AGU Fall Meeting
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Vulnerability to changes in malaria transmission due to climate change in West Africa

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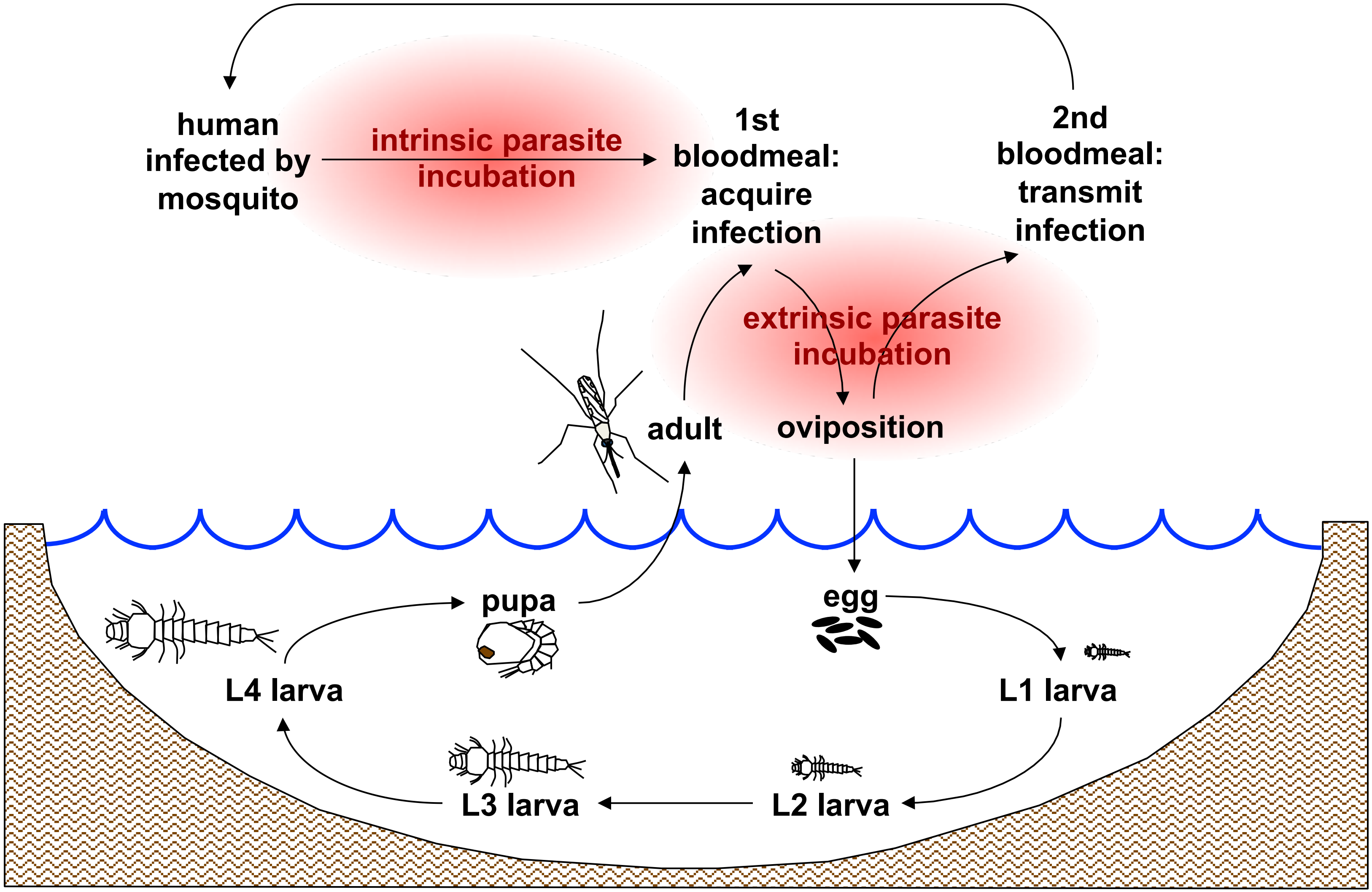
Research Questions

- Which areas in West Africa are most sensitive to changes in malaria transmission due to climate change?
- What changes do we expect to see in these areas?

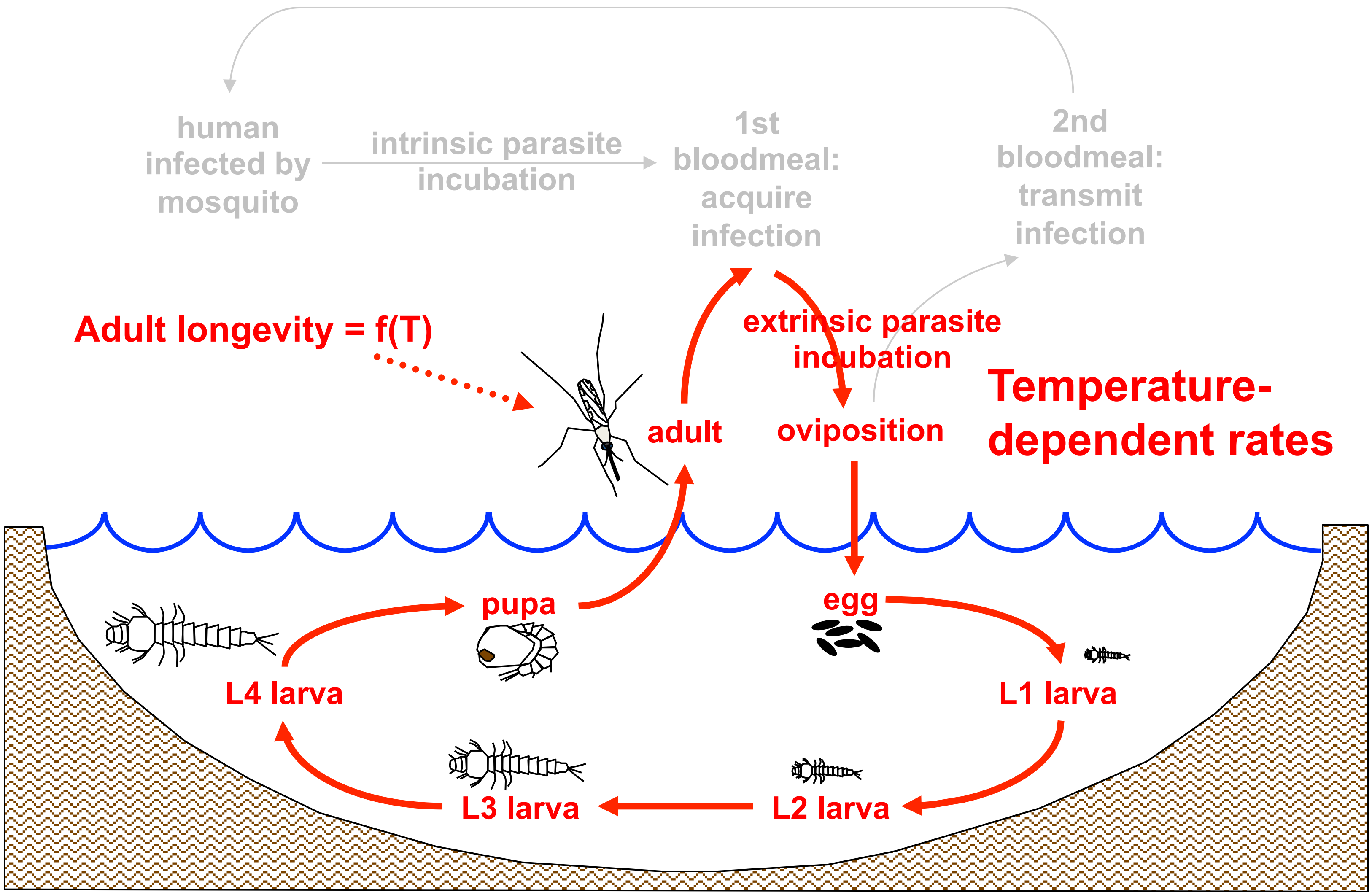
RELATIONSHIP BETWEEN CLIMATE AND MALARIA

