Poljoprivredni Fakultet Univerzitet u Novom Sadu
PFNS
Departman za ratarstvo i povrtarstvo

Università degli Studi Firenze
DISPAA
Dipartimento di Scienze delle Produzioni Agroalimentari e dell'Ambiente

Universität für Bodenkultur Wien
BOKU
Department für Wasser-Atmosphäre-Umwelt

European Commission
Horizon 2020
European Union Funding for Research & Innovation

Workshop 2018

SERBIA FOR EXCELL, WORKSHOP, 2018

MosqDyn

Optimised methods for precision pest management

Mina Petric, Branislava Lalic, Els Ducheyne

Avia-GIS and University of Novi Sad

The big picture

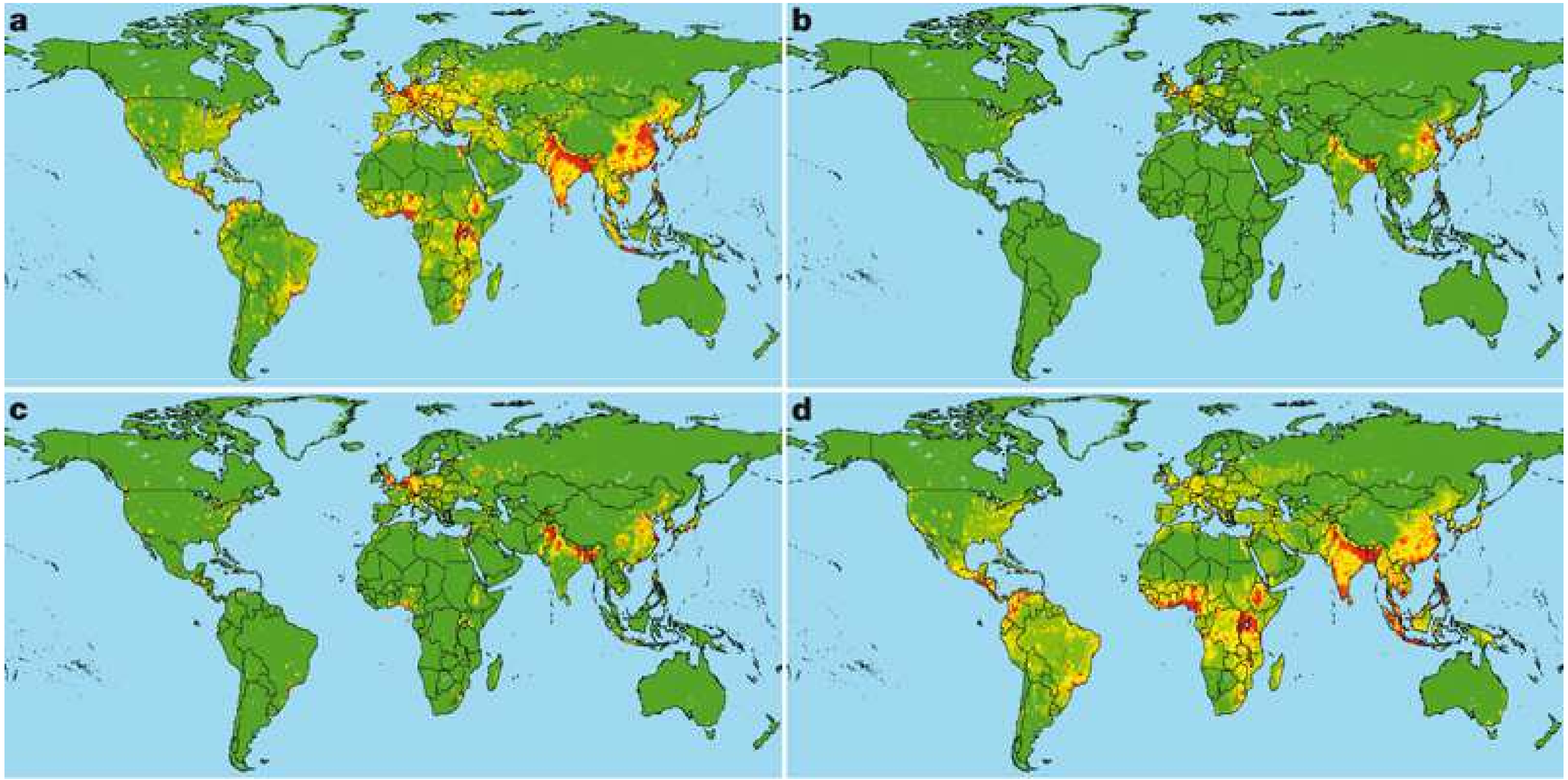


FIGURE AND MODIFIED LEGEND FROM JONES ET AL., 2008 (FIGURE 3). GLOBAL DISTRIBUTION OF RELATIVE RISK OF AN EID EVENT. MAPS ARE DERIVED FOR EID EVENTS CAUSED BY:

