Generalitat de Catalunya
Departament de Territori i Sostenibilitat

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Malaria models for Senegal and the role of climate in malaria predictability

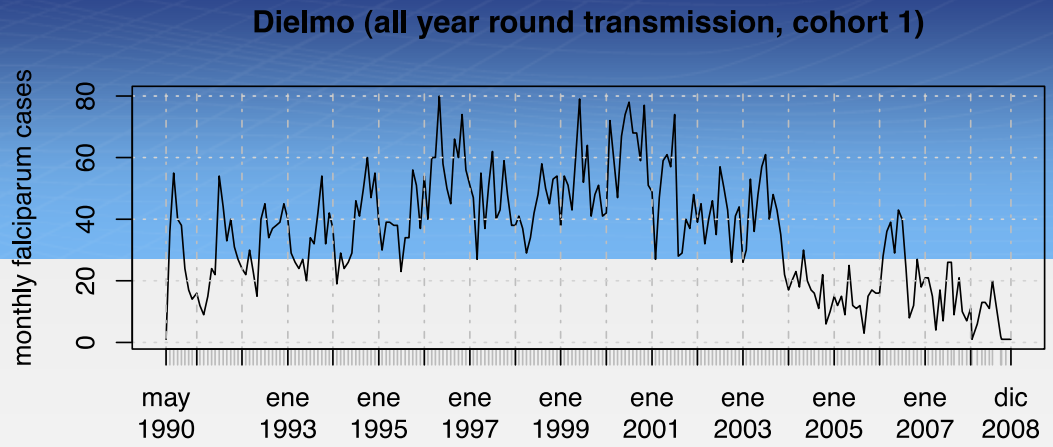
IC3, IPP,IPD

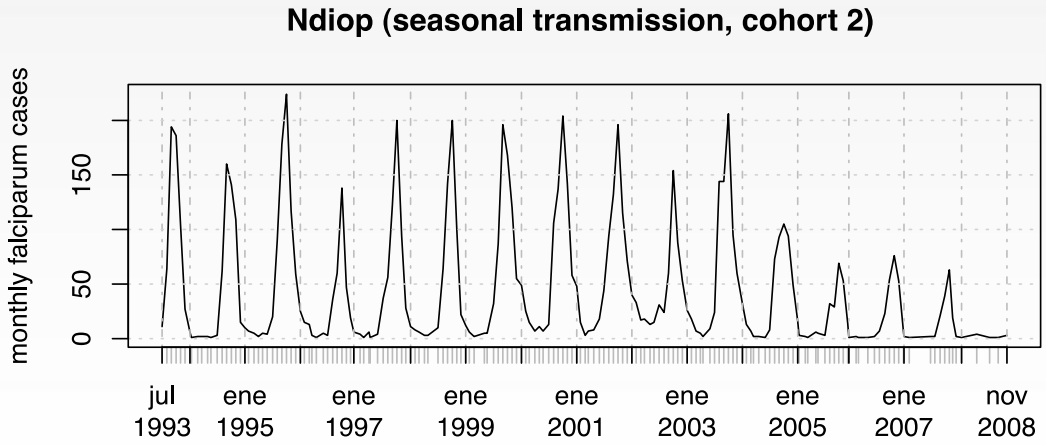
QWeCI MEETING, ILRI, Nairobi, Kenya, Oct. 2012

Quantifying Weather & Climate Impacts on health in developing countries

SEVENTH FRAMEWORK PROGRAMME

Senegal malaria





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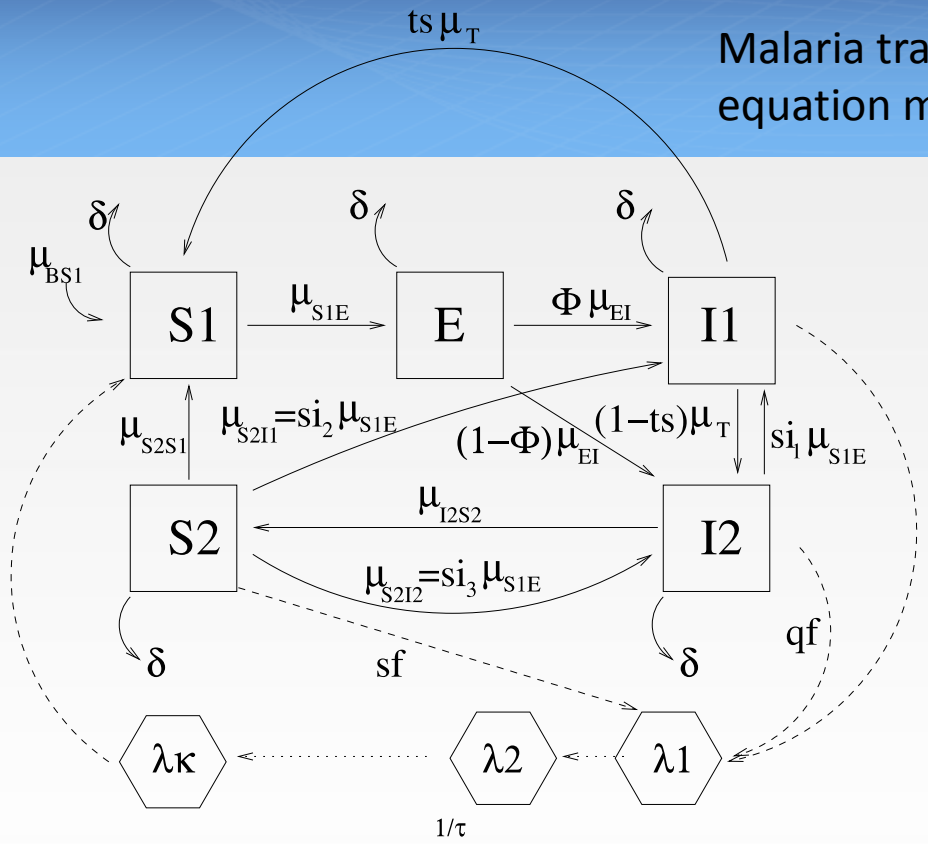
Malaria transmission: Stochastic differential equation model (VIC3 framework)



Flow diagram of the SDE model. Human classes are S1 (susceptible), E (exposed, carrying a latent infection), I1 (infected and infectious), I2 (asymptomatic infection which is minimally infectious) and S2 (recovered having some resistance to reinfection). Mosquito-parasite classes are λ (force of infection at previous time t-s) and λκ (force of infection at time t). The possibility of transition between class X and Y is denoted by a solid arrow, with the corresponding rate written as μXY . The dotted arrows represent interactions between the human and mosquito stages of the parasite. The model is formalized by equations (1–14).