Anopheles mosquito ecology



Bomblies, 2008

Anopheles mosquito ecology



Bomblies, 2008

Measure of climate suitability: Vectorial Capacity

- **Vectorial Capacity: Number of inoculations from a single infected person per day**

$$VC = ma^2 \times \frac{p^n}{-\ln(p)}$$

m: mosquitoes per human
a: bites per mosquito per day
p: probability mosquito survives one day
n: extrinsic incubation period
1/-ln(p): average number of days until mosquito dies

p and n **depend on temperature**
m **and** ***a*** **depend on temperature and rainfall**

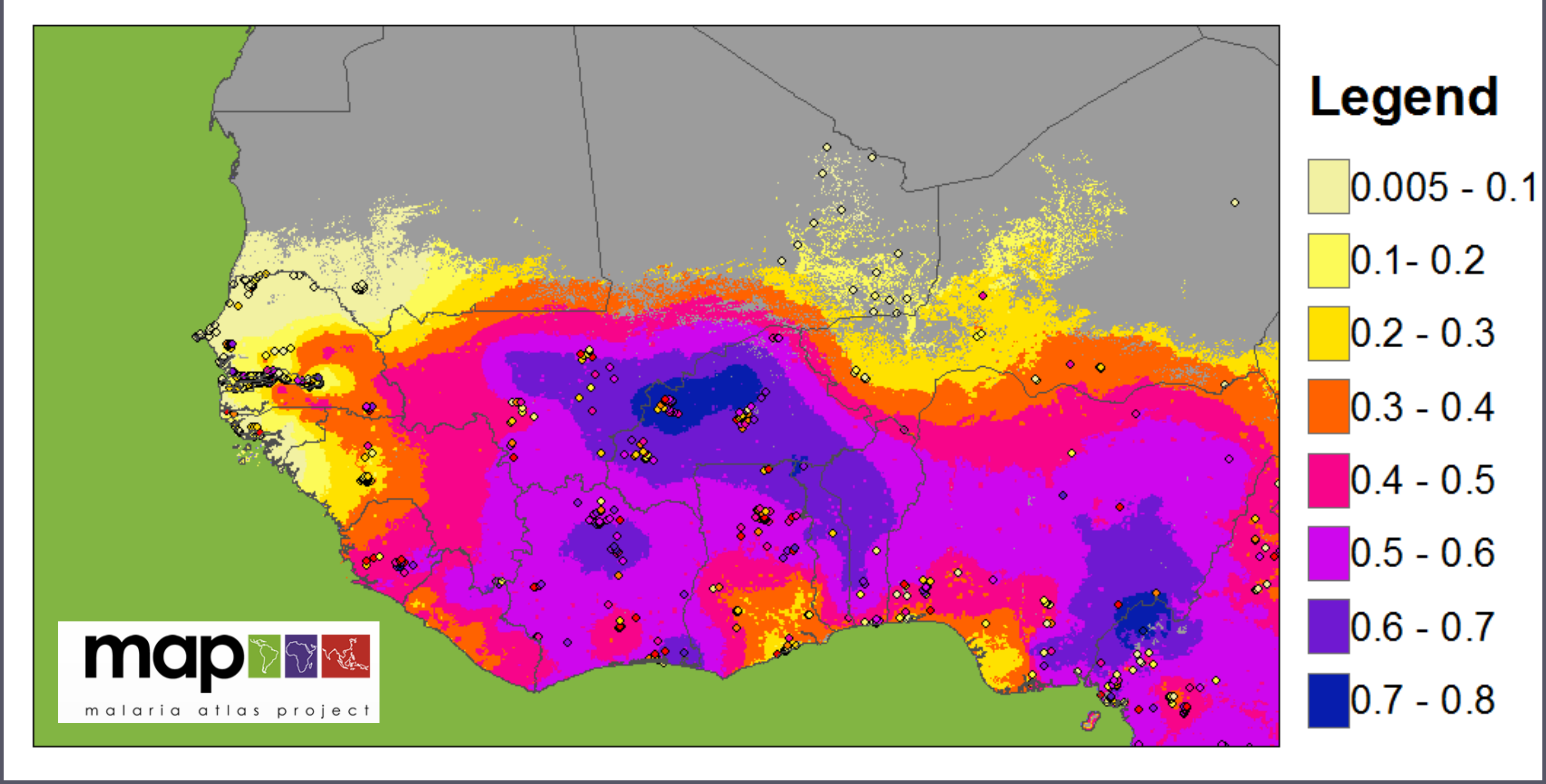
Change in Prevalence due to Climate change

$$\frac{\partial PR}{\partial \text{climate}} = \frac{\partial PR}{\partial VC} \times \frac{\partial VC}{\partial \text{climate}}$$

PR: Prevalence - Proportion of infected individuals in the population

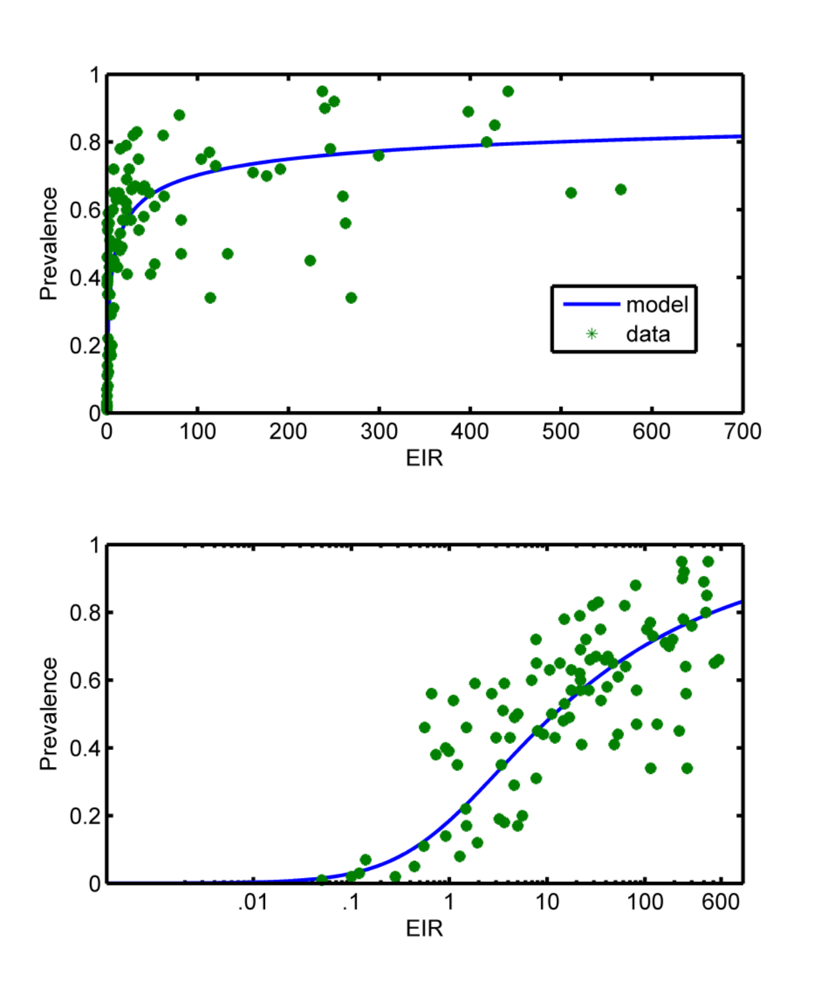
RELATING VECTORIAL CAPACITY TO MALARIA PREVALENCE

Malaria Prevalence in West Africa



Gething, P.W.* et al. (2011). **A new world malaria map: Plasmodium falciparum endemicity in 2010**. *Malaria Journal*, **10**: 378.