(A) ZOONOTIC PATHOGENS FROM WILDLIFE,
(B) ZOONOTIC PATHOGENS FROM NON-WILDLIFE,
(C) DRUG-RESISTANT PATHOGENS, AND

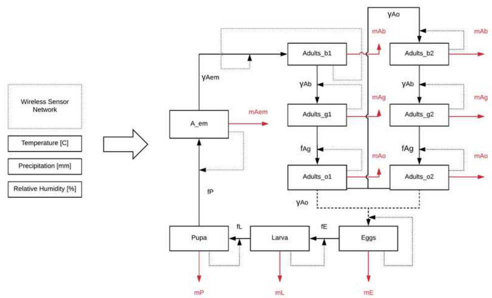
(D)VECTOR-BORNE PATHOGENS

The big picture

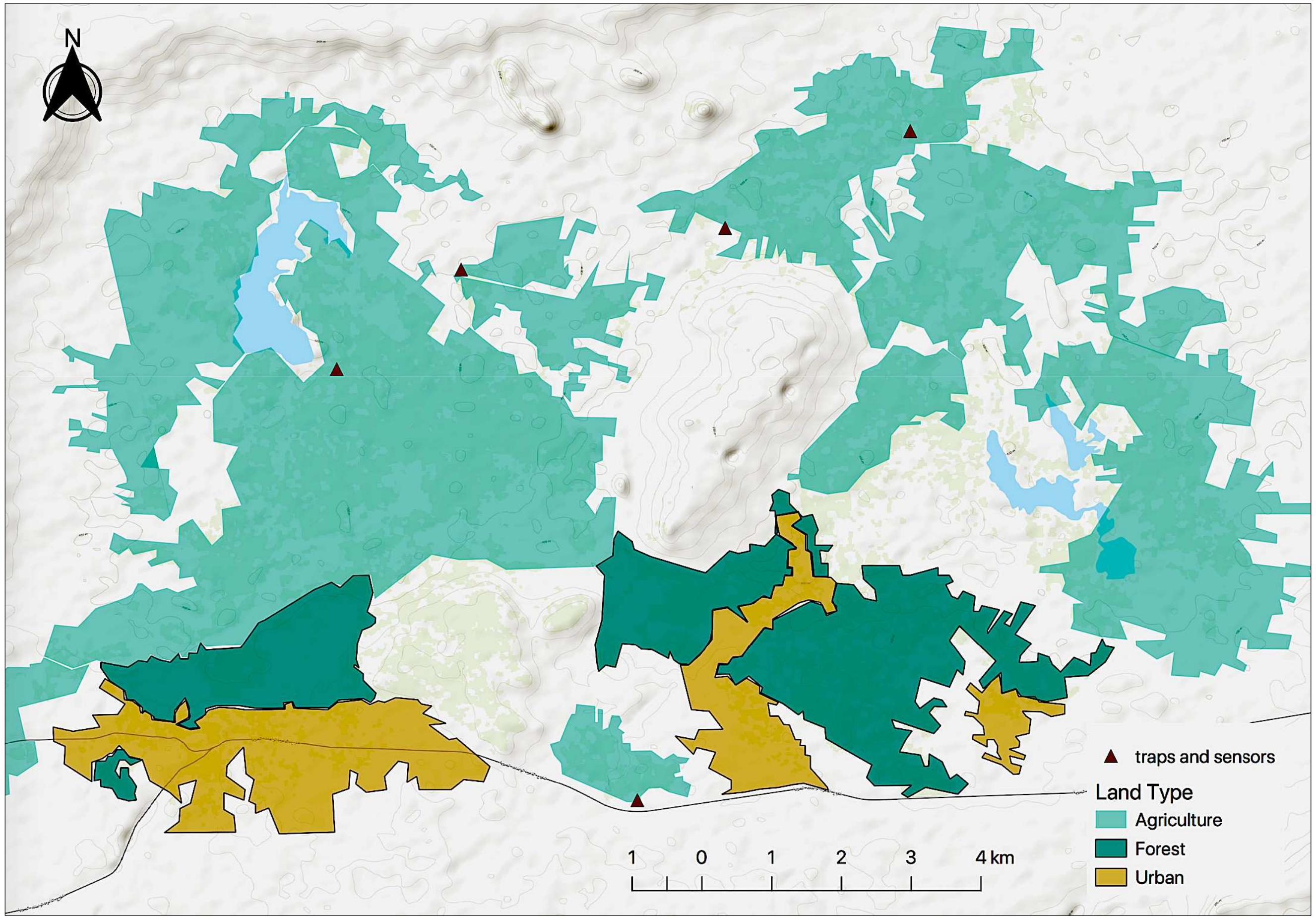
Input
- Trap data
- Meteorological data

Calibration
- Parameter selection and calibration

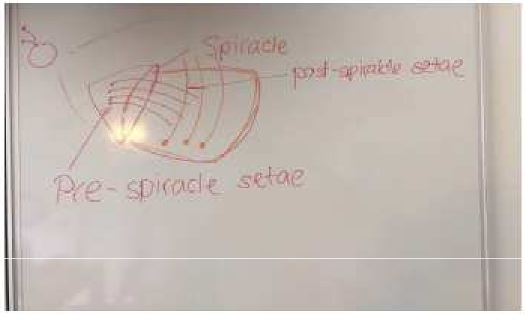
Output
- Population dynamics model



Sampling strategy



Mosquito trap data



Mosquito trap data




- Installed traps across six locations with solar panels powering the batteries
- Solar Panel solution proposed and set-up by DFC

Mosquito trap data

- Fixed fans locally after electrical surge
- Rebuilt the motor
- Minimum data lost

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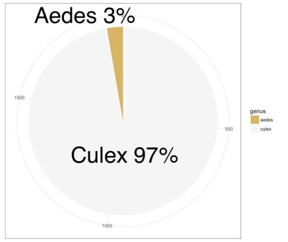
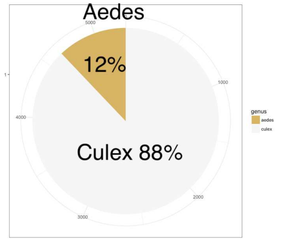
Mosquito trap data