VIC3

The transmission rate μS1E is defined as:

$$\mu_{S_1E}(t) = \int_{-\infty}^{t} \gamma(t-s)\lambda(s)d\Gamma(s)$$

λ(s) is the force of infection at a previous time s when the mosquito bites the infected human, γ(t−s) is a delay distribution (for duration of parasite life cycle inside mosquito + vector survival) and μS1E(t) is the transmission at the current time t

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The force of infection in VIC3

$$\lambda(t) = ba^2c\frac{M}{N}\int_{t_0}^{t}\frac{I(s)}{N}x(s)p(t-s)\,ds$$

x(s): the fraction of uninfected mosquitoes at time u M : total number of mosquitoes (assumed constant) N: total number of humans. Uninfected mosquitoes become infected with malaria with a probability c when they bite (at a rate a) an infected human.
I(s)/N: fraction of infected humans at time s.
p(.): a delay distribution that describes the mosquito stage of the parasite life cycle and vector
survival. We choose p(.) to be a Γ(n, τ) density. n
The infected mosquitoes then contribute to malaria infection in humans when they again bite an uninfected human (at a rate a) and infect with a probability b.

How do we attempt to integrate climate in VIC3 framework

We expect the fraction of uninfected mosquitoes x(s) to be seasonal, to have a dependence on climatic factors and to have a random component.

$$\lambda(t) = \left[\frac{I_1(t) + q_f \times I_2(t) + s_f \times S_2(t)}{N(t)} \exp\left\{ \sum_{i=1}^{k} \beta_i s_i(t) + Z_t \beta \right\} \frac{d\Gamma}{dt} \right] \overline{\beta}$$

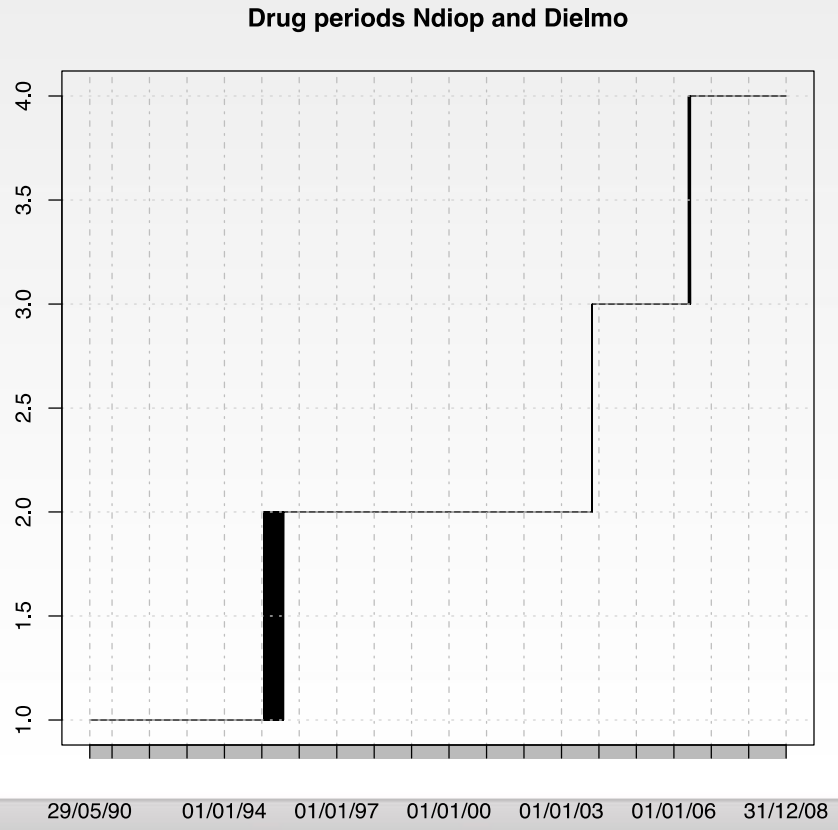
Here, qf represents the fraction of asymptomatics capable to infect mosquitoes.

The seasonality of disease transmission is modeled by the coefficients {βi}

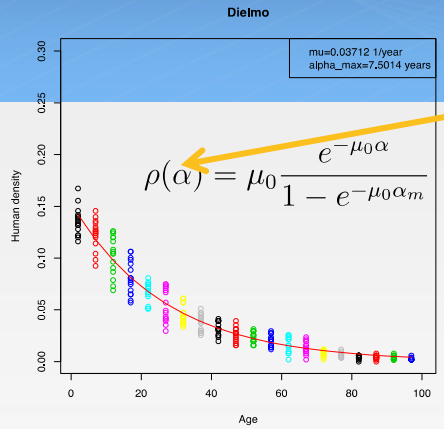
Zt depends on rainfall and drug treatment in the form:

$$Z_t = \beta_r R(t) + \beta_{qui} D[t_{qui}] + \beta_{clo} D[t_{clo}] + \beta_{fan} D[t_{fan}] + \beta_{act} D[t_{act}]$$