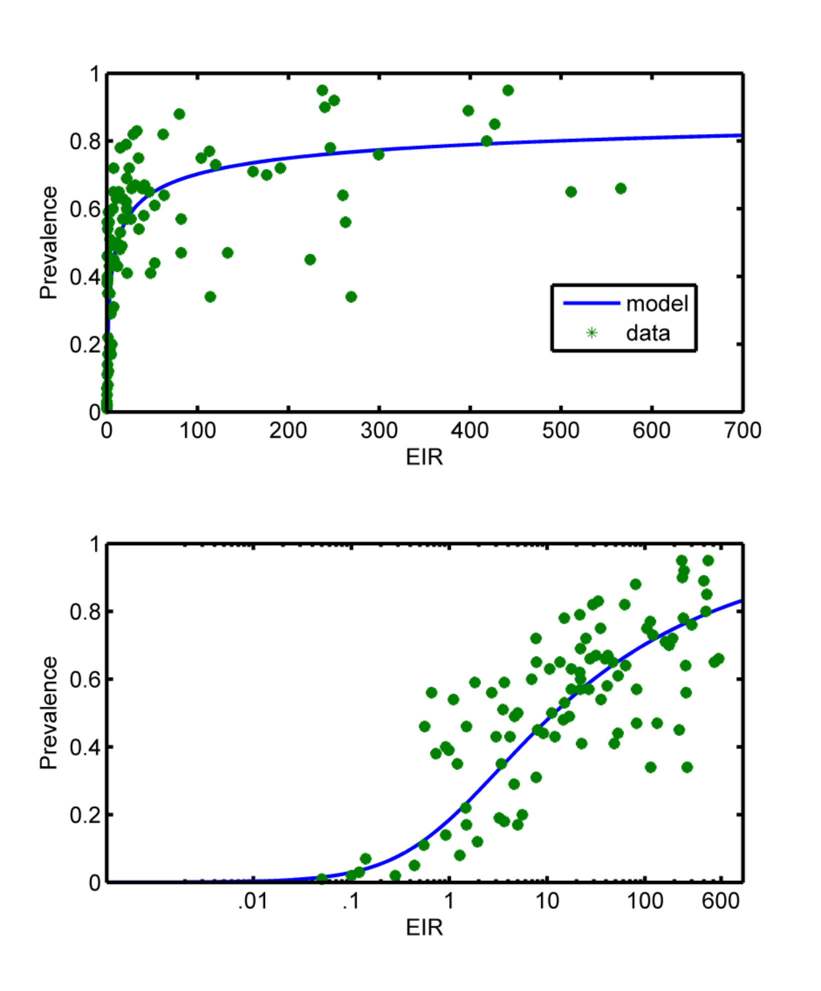
Relationships between PR, EIR, VC



- **Entomological Inoculation Rate (EIR):** Infectious bites per person per year

Smith et al. (2007). *PLoS Biology*

Relationships between PR, EIR, VC



Smith et al. (2007). *PLoS Biology*

$$PR = 1 - \left(1 + \frac{b\alpha EIR}{r}\right)^{-1/\alpha}$$

$$VC = EIR \times \frac{1 + SK}{K}$$

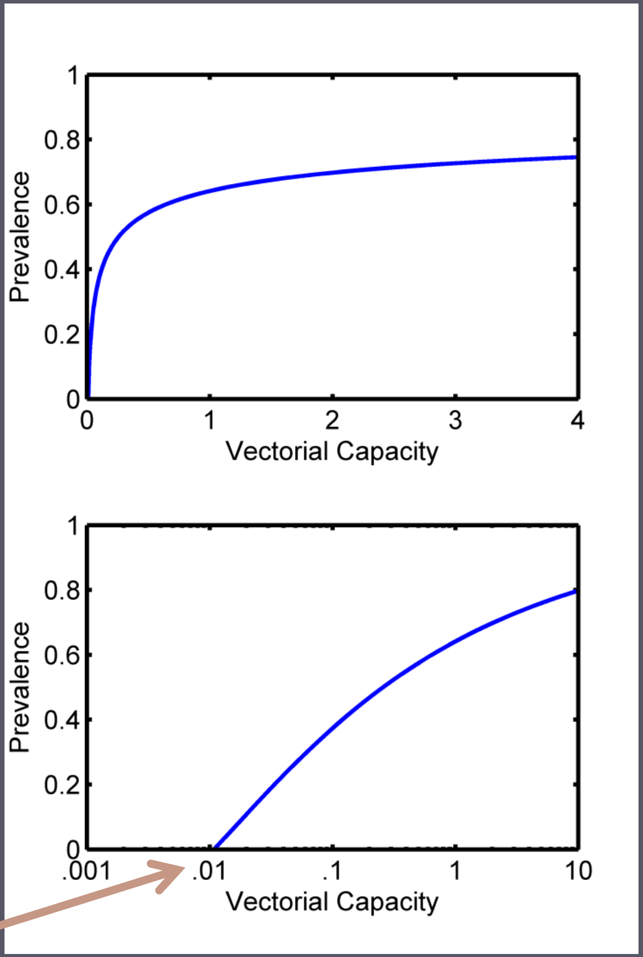
$$K = c(1 - (1 - PR)^{1+\alpha})$$

EIR: Infectious bites per person per year
S=a/-ln(p): bites per mosquito lifetime
a: bites per mosquito per day
p: probability mosquito survives one day
b: mosquito to human transmission efficiency
c: human to mosquito transmission efficiency
α: accounts for heterogeneity in human biting rate

Vectorial Capacity and Prevalence

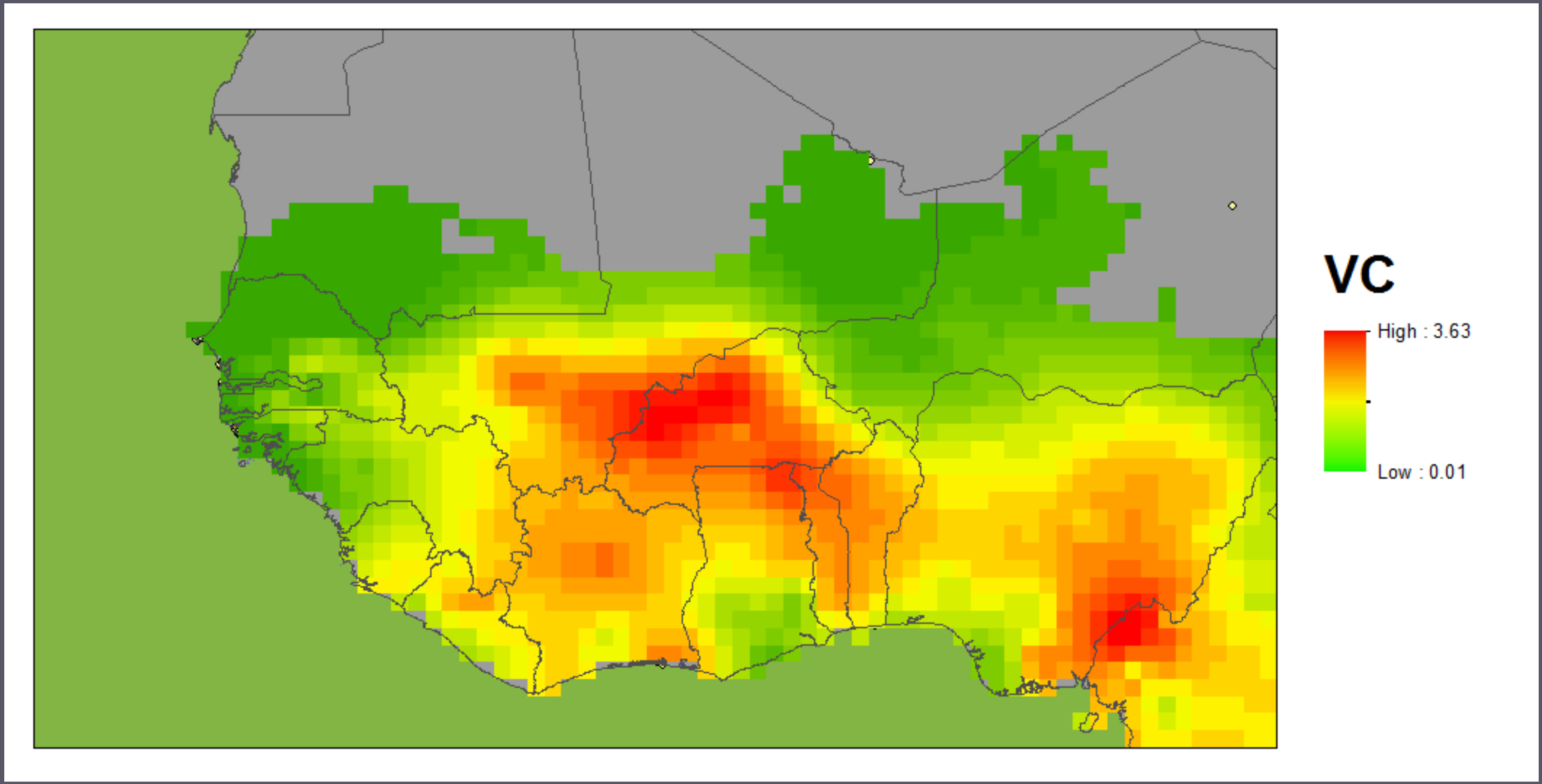
- For effects of climate change, most interested in relationship between VC and prevalence