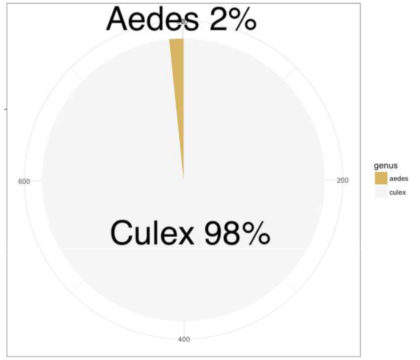
Site 1 – Daabis

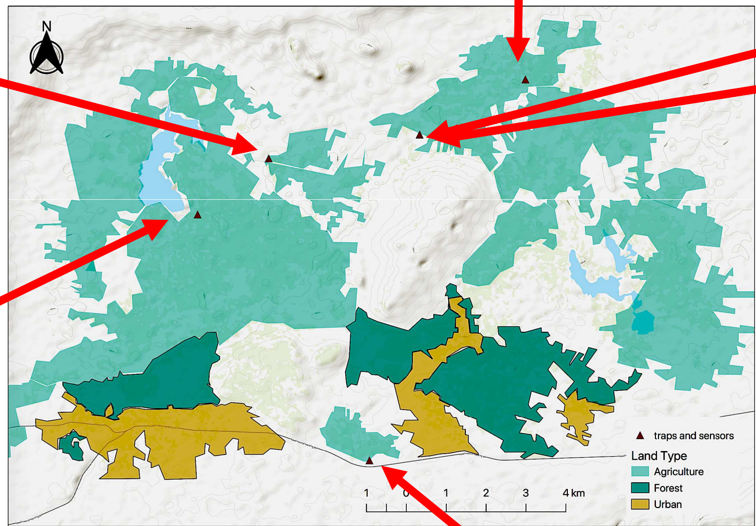


Site 2 – DFC

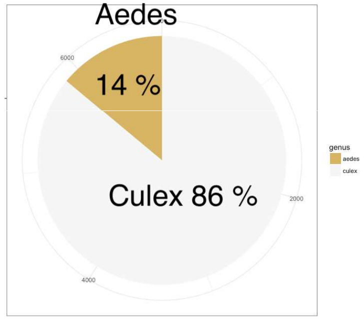


Site 6 – Ahmed

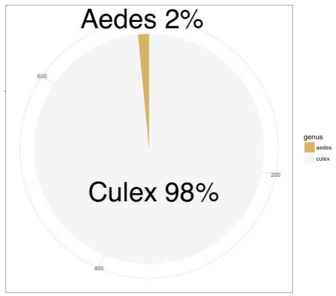


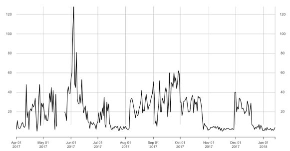


Site 3 – MM

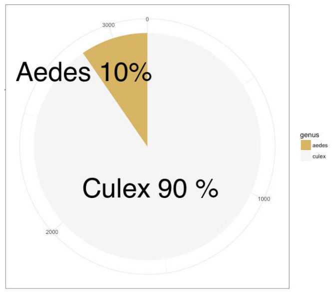


Site 5 – Salt Lake

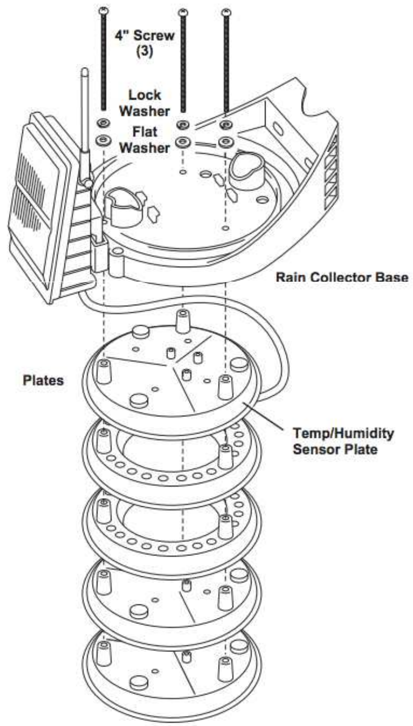




Site 4 – Aliya Hotel



Meteorological ground truth



Before

After

- Set-up a weather station and five loggers to record the meteorological conditions across the oasis
- Set-up radiation shields

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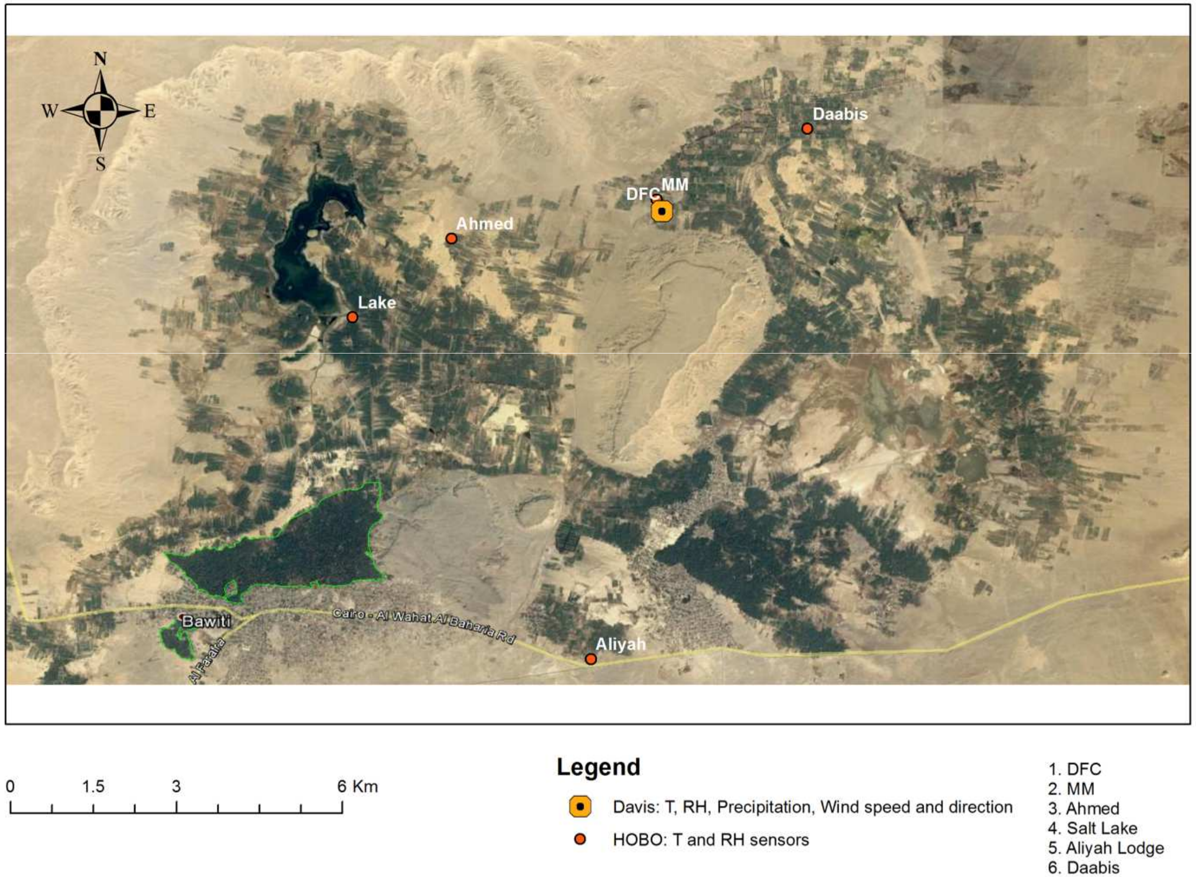
Meteorological ground truth