Integrating drug treatment in VIC3



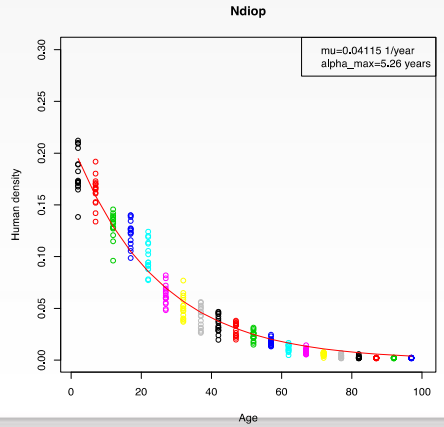
Natural mortality rate estimation



density of people ρ at a given age α

$$\rho(\alpha) = \mu_0 \frac{e^{-\mu_0 \alpha}}{1 - e^{-\mu_0 \alpha_m}}$$

Fixed value for mortality as 0.03



Lose of immunity

$$\mu_{S2S1} = \frac{\mu_{S1E}}{e^{\mu_{S1E} t_{S2S1}} - 1}$$

$$\mu_{I2S2} = \frac{\mu_{S1E}}{e^{\mu_{S1E} t_{I2S2} - 1}}$$

Reinfection

$$\mu_{I2I1} = si_1 \mu_{S1E}$$

$$\mu_{S2I1} = si_2 \mu_{S1E}$$

Superinfection

$$\mu_{S2I2} = si_3 \mu_{S1E}$$

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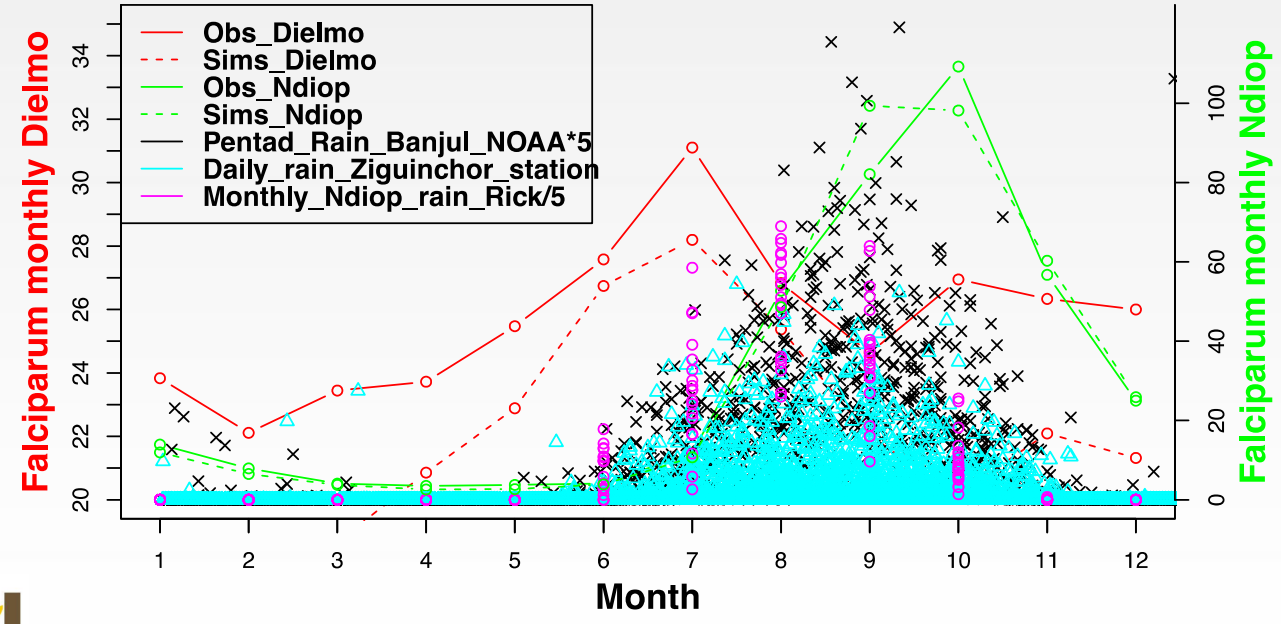
Relationship between cases and rainfall



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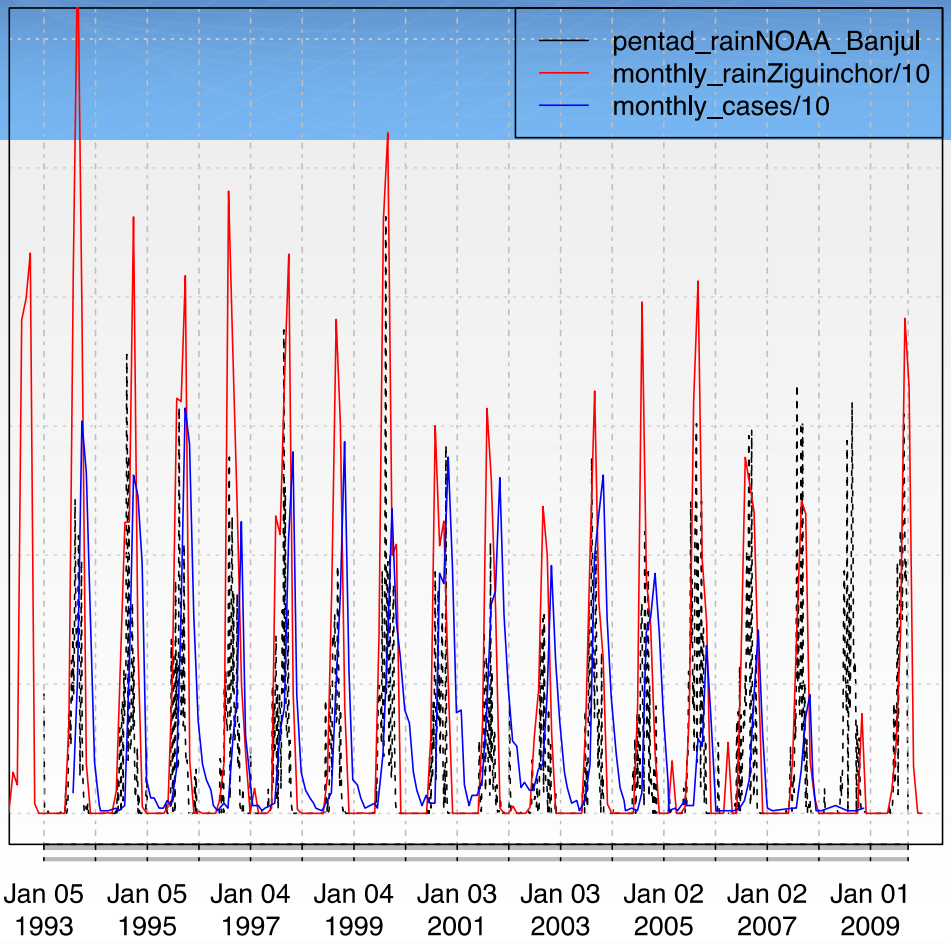
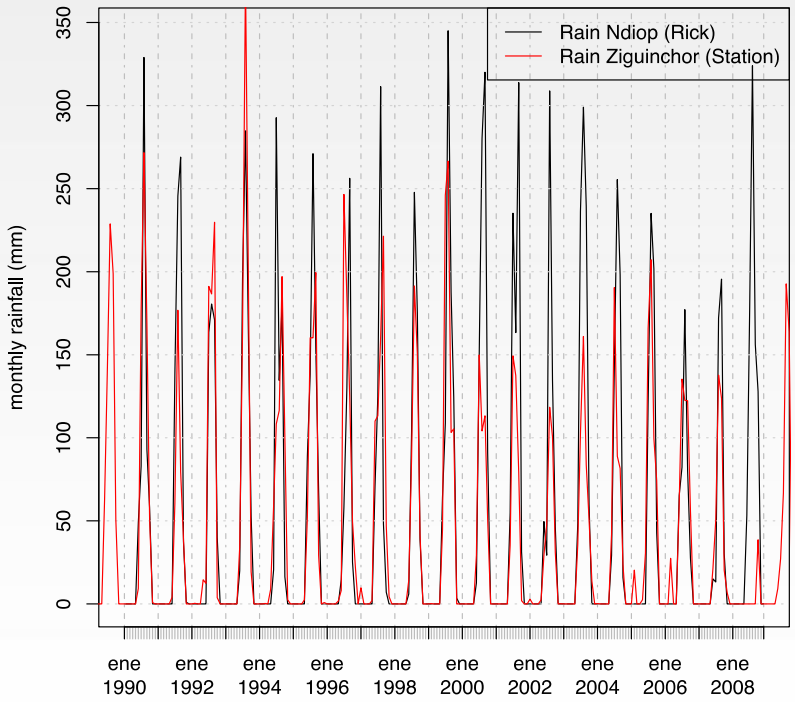
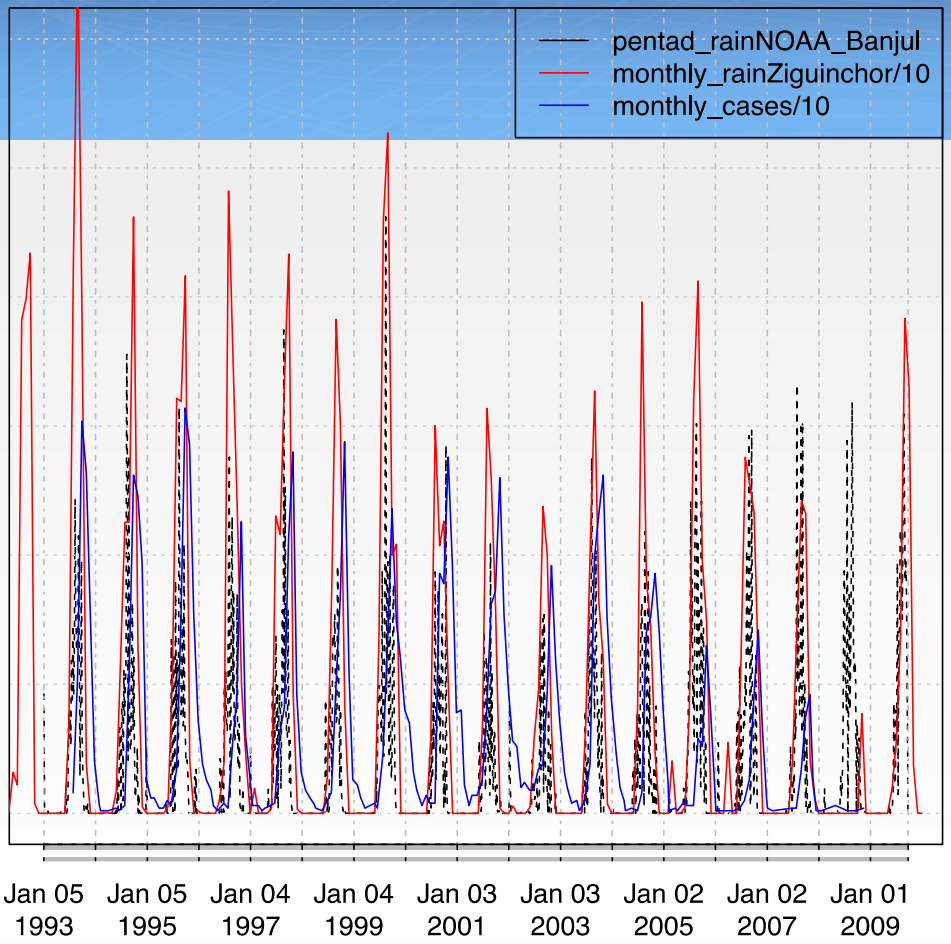
Cases vs rainfall



