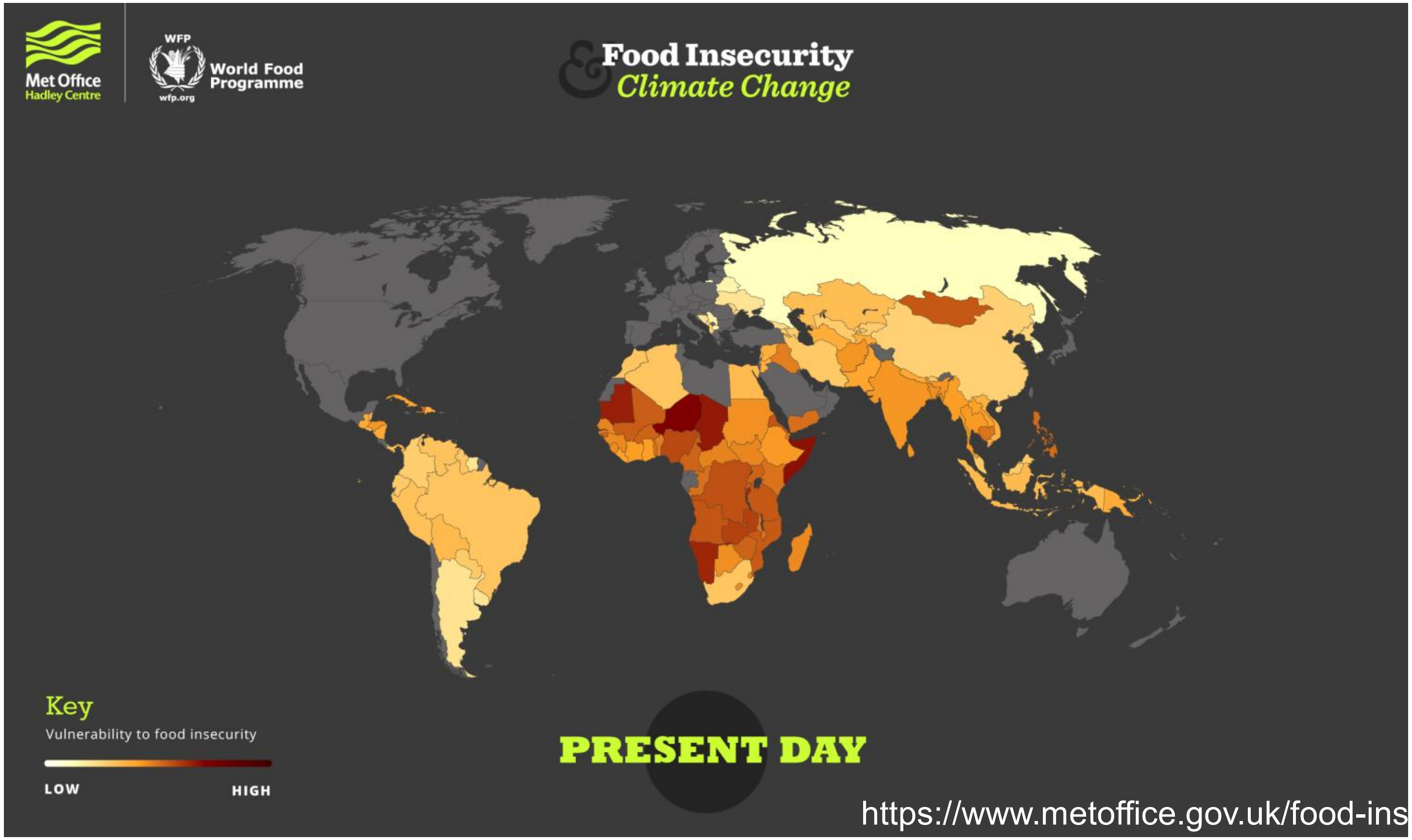
ND-GAIN Index Country Rankings

VIEW FULL RANKINGS

	Top 5 Countries	*Score*		*Bottom 5 Countries*	*Score*
1	**Norway**	74.6	183	**Sudan**	32.7
2	**Finland**	72.9	184	**Dem. Rep. of the Congo**	32.5
3	**Switzerland**	72.1	185	**Eritrea**	30.6
4	**Denmark**	71.0	186	**Central African Rep.**	27.8
5	**Singapore**	71.0	187	**Chad**	27.1