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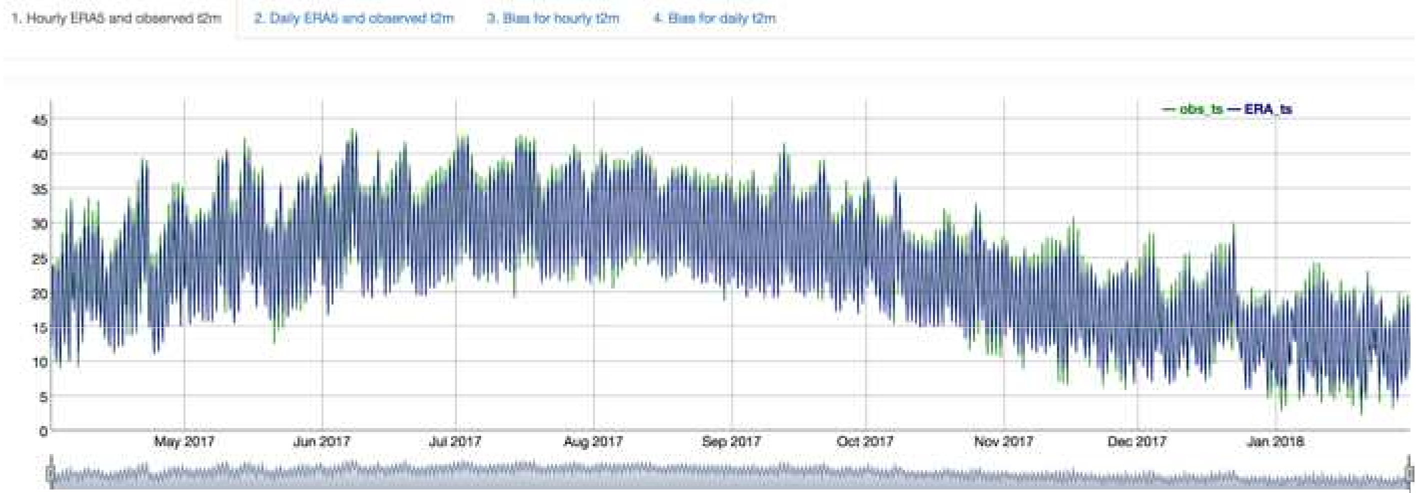
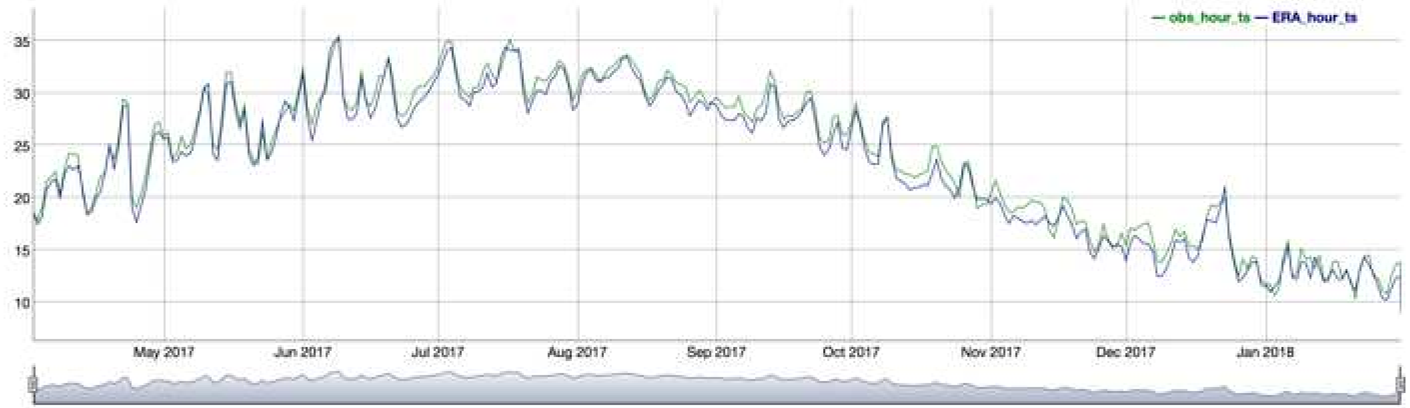
Meteorological ground truth vs ERA5