Discrepancies among rainfall products

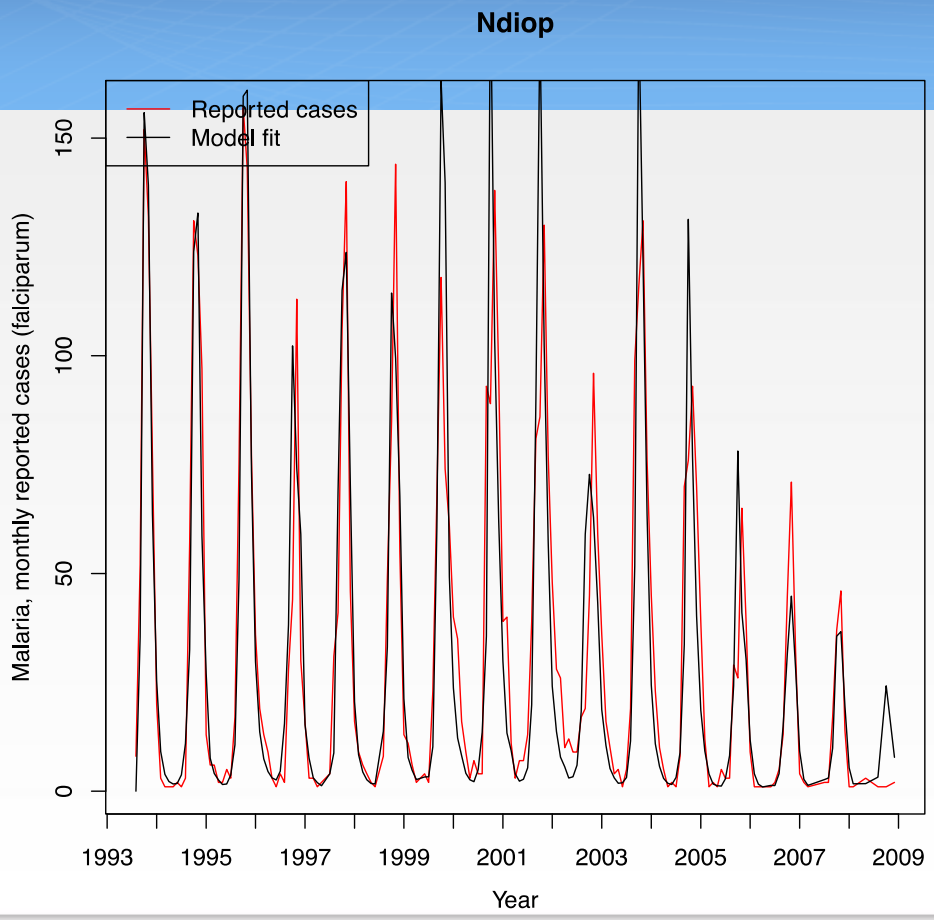


Cases vs rainfall



Preliminary fittings of SDE using MIF

(Including Population change, rainfall and drug treatment)