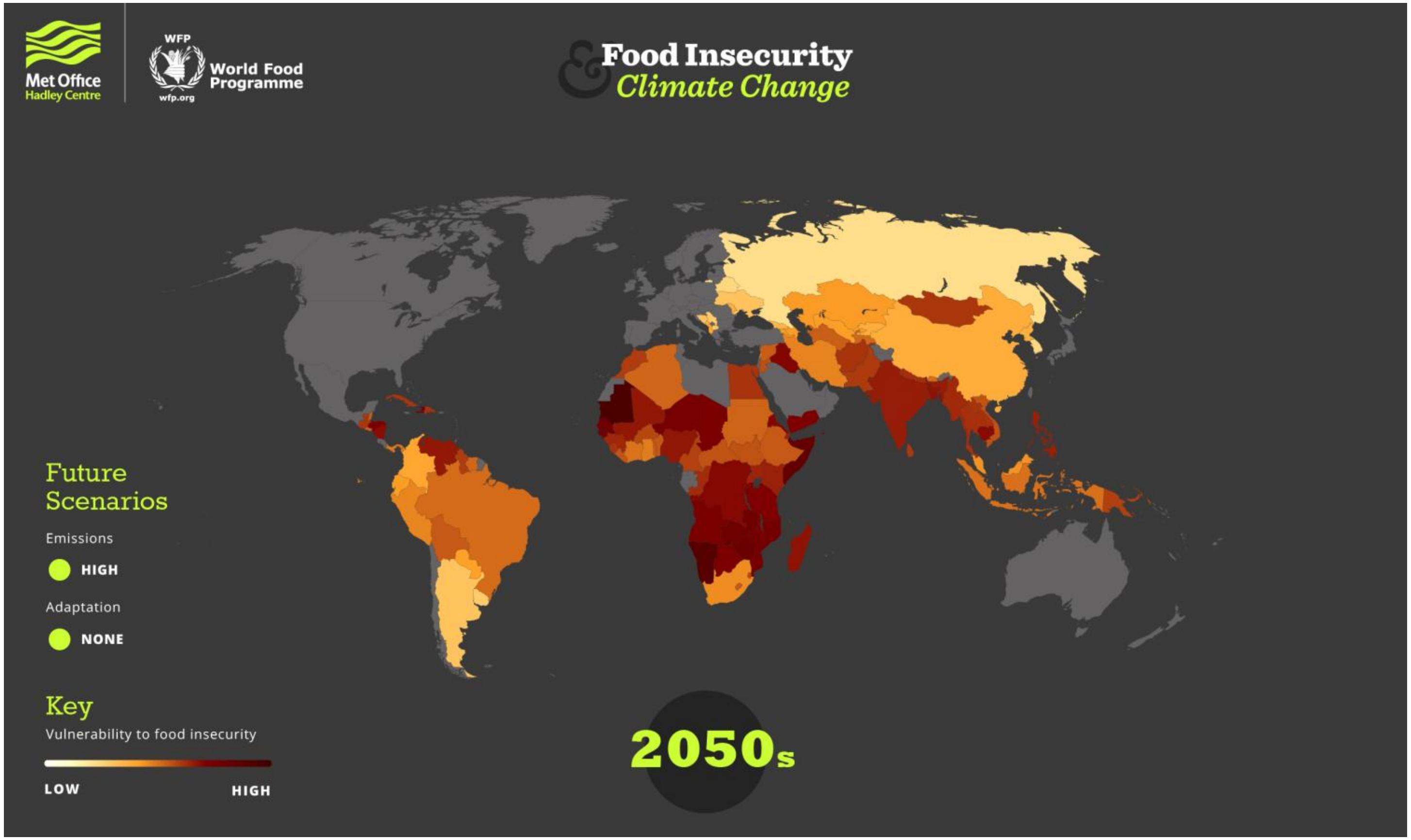
https://gain.nd.edu/our-work/country-index/