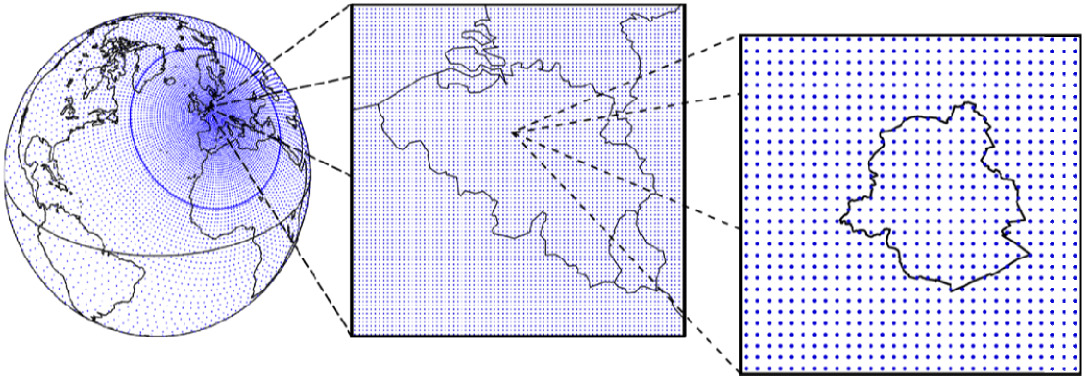


Bias hourly 0.7
RMSE hourly 2.15



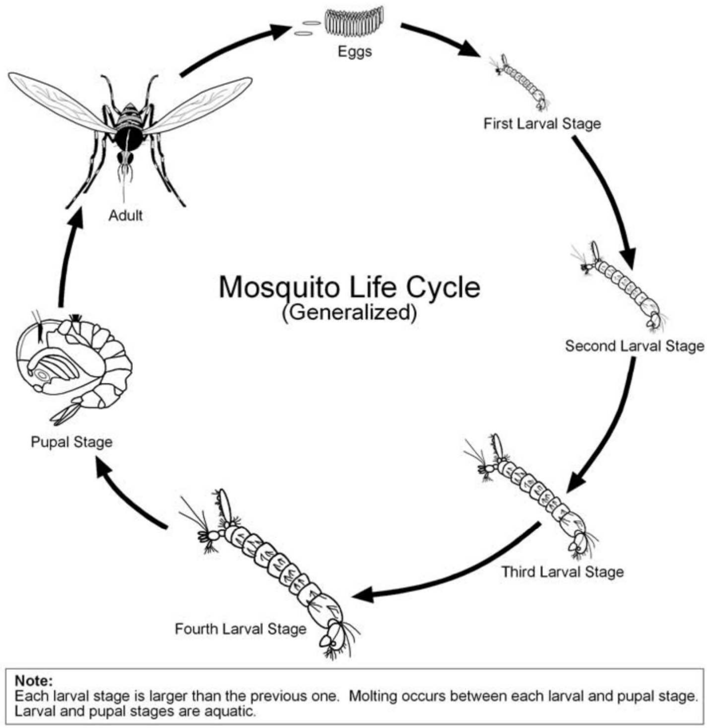
Bias daily 0.7
RMSE daily 0.96

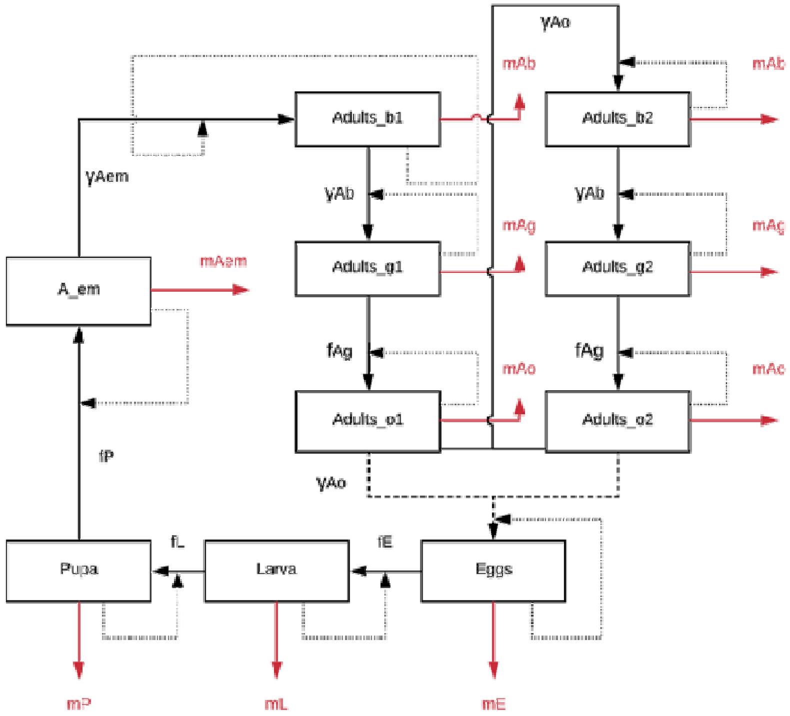
Meteorological data improvement



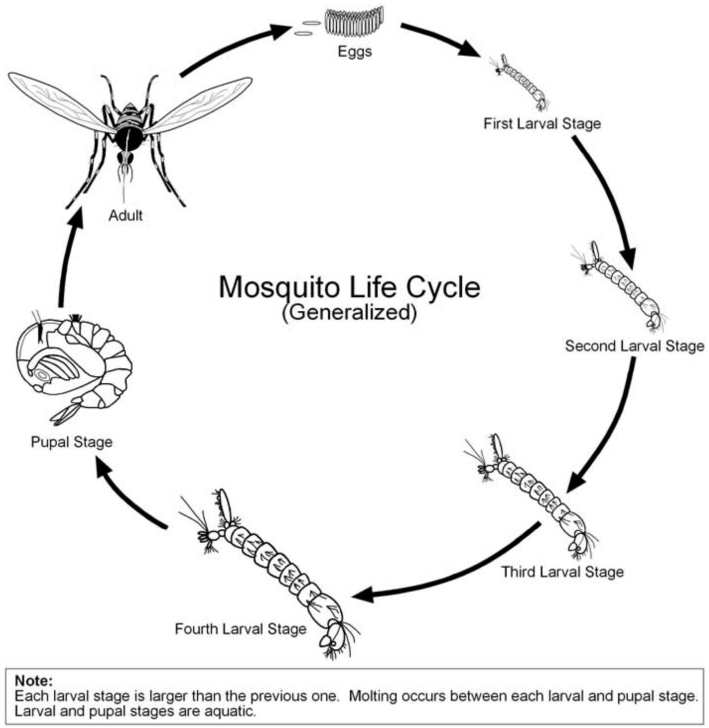
- SURFEX run with HR ECOCLIMAP
- Spatial resolution >=1 km.
- Combine with dynamical atmospheric model of the RMI within the numerical module for the land surface called SURFEX
- This scheme uses a tiling approach to compute the relative contributions from lakes, vegetation and urban surface parts.
- Operational weather forecast model ALARO used to downscale ERA data over the study sites with a spatial resolution of initially 4 km and then 1-km resolution.

Mosquito population model