Preliminary fittings of SDE using MIF

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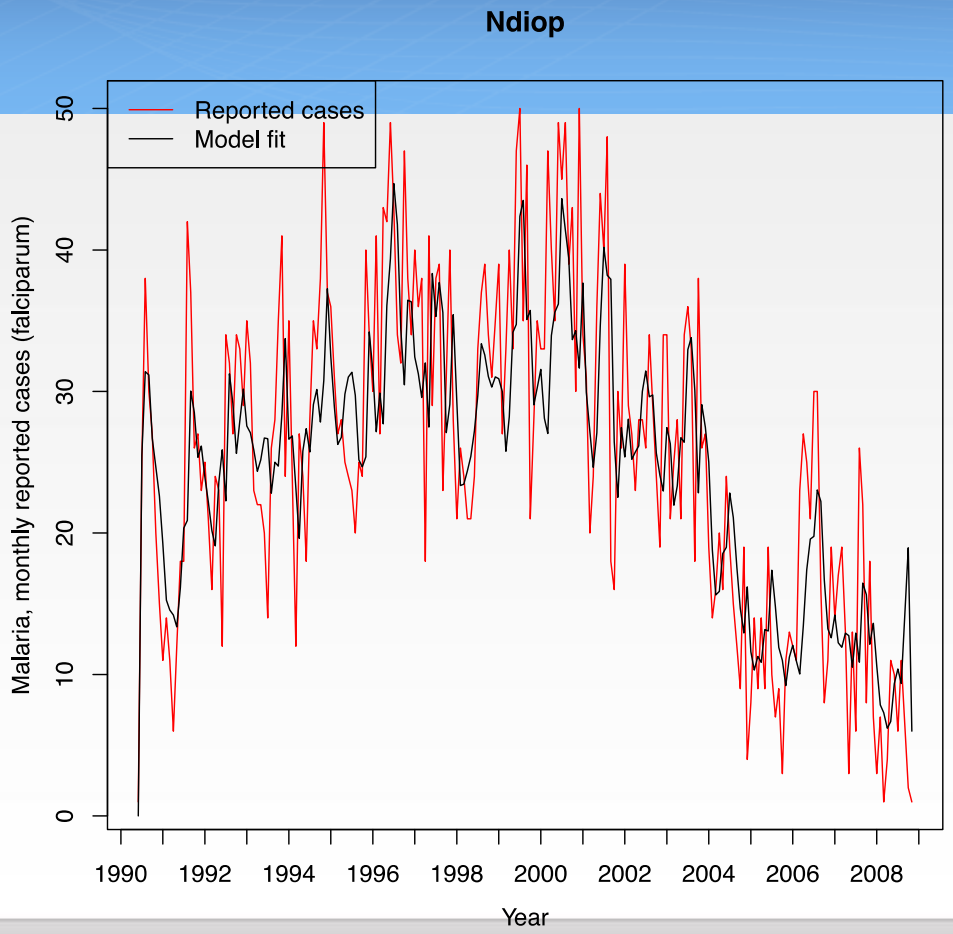
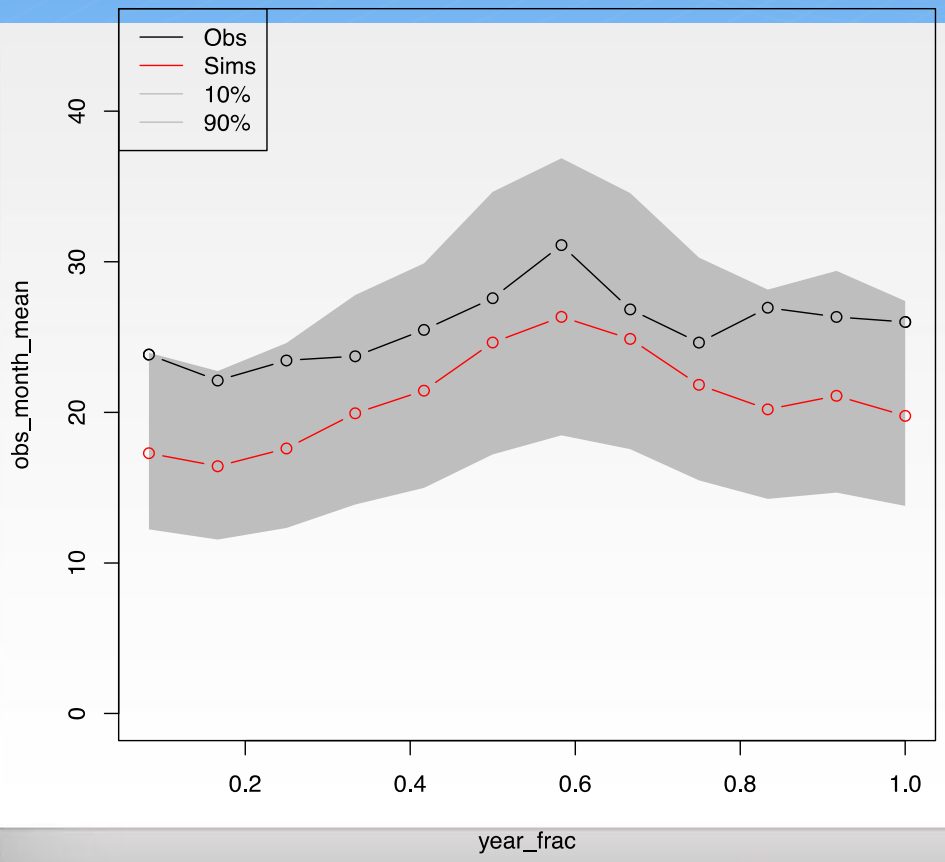


Preliminary fittings of SDE using MIF

(Including Population change, rainfall and drug treatment)