Food security

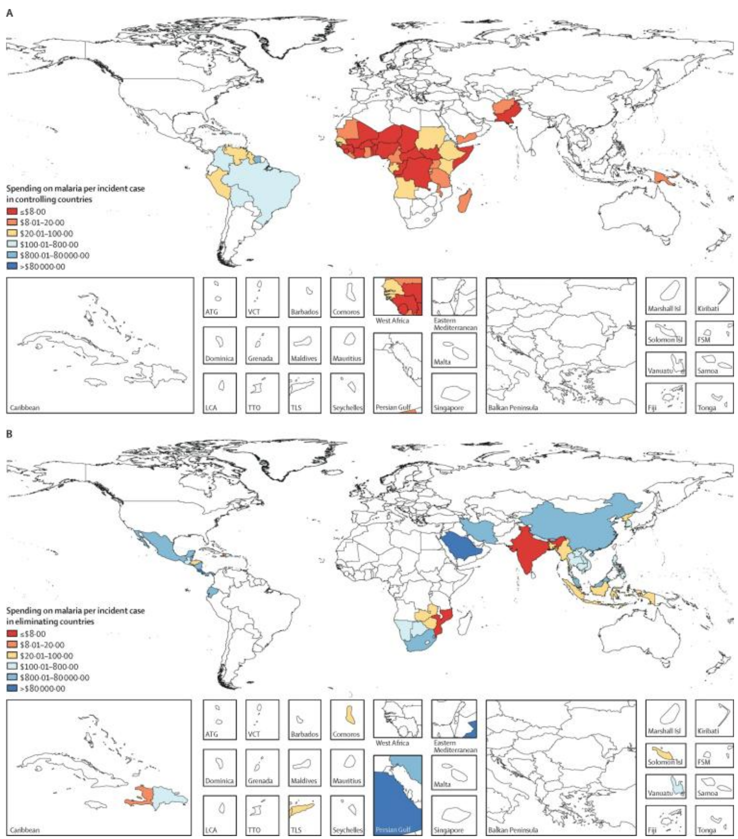


https://www.metoffice.gov.uk/food-ins

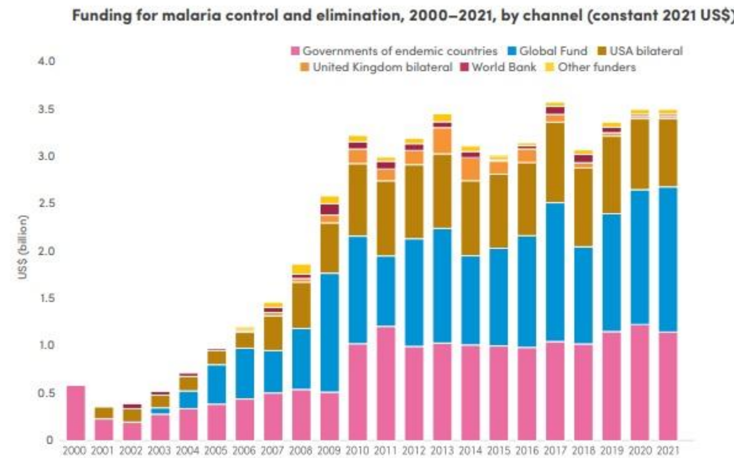
Food security



Finances



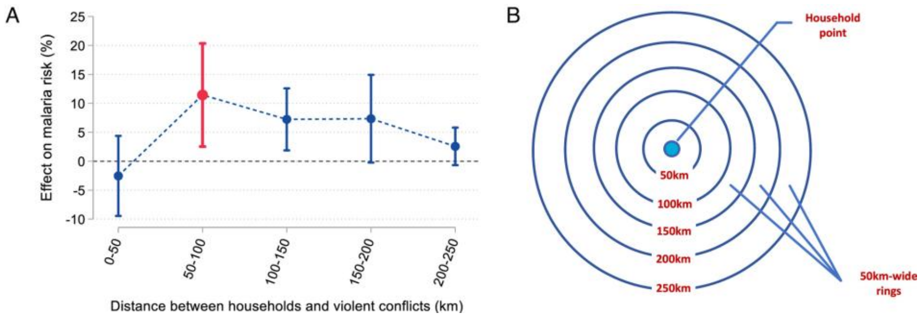
Haakenstad A. et al. [The Lancet Infectious Diseases](), 19(7):703-16

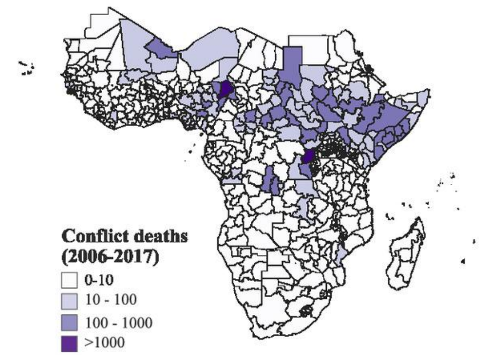


https://endmalaria.org/about-malaria/financing-0

"Without sustained malaria investment, achievements made over the past decades are at risk of reversal. It is therefore critical to work with endemic countries to expand their domestic financing base, and strive to advocate globally to sustain and increase the funding from major donor countries. In addition to these interventions, we need to attract new and emerging donors." **Roll Back Malaria**

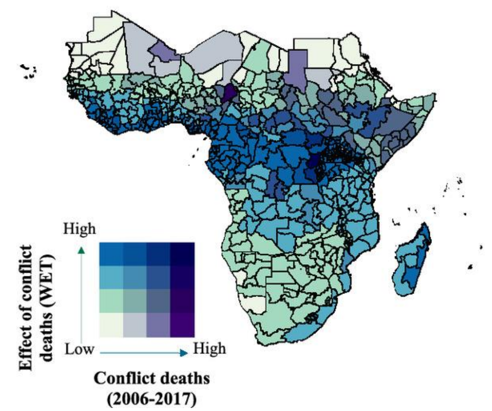
Conflicts and Social unrest





Top: Effects of conflict deaths on malaria risk at pan-African scale.
Right: Mapping of the marginal effects of conflict deaths (50 to 100 km) during 2006 to 2017.

Yu Q et al. (2024). PNAS, 9, 121(15):e2309087121



"We show how violent conflict can worsen malaria risk in Africa. Using localized data on climate, malaria risk, and conflict events, we demonstrate that nearby conflicts can worsen malaria risk in communities up to 100-km distance. Effects are the largest in areas where the climate is most suitable for malaria transmission. Our results suggest that violent conflict poses a substantial barrier to malaria elimination efforts in Africa."

Other challenges for NMCPs

BMC Part of Springer Nature

Malaria Journal

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Climate change and malaria control: a call to urgent action from Africa's frontlines

Cyril Caminade, Diego Ayala, Thibaud de Chevigny, Olivia Ngou, André Tchouatieu, Florian Girond, Gildas A. Yahouedo, Corinne S. Merle, Emilie Pothin, Ibrahima Diouf, Emmanuel Hakizimana, Veronica Noseda, Jane L. Deuve & NMCP consortium

Malaria Journal **24**, Article number: 179 (2025) | Cite this article

resistance-across-africa

"Following the floods in Pakistan, a major malaria epidemic ensued, leading to a fivefold increase in malaria cases in 2022, compared with the previous year" (WHO 2024 malaria report)