$$VC = \frac{r}{b\alpha}[(1-PR)^{-\alpha} - 1] \times \frac{1+SK}{K}$$



$$VC_{\text{critical}} = \frac{r}{bc(1+\alpha)}$$

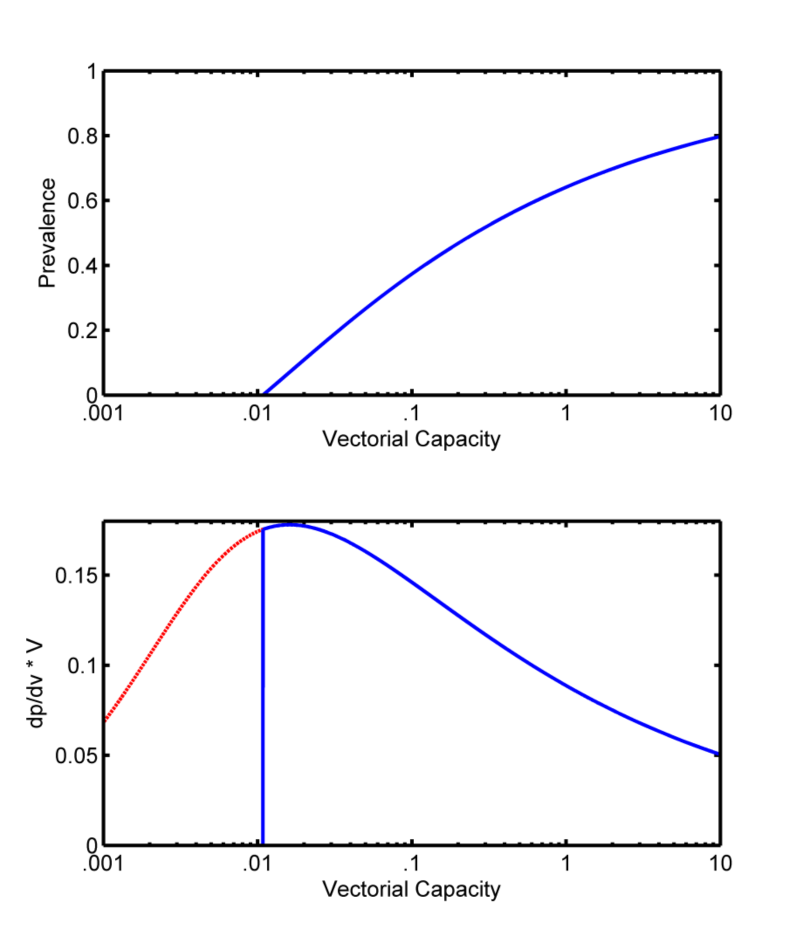
Estimated Vectorial Capacity



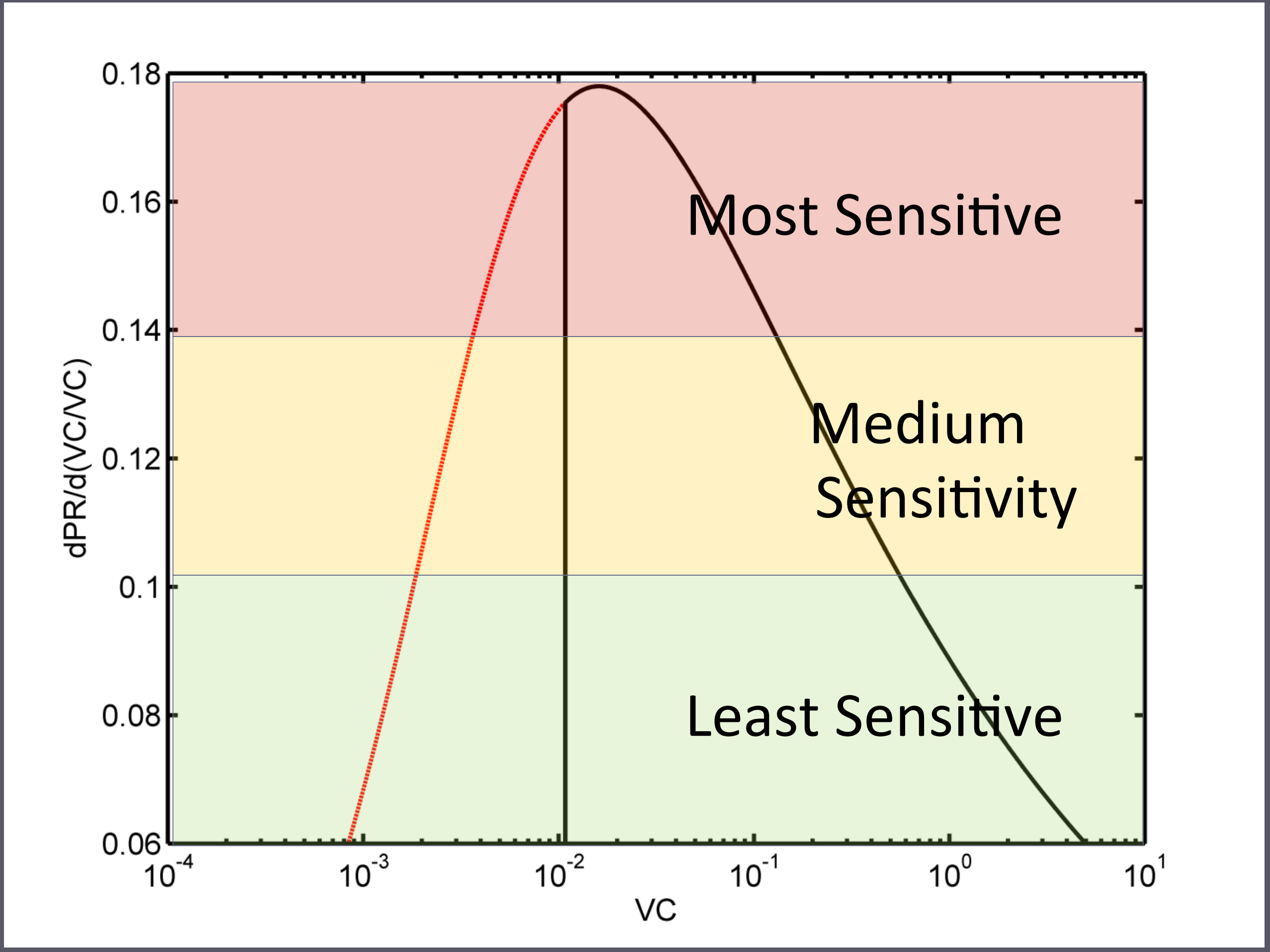
Derivative of Prevalence w.r.t. VC

- Numerically differentiate

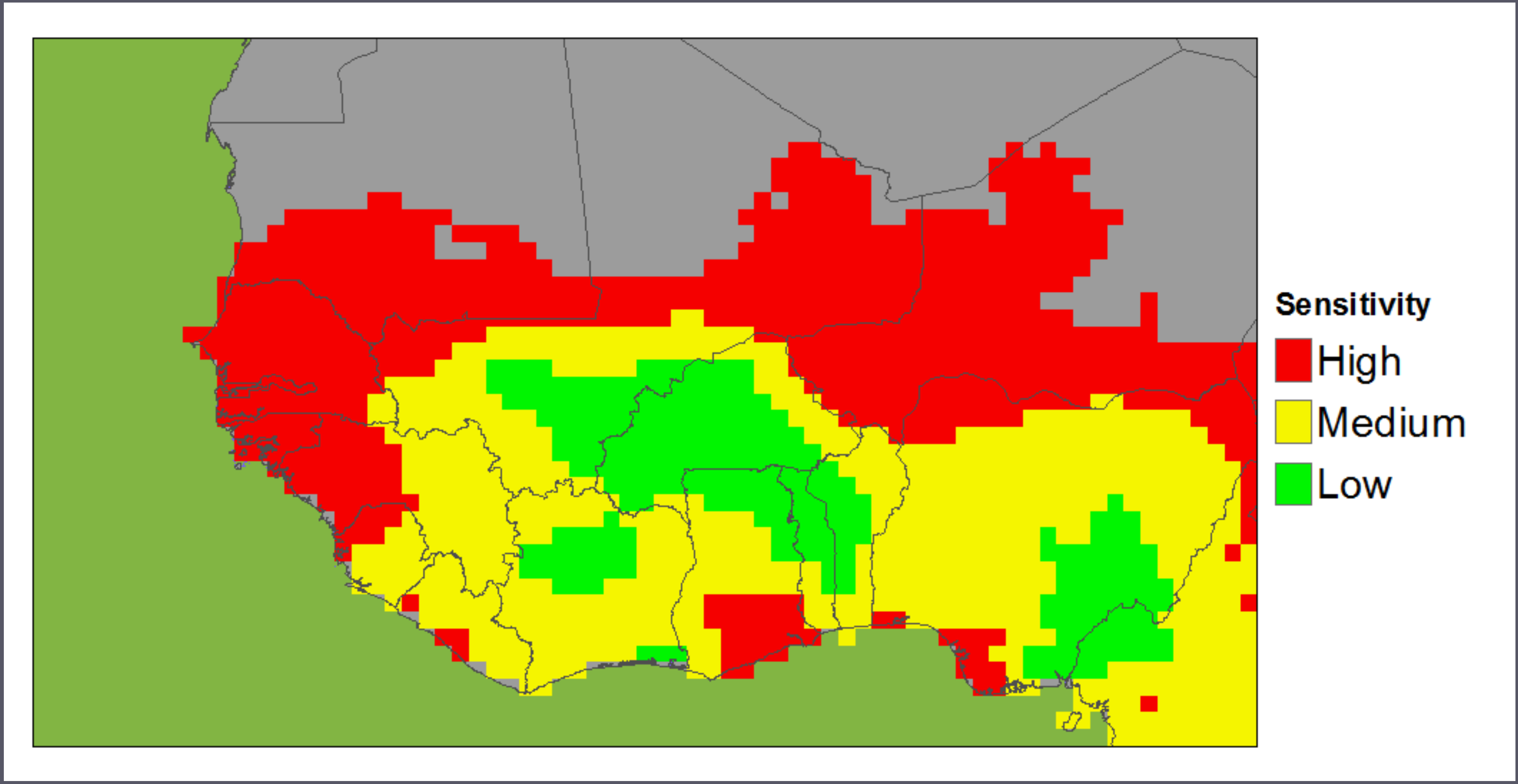
$$\frac{\partial PR}{\partial \text{climate}} = \frac{\partial PR}{\partial VC/VC} \times \frac{\partial VC/VC}{\partial \text{climate}}$$