Dielmo



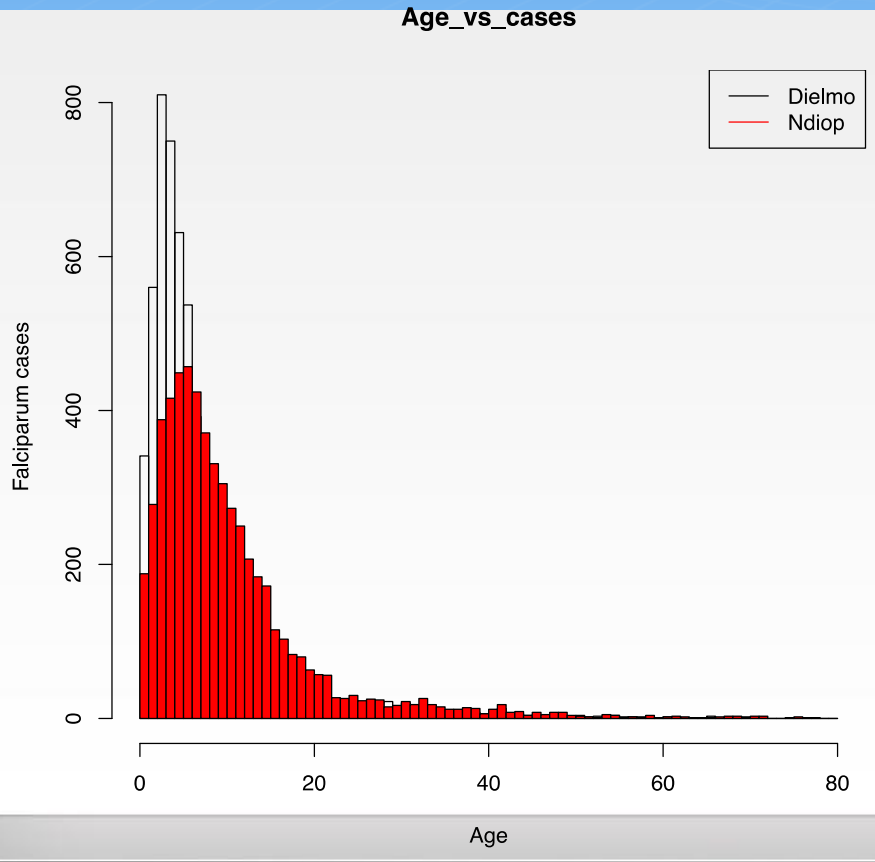
Parameters estimated

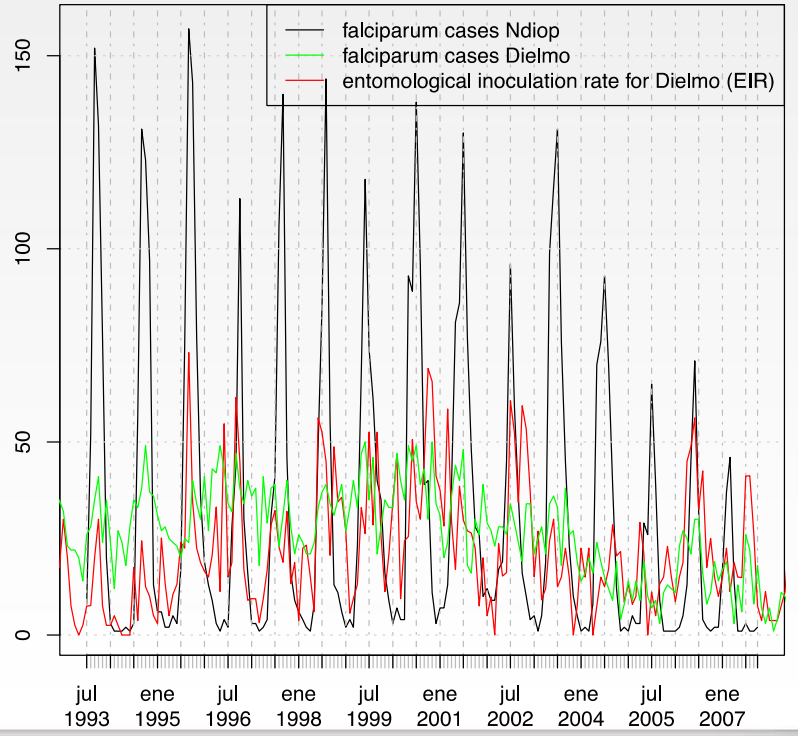
symbol	description	unit	estimated? (y/n)
μ_{XY}	per-capita rate of transition from compartment X to Y; X, Y $\in$ {S1,E,I1,I2,S2}	yr^{-1}	y
β_i	ith spline coefficient	-	y
$\overline{\beta}$	dimensionality constant	yr	n
τ	mean development delay for mosquitoes	yr	n
σ	standard deviation of the process noise	$\mathrm{yr}^{1/2}$	y
ρ	reporting fraction of people in the transition from E to I	-	y
Δ	time step for stochastic Euler integration	day	n
$1/\delta$	average human life expectancy	yr	n
σ_{obs}	standard deviation of the observation noise	-	y
X_0	initial fraction of people in compartment X; X $\in$ {S1,E,I1,I2,S2}	-	y
q_f	infectivity of asymptomatic people	-	y
s_f	infectivity of subpatent infected people	-	y
Φ	probability of becoming a symptomatic case	-	y
ts	fraction of successful tratments	-	y
si_1	fraction of force of infection for superinfection (from I_2 to I_1)	-	y
si_2	fraction of force of infection for superinfection (from S_2 to I_1)	-	y
si_3	fraction of force of infection for superinfection (from S_2 to I_2)	-	y

Table 1: List of symbols for the malaria model. Fixed parameters are $\overline{\beta} = 1$yr, $n_\lambda = 2$, $\Delta = 1$ day, $1/\delta = 33$ yr and $ft = 1$.

Next steps: To include in the model

(Demography, age-incidence, EIR, more environment)



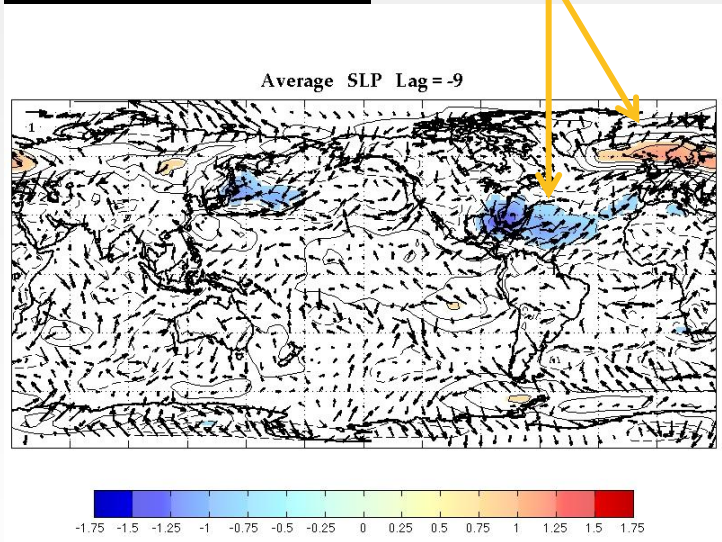


Next steps: To improve integration of extrinsic drivers and test the interplay with intrinsic factors

(New predictors? Where to integrate them? Are they given their actual weight?)

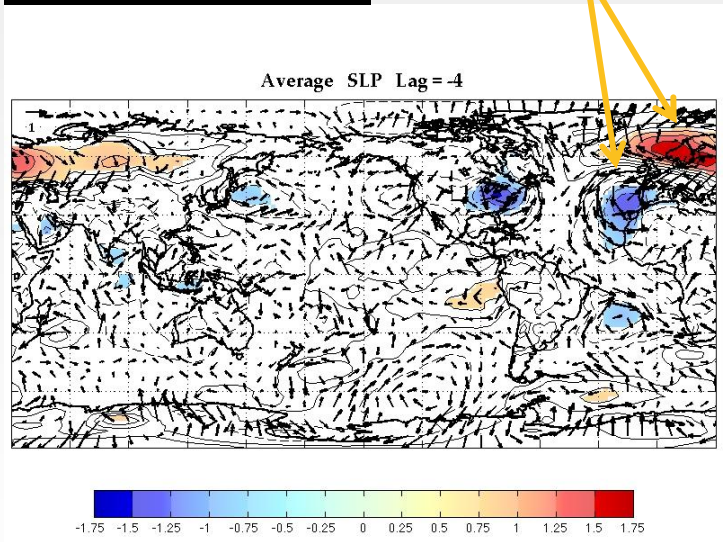
9 months before

New indices



4 months before

Adding skill



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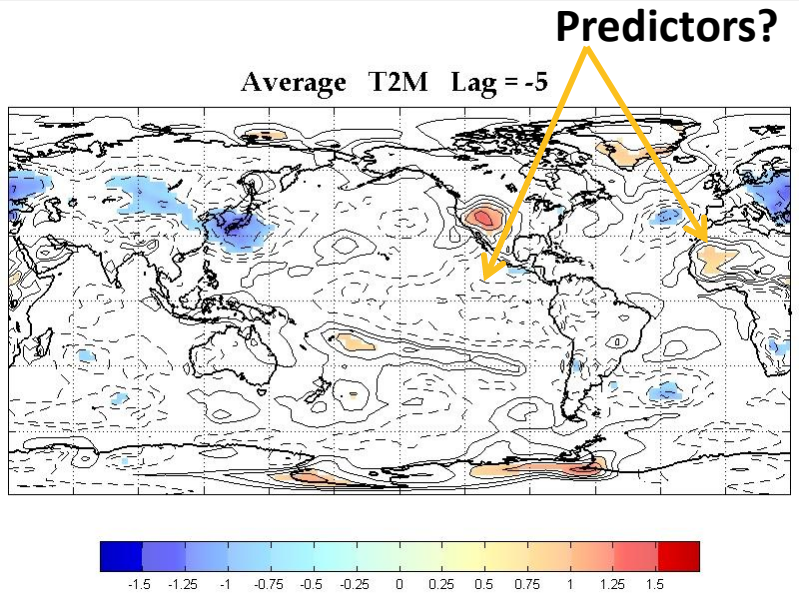
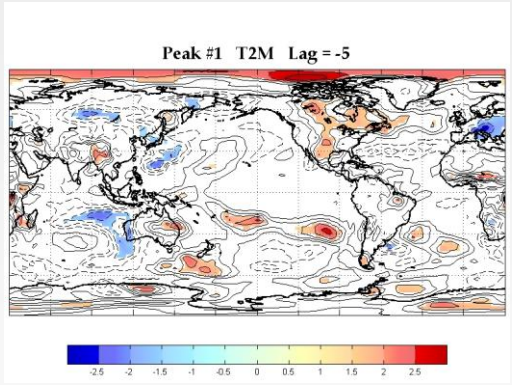
Next steps: To improve integration of extrinsic drivers and test the interplay with intrinsic factors

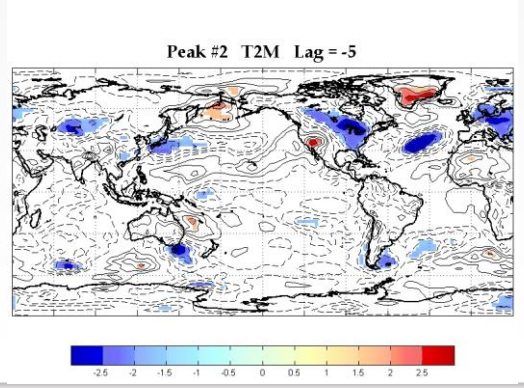
(New predictors? Where to integrate them? Are they given their actual weight?)