Mosquito population model



$$\frac{dE}{dt} = \gamma_{A_o}(\beta_1 A_{o1} + \beta_2 A_{o2}) - (\mu_E + f_E)E$$

$$\frac{dL}{dt} = f_E E - \left(m_L\left(1 + \frac{L}{\kappa_L}\right) + f_L\right)L$$

$$\frac{dP}{dt} = f_L L - (m_P + f_P)P$$

$$\frac{dA_{em}}{dt} = f_P P \sigma e^{-\mu_{em}\left(1+\frac{P}{\kappa_P}\right)} - (m_A + \gamma_{A_{em}})A_{em}$$

$$\frac{dA_{b1}}{dt} = \gamma_{A_{em}} A_{em} - (m_A + \mu_r + \gamma_{A_b})A_{b1}$$

$$\frac{dA_{g_1}}{dt} = \gamma_{A_b} A_{b_1} - \left(m_A + f_{A_g}\right)A_{g_1}$$

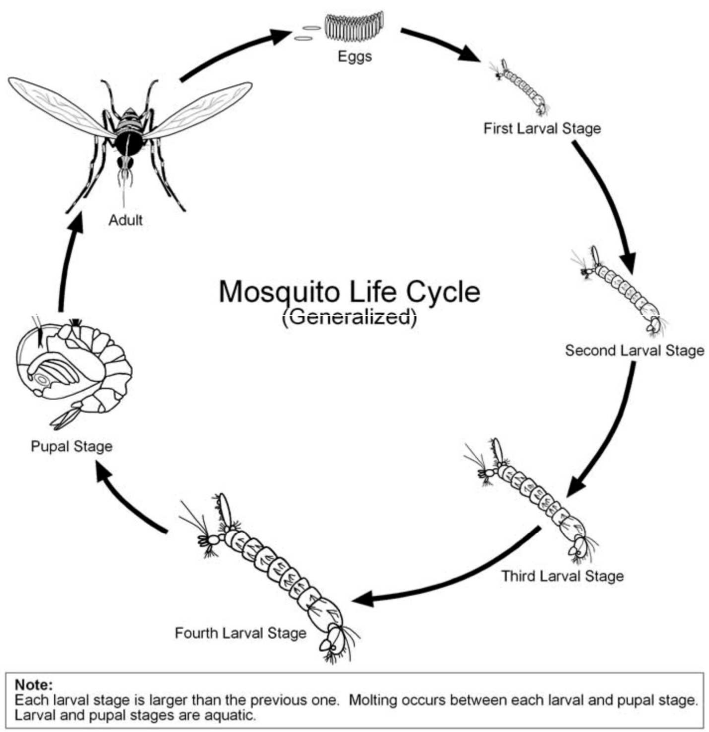
$$\frac{dA_{o_1}}{dt} = f_{A_g} A_{g_1} - (m_A + \mu_r + \gamma_{A_o})A_{o_1}$$

$$\frac{dA_{b_2}}{dt} = \gamma_{A_o}(A_{o1} + A_{o2}) - (m_A + \mu_r + \gamma_{A_b})A_{b2}$$