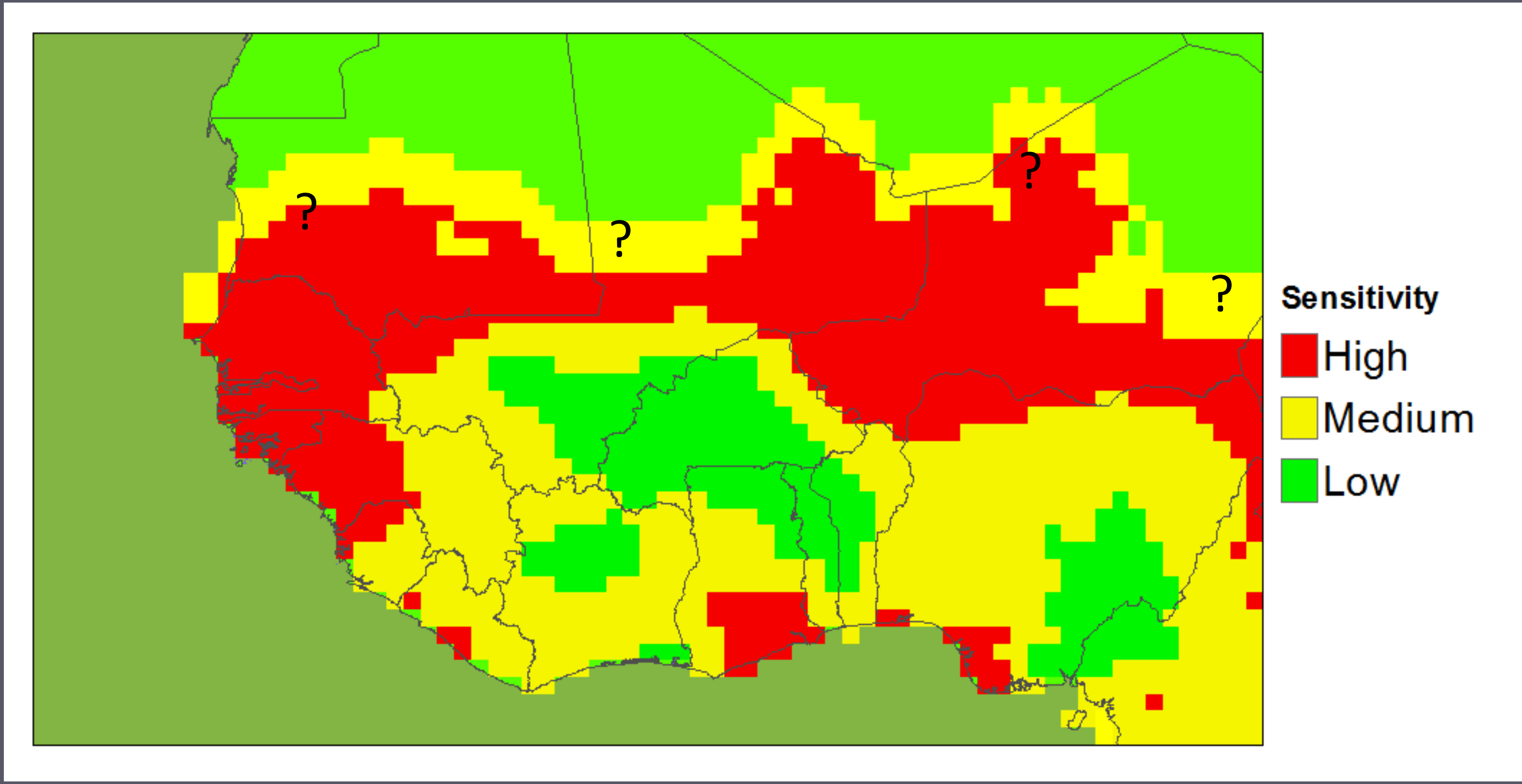
Derivative of Prevalence w.r.t. VC



Sensitivity to Vectorial Capacity

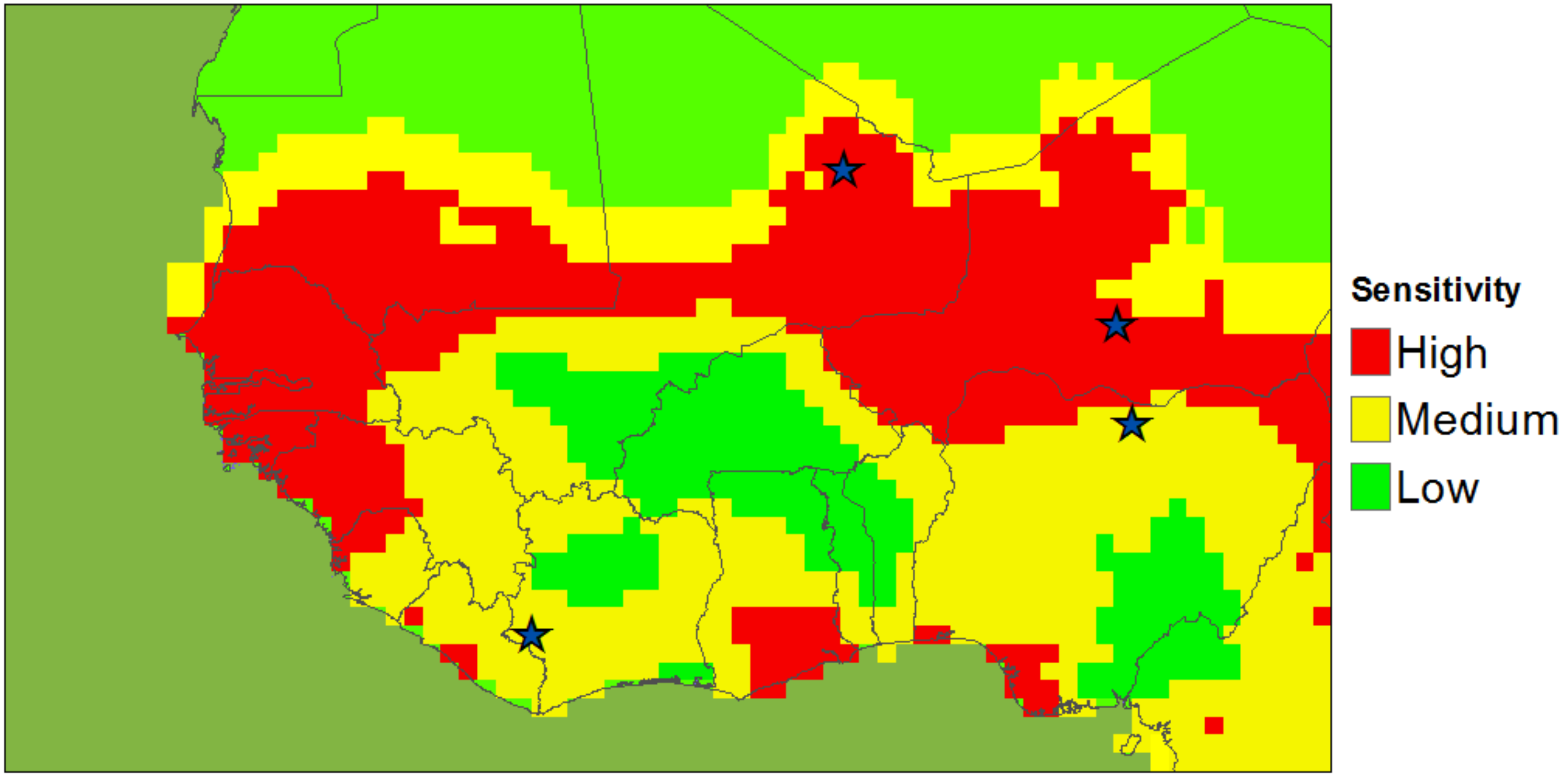


Sensitivity to Vectorial Capacity

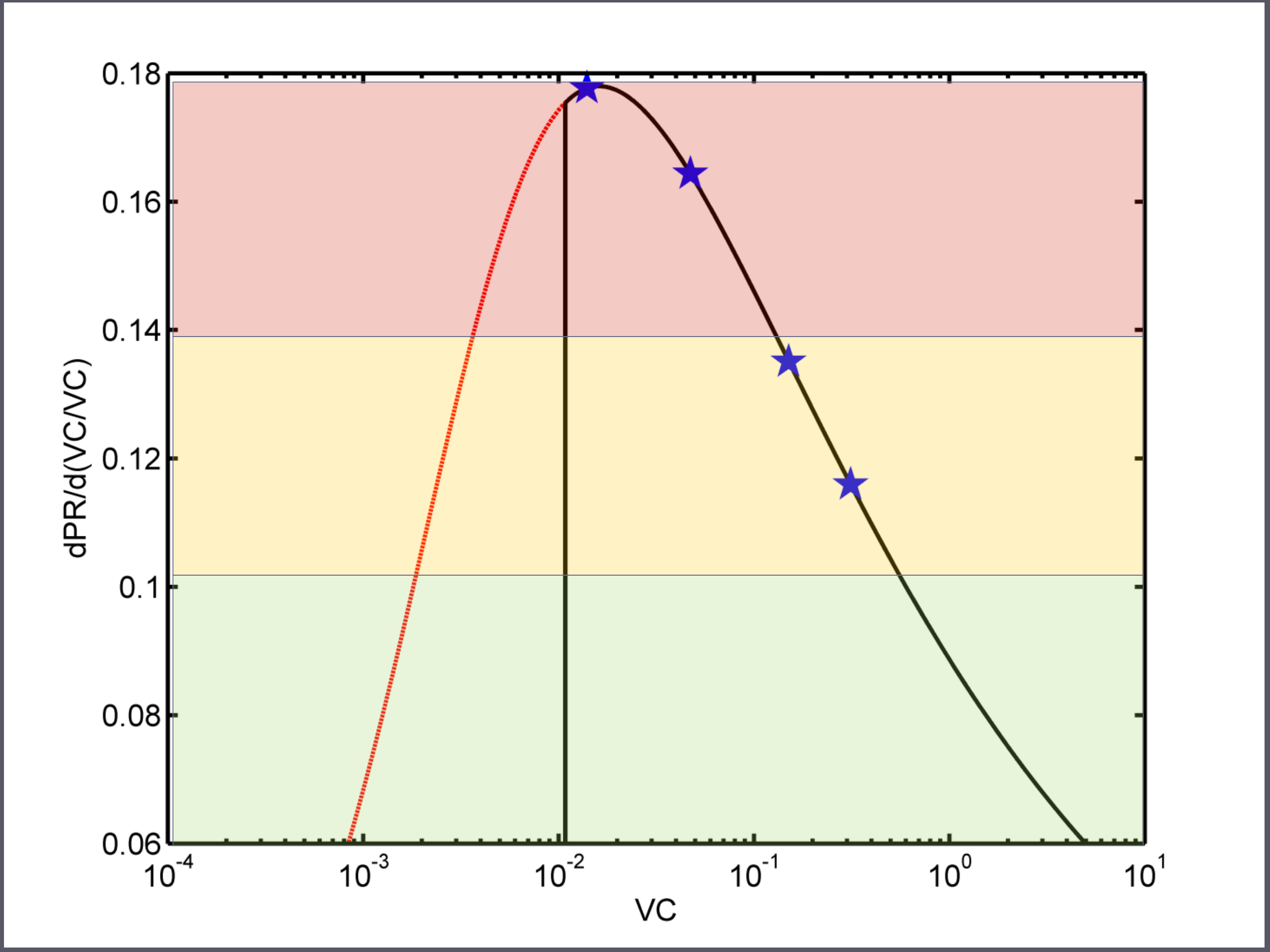


CHANGE IN VECTORIAL CAPACITY DUE TO CLIMATE CHANGE

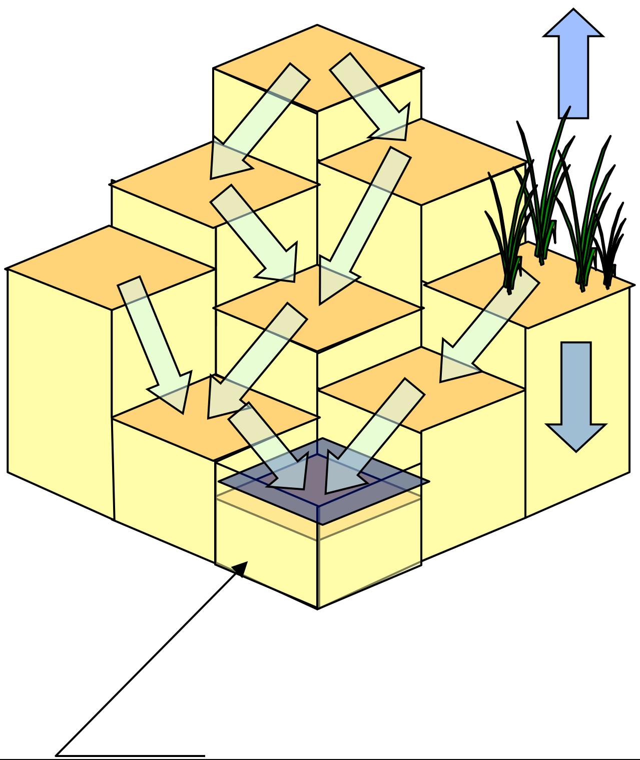
Simulating Vectorial Capacity



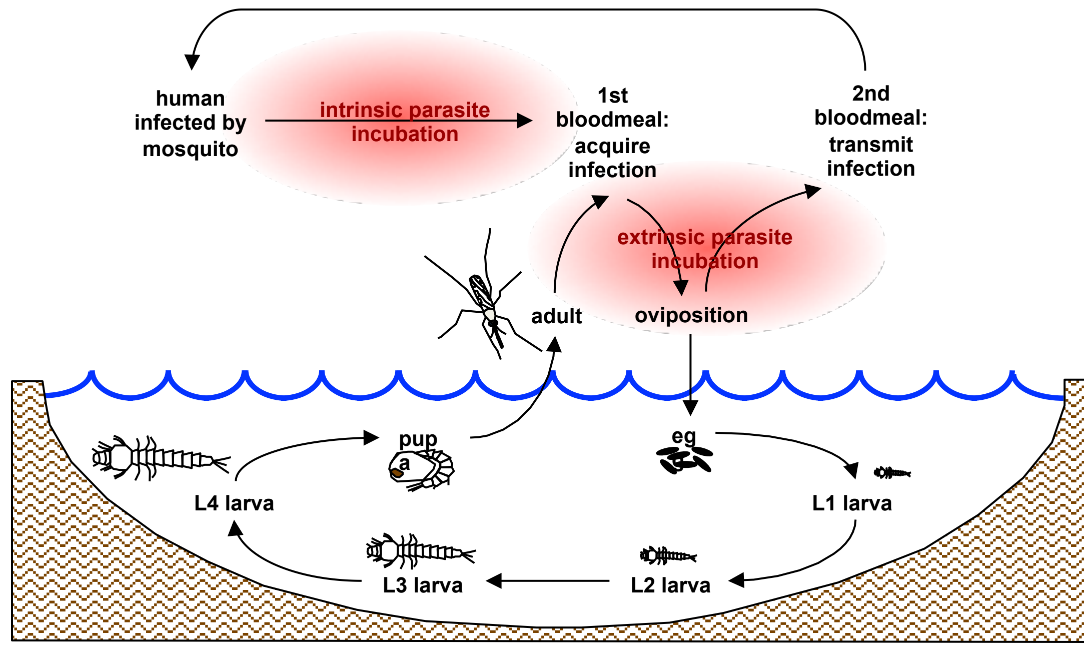
Simulating Vectorial Capacity



HYDREMATS: Hydrology Entomology & Malaria Transmission Simulator

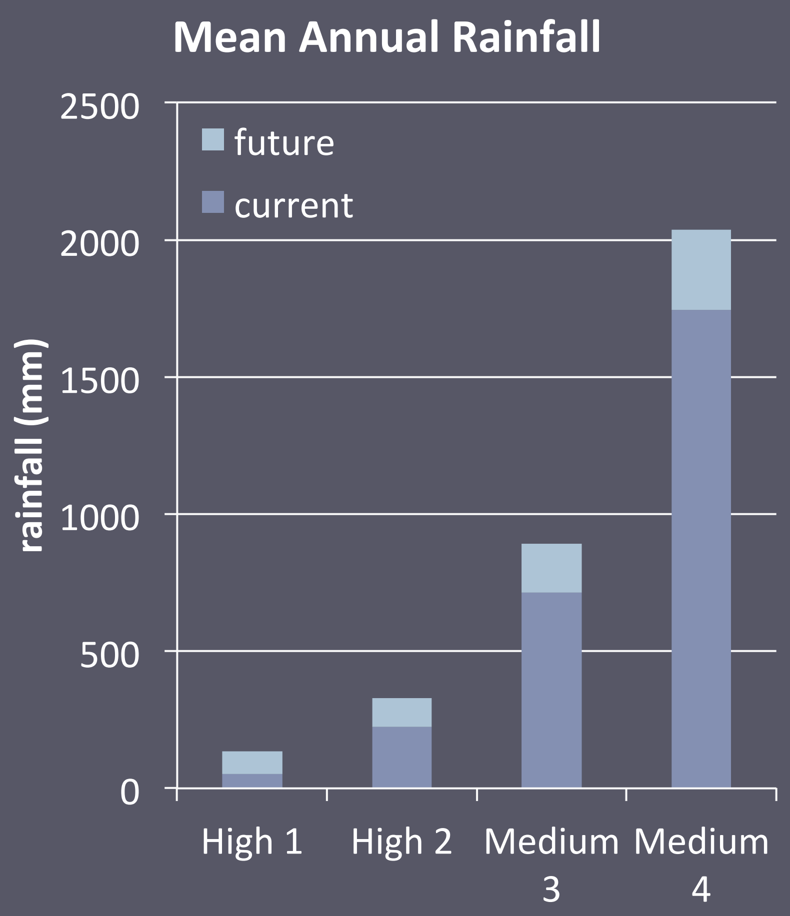


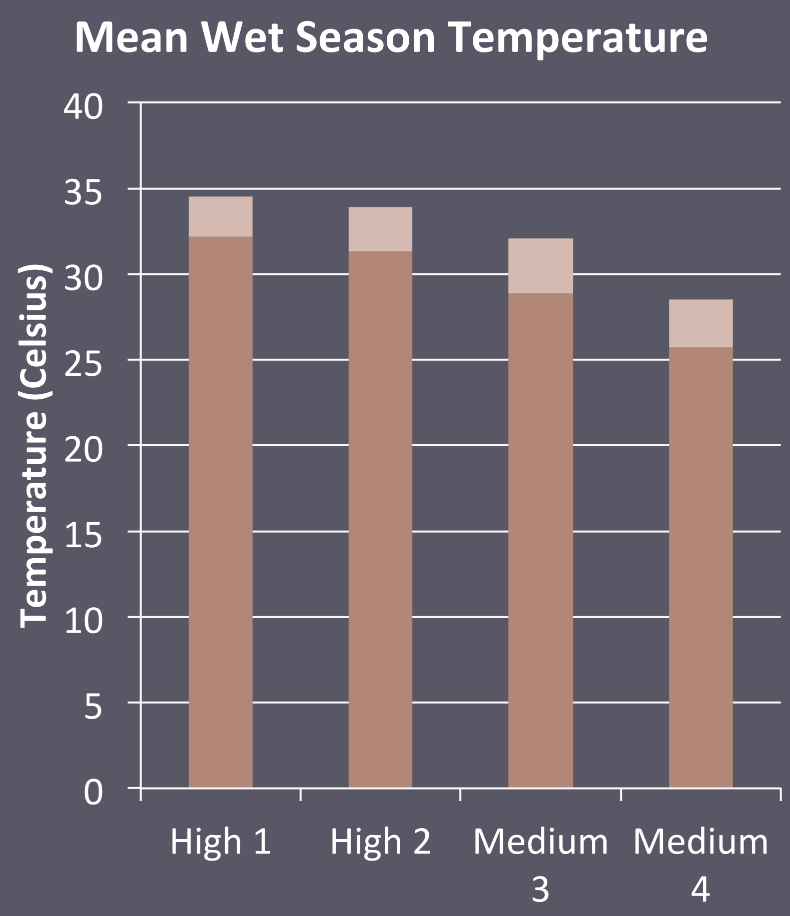
Overland flow model will pool water and simulate pool losses to infiltration/evaporation



Bomblies et al. *Water Resources Research*, 2008