Average composite 5 months before



Nonlinearity





but..

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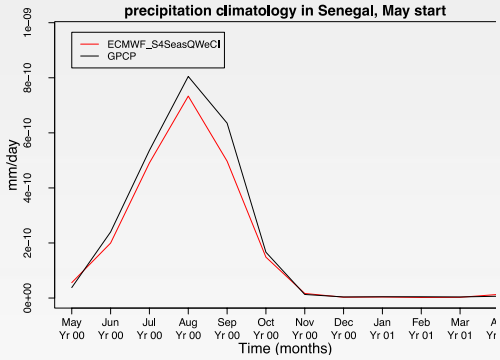
Incorporating climate predictions

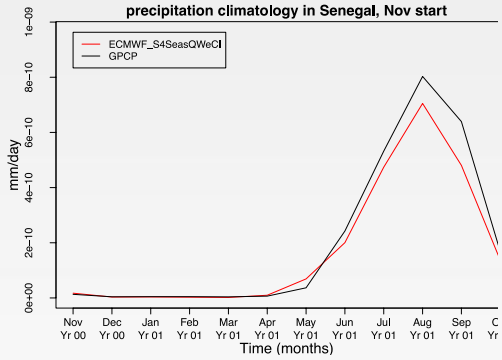
(ECMWF System4, GPCP 2.5º,GHCN 0.5º, 1981-2010)

MAY

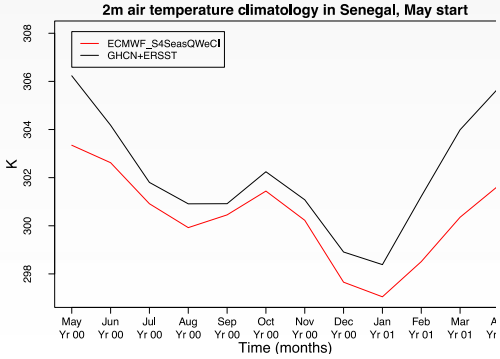
NOVEMBER

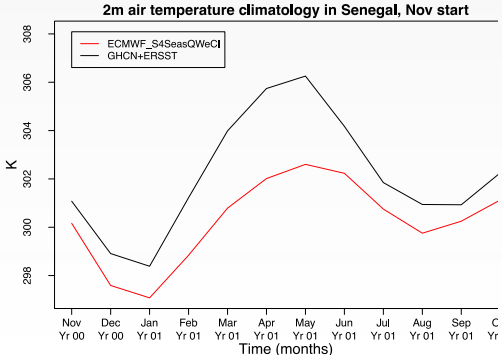
PRECIP





T2m





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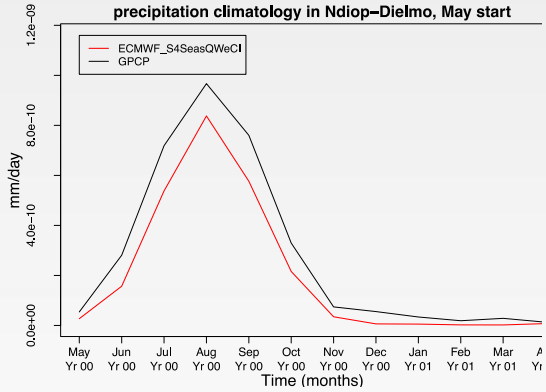
Incorporating climate predictions

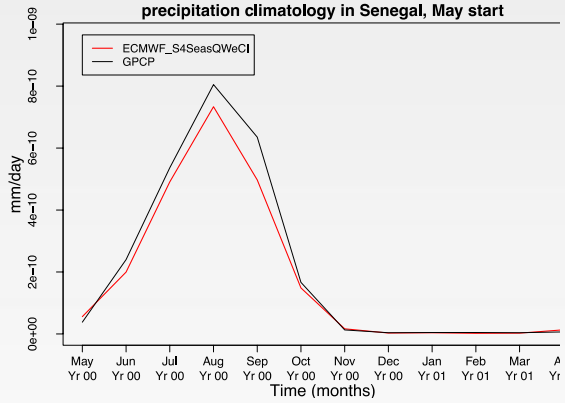
(ECMWF System4, GPCP 2.5º,GHCN 0.5º, 1981-2010)