$$\frac{dA_{g_2}}{dt} = \gamma_{A_b} A_{b2} - \left(m_A + f_{A_g}\right)A_{g2}$$

$$\frac{dA_{o_2}}{dt} = f_{A_g} A_{g2} - (m_A + \mu_r + \gamma_{A_o})A_{o2}$$

Mosquito population model



Input parameters	Description	*Culex pipiens*	*Aedes Caspius*
$\gamma_{A_{em}}$	Development rate of emerging adults $f(T,RH)$	1.143	0.40
γ_{A_b}	Blood-seeking adult development rate $f(T,RH)$	0.885	0.222
γ_{A_o}	Ovipositing adult development rate $f(T,RH)$	2	0.222
f_E (>0)	Egg development rate $f(T,PP)$	$0.16\left(e^{0.105(T-10)} - e^{0.105(35-10)-\frac{35-T}{5.007}}\right)$	Boolean
f_P	Pupa development rate $f(T, q_{culex} = 0.021, q_{aedes} = 0.14)$	$q\left(e^{0.162\,(T-10)} - e^{0.162\,(35-10)-\frac{(35-T)}{5.007}}\right)$	-||-
f_L	Larva development rate $f(T)$	$\frac{f_P}{4}$	$\frac{f_P}{1.65}$
f_{Ag}	Transition rate of gestating adults $f(T)$	$f_{Ag} = \frac{T-T_{Ag}}{TDD_{Ag}} = \frac{T-9.8\ ℃}{64.4}$	
m_E	Egg mortality rate $f(T)$	$m_E = \mu_E$	
m_L	Larva mortality rate $f(T)$	$e^{-\frac{T}{2}} + \mu_L$	-||-
m_P	Pupa mortality rate $f(T)$	$e^{-\frac{T}{2}} + \mu_P$	-||-
$m_{A_{em}}$	Mortality rate of emerging adults $f(T)$	$m_{A_{em}} = m_A$	μ_A
$m_A(> \mu_A)$	Mortality rate of blood-seeking adults $f(T)$	$-0.005941 + 0.002965T$	μ_A
μ_E	Minimum egg mortality rate	0.0262 (day^{-1})	0
μ_L	Minimum larva mortality rate	0.0304	0.0367
μ_p	Minimum pupae mortality rate	0.0146	
μ_{em}	Mortality rate during emergence	0.1	0.1
μ_r	Mortality rate during blood-seeking	0.08	0.08
μ_A	Minimum adult mortality rate	1/43	0.07
κ_L	Carrying capacity for larvae $f(PP)$	8 10^8	10^{10}
κ_P	Carrying capacity for pupae $f(PP)$	10^7	10^8
σ	Sex ratio at emergence	0.5	0.5
β	Number of eggs laid/ovipositing female	β_1 = 141 (nulliparous) + β_2 = 80 (parpus)	160 + 80

Mosquito population model

$$\frac{dE}{dt} = \gamma_{Ao}(\beta_1 A_{o1} + \beta_2 A_{o2}) - (\mu_E + f_E)E \quad (1)$$

$$\frac{dL}{dt} = f_E E - \boxed{(m_L(1 + \frac{L}{\kappa_L}) + f_L)L} \quad (2)$$

$$\frac{dP}{dt} = f_L L - (m_P + f_P)P \quad (3)$$

$$\frac{dA_{em}}{dt} = \boxed{f_P P \sigma e^{-\mu_{em}(1+\frac{P}{\kappa_P})}} - (m_A + \gamma_{Aem})A_{em} \quad (4)$$

$$\frac{dA_{b1}}{dt} = \gamma_{em} A_{em} - (m_A + \mu_r + \gamma_{Ab})A_{b1} \quad (5)$$

$$\frac{dA_{g1}}{dt} = \gamma_{A_b} A_{b1} - (m_A + f_{Ag})A_{g1} \quad (6)$$

$$\frac{dA_{o1}}{dt} = f_{Ag} A_{g1} - (m_A + \mu_r + \gamma_{Ao})A_{b1} \quad (7)$$

$$\frac{dA_{b2}}{dt} = \gamma_{Ao}(A_{o1} + A_{o2}) - (m_A + \mu_r + \gamma_{Ab})A_{b2} \quad (8)$$

$$\frac{dA_{g2}}{dt} = \gamma_{Ab} A_{b2} - (m_A + f_{Ag})A_{g2} \quad (9)$$

$$\frac{dA_{o2}}{dt} = f_{Ag} A_{g2} - (m_A + \mu_r + \gamma_{Ao})A_{o2} \quad (10)$$

Numerical integration of stiff, non-linear ODE system of equations
Fully implicit solution with full or banded Jacobian

Mosquito population model

	lsoda	lsode	Lsodes	lsodar	Vode	Daspk	Radau	Bdf	Adams	impAdams	euler
Combination	Adams (nonstiff), bdf (stiff)			Adams (nonstiff), bdf (stiff)			implicit	implicit		implicit	
Method order	2	2	1	2	3	2	~	2	1	2	
Type	~	~	~	~	~	~	~	~	~	~	~
Time step	1.792298e-05	1.297301e-05	6.718752e-06	1.792298e-05	2.609352e-05	5.571375e-06	0.1800048	1.297301e-05	1.716158e-06	9.858492e-06	
Number of steps	2851	3337	3395	2851	4080	3552	1816	3337	2736	2581	75
Number of Jacobians evaluated	0	1339	67	0	78	2093	412	1339	0	933	
LU	0	/	/	/	1923	/	/	/	/	/	
Non-linear Newton iterations	/	/	/	/	/	7343	/	/	/	/	
Number of function evaluated in total	7372	20200	5864	7372	7660	30366	14439	20200	4221	14737	76
Order of local truncated error	$O(h^2)$	$O(h^2)$	$O(h)$	$O(h^2)$	$O(h^3)$	$O(h^2)$		$O(h^2)$	$O(h)$	$O(h^2)$	$O(h)$
Computational time (mins)	8.5	2.8	0.915	1.17	1.11	4.6	2.26	2.96	0.66	2.22	0.0011