Best- & Worst-case scenario for vector control

Box 1: Speculative 'best' and 'worst' case examples of how climate change may impact malaria vector control interventions in Africa

		"Best Case"	*"Worst Case"*
Direct Biological Impacts	***Vector ecology***	-Contraction of vector distribution and abundance with drying -Reduction in vector survival and length of seasonal activity period due to unfavourable temperature and rainfall -Shifts in vector species composition towards species that are better adapted to dry conditions but easier to target with some interventions (e.g *An. funestus* by larviciding and indoor interventions)	-Increased mosquito vector abundance and longer seasonal activity in areas receiving increased rainfall -Shifts in vector species composition with drying towards species that are better adapted to dry conditions but harder to target with indoor interventions (e.g *An. arabiensis* and *An. stephensi*) -Spread of invasive An. stephensi (urban adapted, efficient transmission at high temperatures)
	Interventions	-Larval habitats may become fewer and more 'findable' under drying conditions; improving the feasibility of larviciding -Possible enhancement of some novel vector control tools (e.g ATSBS) under drier conditions	-Reduced toxicity and residual efficacy of some chemical and biological insecticides at higher temperatures -Lower coverage and need for more frequent application of larvicides with increasing rainfall /extreme weather events -Possible reduced feasibility or acceptability of some novel control strategies at higher temperature/lower rainfall
	Vector Resistance Strategies	-Reduced ability for vectors to mount energetically costly resistance mechanisms under environmental stress	-More effective physiological resistance to insecticides due to enhanced expression of detoxification genes at higher temperatures -Emergence of mosquito adaptations to warming conditions that also enhance insecticide resistance (e.g cuticle thickening as a strategy for desiccation resistance) -Shift to outdoor biting by mosquito vectors where warmer conditions reduce the suitability of indoor microclimatic conditions

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Best- & Worst-case scenario for vector control

‘We conclude highlighting the need to build “climate-proof” strategies into future vector control planning.’

Indirect Impacts	*Human Behaviour*		-Lower usage and effective coverage of ITNs due to changes in human behaviour and sleeping patterns at warmer temperatures
	Land use	-Changes in livestock keeping practices that reduce mosquito vector populations -Increasing urbanization enhances the feasibility and implementation of some vector control interventions	-Changes in livestock keeping practices that reduce potential for livestock-based interventions -Higher selection for insecticide resistance due to intensification of pesticide use as a strategy for minimizing agricultural losses due to adverse weather and drought conditions -Influx of urban migrants who are exposed to malaria vectors due to insecure housing, limited infrastructure and exposure to environmental risks
	Political and economic	Climate-driven reductions in malaria reduce the costs needed to run vector control programmes	-Rise in climate refugees who are at greater risk of malaria -Constraints on health systems due to rises in other health issues -Reduction in financing for control due to national and global economic constraints -Increased conflict and political insecurity impeding health services and control programmes

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Conclusions & recommendations

- Climate impacts vector borne diseases distribution in the background **BUT**
- Multi-factorial dimension: environment, socio-economic factors, demography, land use changes, drug and insecticide resistance, technological break through…. Largest historical pandemics were driven by environmental change, movements of persons/animals/goods and socio-economic factors.
- Increasing evidences that climate change already impacted the distribution of important vectors over the past 20 years: worrying vector trends have been observed in different temperate, arctic and highland regions (**higher altitudes and latitudes**).
- **Climate change** will alter the distribution and seasonality of some infectious diseases (vector-borne and water-borne) affecting **humans** and **animals: Need for One Health framework.**
- **El Niño** climate phenomenon was associated with the emergence of arboviruses in Latin America, South-east Asia, malaria in East Africa, plague in Madagascar… Prototypes tools are available to forecast risk of arbovirus emergence in Tropical countries. **El Niño 2026-27.**
- On a positive note, surveillance, diagnostic tests and modern medicine (vaccines, drugs and novel control methods) have played a primordial role to protect populations.