local

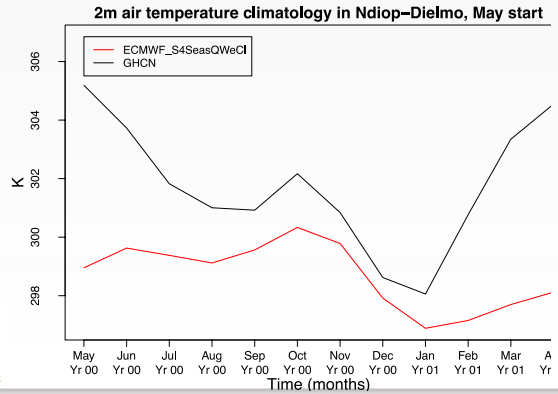
Senegal

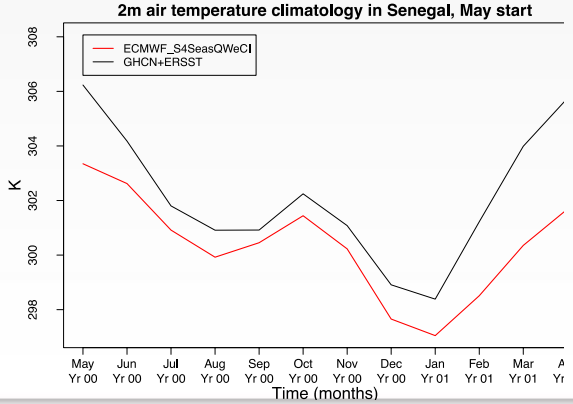
PRECIP





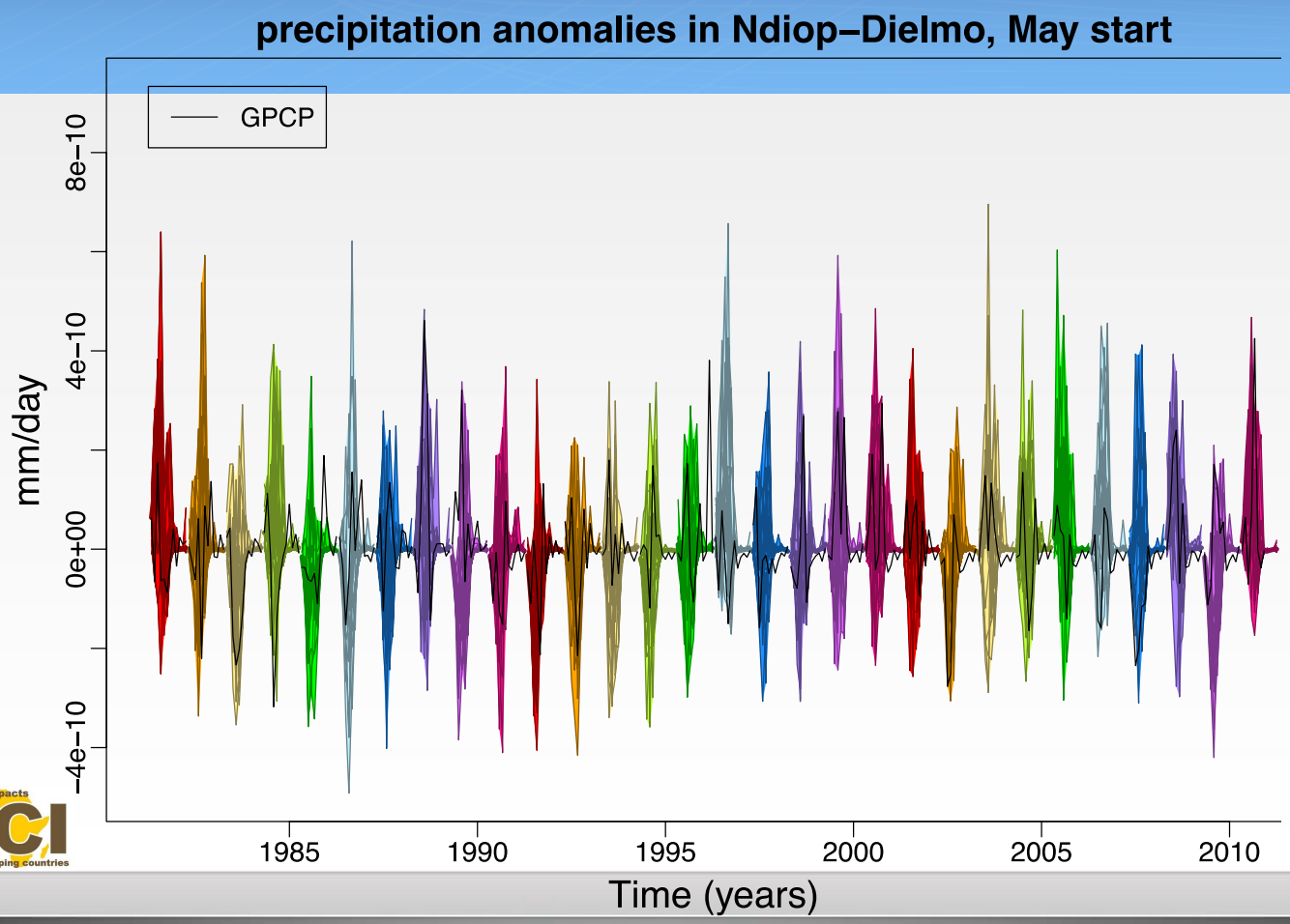
T2m





Incorporating climate predictions

(ECMWF System4, GPCP 2.5°,GHCN 0.5°, 1981-2010)



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Incorporating climate predictions

NDIOP/DIELMO *(ECMWF System4, GPCP 2.5º,GHCN 0.5º, 1981-2010)*

MAY

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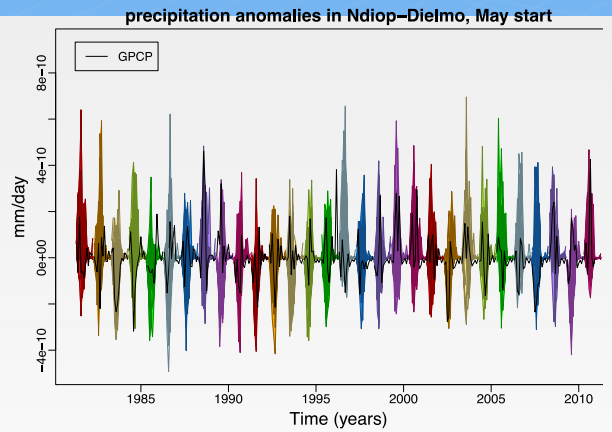
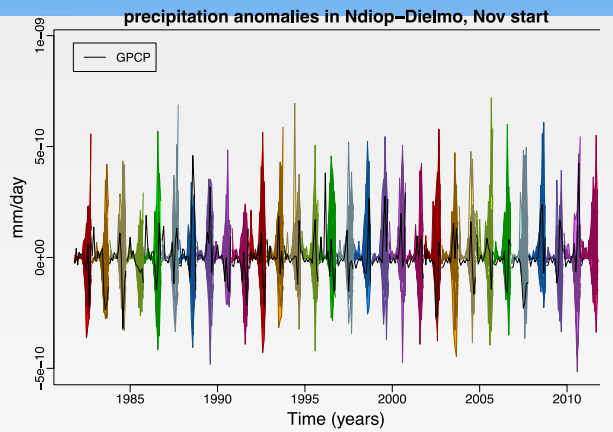
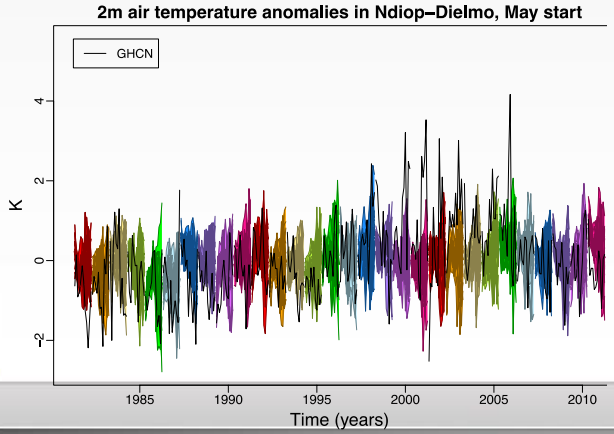
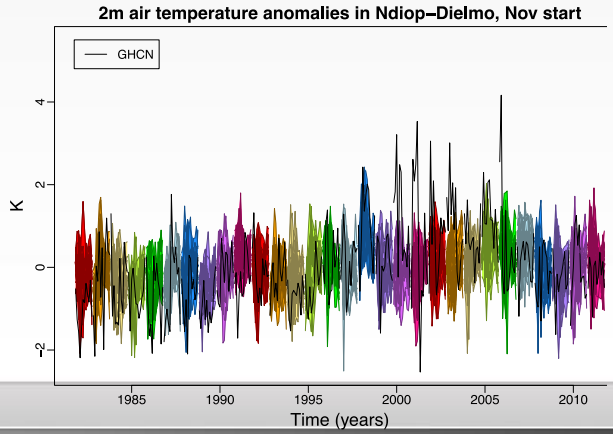




T2m





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Thank you!

Gràcies!

Asante Sana!

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