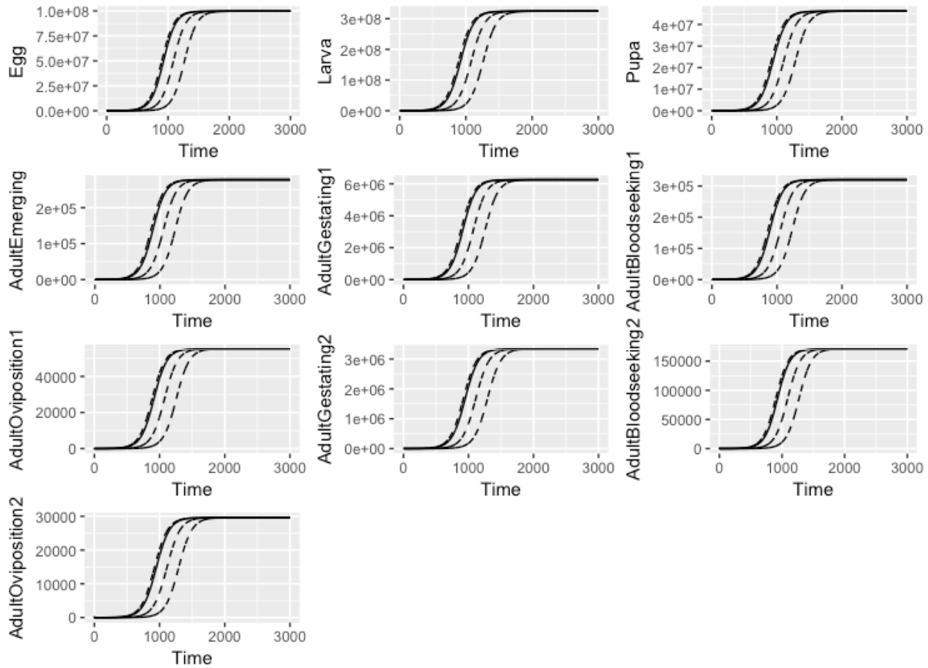
Mosquito population model

$$
\boldsymbol{J} = \begin{pmatrix}
-(\mu_E + f_E) & 0 & 0 & 0 & 0 & 0 & \gamma_{A_o}\beta_1 & 0 & 0 & \gamma_{A_o}\beta_2 \\
f_E & -(m_L + f_L + 2\frac{m_L}{\kappa_L} L) & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & f_L & -(m_P + f_P) & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & \left(1 - \frac{\mu_{em}}{\kappa_P} P\right) f_P \sigma e^{-\mu_{em}\left(1 + \frac{P}{\kappa_P}\right)} & -(m_A + \gamma_{em}) & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & \gamma_{em} & -(m_A + \mu_r + \gamma_{A_b}) & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & \gamma_{A_b} & -(m_A + f_g) & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & \gamma_{A_g} & -(m_A + \mu_r + \gamma_{A_o}) & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & \gamma_{A_o} & -(m_A + \mu_r + \gamma_{A_b}) & 0 & \gamma_{A_o} \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & \gamma_{A_b} & -\left(m_A + f_{A_g}\right) & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & f_{A_g} & -(m_A + \mu_r + \gamma_{A_o})
\end{pmatrix}
$$

$$
\nabla \cdot \boldsymbol{F} = \sum_{i=1}^{10} \frac{\partial F_i}{\partial X_i} < 0
$$

- Two regimes identified based on the sign and magnitude of the eigenvalues of the Jacobian evaluated at the equilibrium points ($\boldsymbol{\lambda_i}$)
- For the first regime all solutions quickly converge to zero equilibrium
- For the second regime the trivial solution is unstable and all solutions diverge
- Same behavior is observed for different initial conditions

Mosquito population model



- The trivial equilibrium is stable for $T < 9.8^\circ\, C$ and unstable for higher temperatures.
- The non-trivial equilibrium is stable for $T > 9.8^\circ C$
- When a model forced with only temperature is run all stages reached an equilibrium an interval that is inversely proportional to temperature.
- However, when the model was run with parameters forced by temperature, a seasonal trend emerged.

Independent* Equilibrium points	**Nature of equilibrium points**	
	Case I ($T < 9.8^\circ C$)	Case II ($T > 9.8^\circ C$)
$X_{eq}^{1} = (0,0,0,0,0,0,0,0,0,0)$	Stable node	Unstable node
$X_{eq}^{2} = (E^*, L^*, P^*, A_{em}^*, A_{b_1}^*, A_{g_1}^*, A_{o_1}^*, A_{b_2}^*, A_{g_2}^*, A_{o_2}^*)$	Unstable node	Stable node

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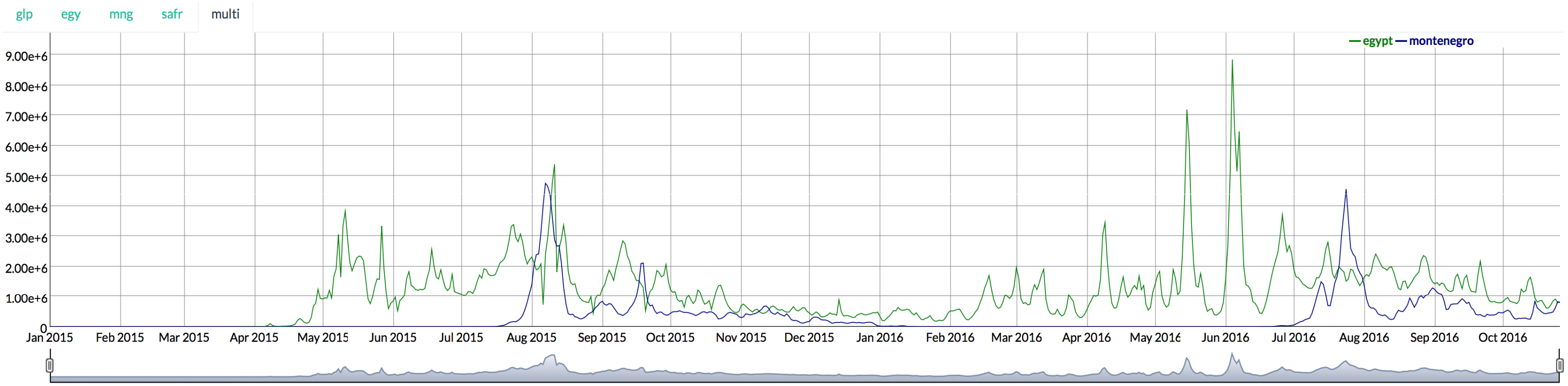
Mosquito population model



Thank you for your questions!

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