Climate Projections





Percent change in simulated VC

High 1	40%
High 2	-66%
Medium 3	-35%
Medium 4	95%

$$\frac{\partial PR}{\partial \text{climate}} = \frac{\partial PR}{\partial VC/VC} \times \frac{\partial VC/VC}{\partial \text{climate}}$$

Change in Prevalence assuming wettest future climate

	$\frac{\partial PR}{\partial VC/VC}$	$\frac{\partial VC/VC}{\partial \text{climate}}$	$\frac{\partial PR}{\partial \text{climate}}$	New P
High 1	0.18	40%	0.07	0.12
High 2	0.16	-66%	-0.11	0.15
Medium 3	0.14	-35%	-0.05	0.38
Medium 4	0.12	95%	0.11	0.63

Conclusions

- Malaria prevalence is most sensitive to changes in vectorial capacity in areas along the northern boundary of current malaria areas, where transmission is currently low
- The areas where we expect to see the greatest increases in VC are not necessarily the areas where prevalence is most sensitive to changes in VC

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EXTRA SLIDES

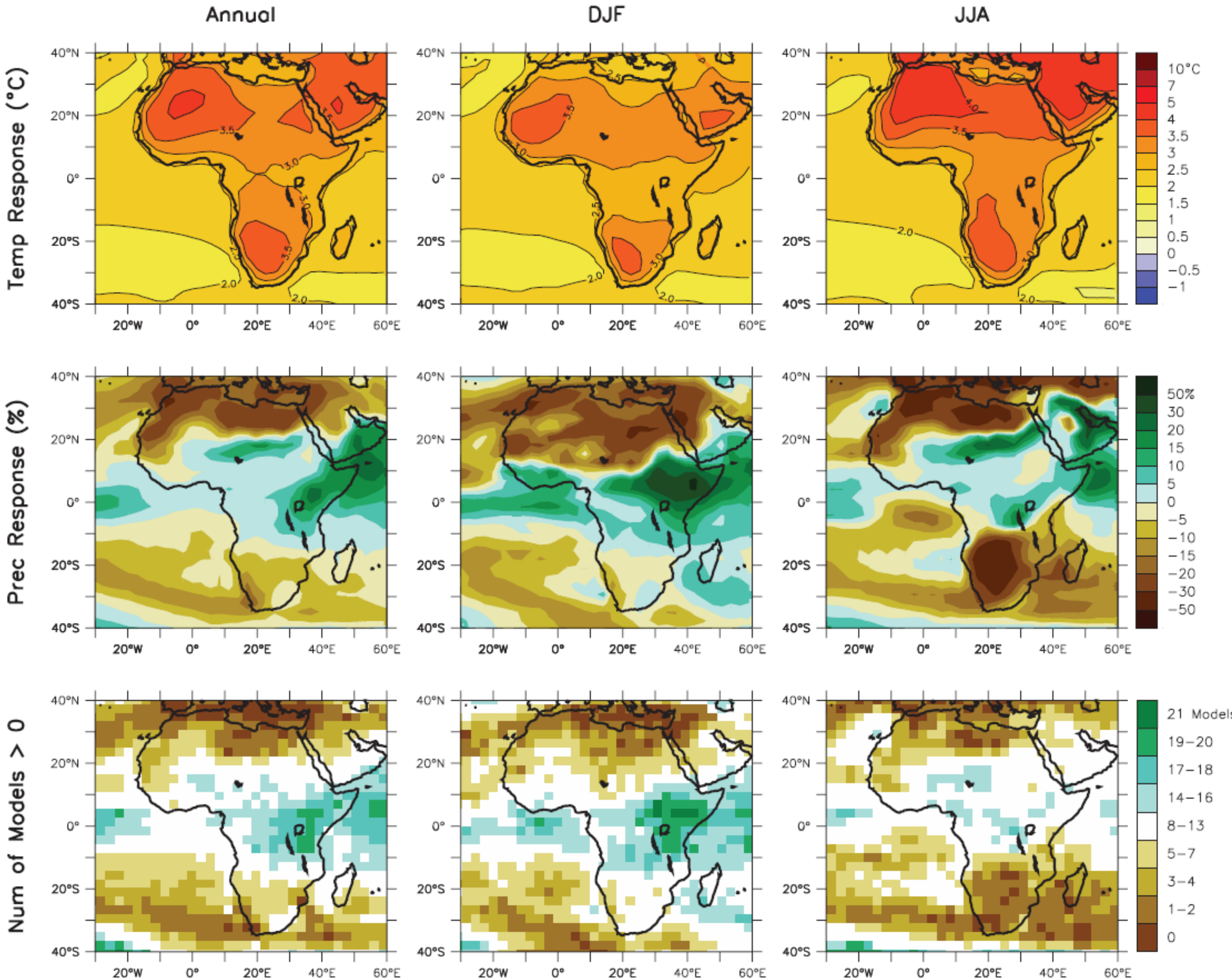

Figure 11.2. *Temperature and precipitation changes over Africa from the MMD-A1B simulations. Top row: Annual mean, DJF and JJA temperature change between 1980 to 1999 and 2080 to 2099, averaged over 21 models. Middle row: same as top, but for fractional change in precipitation. Bottom row: number of models out of 21 that project increases in precipitation.*

Range of predicted changes in temperature

Box	CRU 1980-1999: temperature in rainy months	Max rainy season increase 2080-2099	Model predicting max increase	Min rainy season increase 2080-2099	Model predicting min increase
1	32.2	5.6	GFDL/NOAA	2.3	NCAR - CCSM
2	31.3	5.2	ECHAM	2.6	NCAR - CCSM
3	28.9	5.1	University of Tokyo – MIROC high-res	2.8	NCAR - CCSM
4	26.8	4.8	University of Tokyo – MIROC high-res	2.6	NASA/GISS - AOM
5	25.7	4.4	University of Tokyo – MIROC high-res	2.3	CSMK3

Range of predicted changes in rainfall

Box	CRU 1980-1999	Max increase 2080-2099	wettest	Max decrease 2080-2099	driest
1	52	83	NCAR	-105	GFDL/NOAA
2	223	107	NCAR	-206	GFDL/NOAA
3	715	178	ECHAM + HOPEG	-254	GFDL/NOAA
4	1286	214	ECHAM + HOPEG	-212	GFDL/NOAA
5	1743	295	NASA/GISS E-H	-227	University of Tokyo – MIROC med-res