### Epidemiology and Infection

### P.Zeman: Predictability of tick-borne encephalitis fluctuations

### Supplementary Material

### Model examples

### example 1 (harmonic regression)

rm(list=ls(all=TRUE))

library(rstan)

scode <- " // model code for Stan ...

data {

 int<lower=0> N; // no. items

 vector[N] x; // predictor

 vector[N] y; // outcome

}

parameters { // The definition of priors on the

 real<lower=0, upper=10> a2; // amplitude,

 real<lower=2.65, upper=2.95> b2; // frequency (the boundaries were adjusted to yield a unimodal

 // and maximally symmetric posterior distribution),

 real<lower=3, upper=11> c2; // and phase of the biennial cycle;

 real<lower=0, upper=10> a3; // ditto triennial cycle;

 real<lower=2.03, upper=2.23> b3; //

 real<lower=3, upper=10> c3; //

 real<lower=0, upper=10> a5; // ditto pentennial cycle;

 real<lower=1.062,upper=1.298> b5; //

 real<lower=1.5, upper=7.5> c5; //

 real<lower=0, upper=10> a10; // ditto decadal cycle;

 real<lower=0.65, upper=0.85> b10; //

 real<lower=1.5, upper=7.5> c10; //

 real<lower=0> sigma; // error scale.

}

model {

 vector[N] lmb2;

 vector[N] lmb3;

 vector[N] lmb5;

 vector[N] lmb10;

 for (i in 1:N) { // model loop

 lmb2[i] <- a2 \* cos(b2 \* x[i] - c2);

 lmb3[i] <- a3 \* cos(b3 \* x[i] - c3);

 lmb5[i] <- a5 \* cos(b5 \* x[i] - c5);

 lmb10[i] <- a10 \* cos(b10 \* x[i] - c10);

 y[i] ~ normal(lmb2[i] + lmb3[i] + lmb5[i] + lmb10[i], sigma); // likelihood

 }

}

generated quantities {

 vector[N] y\_new; // predictions

 for (i in 1:N) { // pseudo-random draw from a normal distribution

 y\_new[i] <- normal\_rng(a2\*cos(b2\*x[i]-c2) + a3\*cos(b3\*x[i]-c3)

 + a5\*cos(b5\*x[i]-c5) + a10\*cos(b10\*x[i]-c10), sigma);

 }

}

" ## ... end of Stan code

N <- 45 ## time-series length

x <- c(1:N) ## data: de-trended and standardised TBE incidence in the Czech Rep., 1971-2015

y = c(-0.565988652, -0.461807036, 1.262955324, 0.359093502, 0.271684996,

 0.326954572, -0.200176742, -1.388726722, 2.589358404, -0.638522364,

 -1.569547221, 0.532128739, -0.985093454, 0.672238621, 1.149091086,

 1.05096462, -0.570536114, -0.587868034, -1.085327034, -1.267301906,

 -0.086477288, -0.676214433, 1.302882292, 0.880165109, 1.649808198,

 0.272077881, -0.920301887, -0.864221153, -0.375689415, 1.258965613,

 0.445305797, 0.307718718, -0.2454201, -1.149735397, -0.405334314,

 2.013075321, -1.234978163, -0.685438882, 0.626516086, -0.667155566,

 1.486234145, -0.21453795, 0.462976831, -0.905183595, -1.168612431)

data1 <- list(x = x, ## data passed to Stan

 y = y,

 N = N)

fit1 <- stan(model\_code = scode, data = data1, iter = 2000, verbose = TRUE) ## invokes Stan

print(fit1) ## prints summary for the fitted model

### example 2 (weighted harmonic regression and forecast)

rm(list=ls(all=TRUE))

library(rstan)

scode <- " // model code for Stan …

data {

 int<lower=0> M;

 int<lower=0> N;

 int<lower=0> O;

 vector[N] x;

 vector[M+10] x\_new;

 vector[N] y;

 vector[M] weight;

 real b2;

 real b3;

 real b5;

 real b10;

}

parameters { // The definition of priors on the

 real<lower=0, upper=10> a2; // amplitude

 real<lower=4, upper=11> c2; // and phase of the biennial cycle;

 real<lower=0, upper=10> a3; // ditto triennial cycle;

 real<lower=3.0, upper=10.0> c3; //

 real<lower=0, upper=10> a5; // ditto pentennial cycle;

 real<lower=1.5, upper=7.5> c5; //

 real<lower=0, upper=10> a10; // ditto decdal cycle;

 real<lower=2.0, upper=7.5> c10; //

 real<lower=0> sigma; // error scale.

}

model {

 vector[M] lmb2;

 vector[M] lmb3;

 vector[M] lmb5;

 vector[M] lmb10;

 for (i in 1:M) {

 lmb2[i] <- a2 \* cos(b2 \* x[O+i-1] - c2);

 lmb3[i] <- a3 \* cos(b3 \* x[O+i-1] - c3);

 lmb5[i] <- a5 \* cos(b5 \* x[O+i-1] - c5);

 lmb10[i] <- a10 \* cos(b10 \* x[O+i-1] - c10);

 y[O+i-1] ~ normal(lmb2[i] + lmb3[i] + lmb5[i] + lmb10[i], sigma\*weight[i]);

 }

}

generated quantities {

 vector[M+10] y\_new;

 for (i in 1:M+10) {

 y\_new[i] <- normal\_rng(a2\*cos(b2\*x\_new[i]-c2) + a3\*cos(b3\*x\_new[i]-c3)

 + a5\*cos(b5\*x\_new[i]-c5) + a10\*cos(b10\*x\_new[i]-c10), sigma);

 }

}

" ## end of Stan code

N <- 45 ## total time-series length

M <- 20 ## training segment length

O <- 26 ## offset

x <- c(1:N) ## data: de-trended and standardised TBE incidence in the Czech Rep., 1971-2015

y = c(-0.565988652, -0.461807036, 1.262955324, 0.359093502, 0.271684996,

 0.326954572, -0.200176742, -1.388726722, 2.589358404, -0.638522364,

 -1.569547221, 0.532128739, -0.985093454, 0.672238621, 1.149091086,

 1.05096462, -0.570536114, -0.587868034, -1.085327034, -1.267301906,

 -0.086477288, -0.676214433, 1.302882292, 0.880165109, 1.649808198,

 0.272077881, -0.920301887, -0.864221153, -0.375689415, 1.258965613,

 0.445305797, 0.307718718, -0.2454201, -1.149735397, -0.405334314,

 2.013075321, -1.234978163, -0.685438882, 0.626516086, -0.667155566,

 1.486234145, -0.21453795, 0.462976831, -0.905183595, -1.168612431)

x\_new <- c(O:(O+M+9)) ## predictor

R = 3.0 ## weight gradient ≥ 1.0

beta = (R \* 2)/(1 + R)

alpha = 2 - beta

delta = (beta - alpha)/(M - 1)

weight <- rep(0, times=M)

for (i in 1:M){

 weight[M-i+1] <- alpha + (i - 1)\*delta

}

#plot(weight)

data1 <- list(x = x, ## data passed to Stan

 x\_new = x\_new,

 y = y,

 weight = weight,

 M = M,

 N = N,

 O = O,

 b2 = 2.786639028, ## the frequency of the biennial cycle

 b3 = 2.129077026, ## ditto triennial cycle

 b5 = 1.17033217, ## ditto pentennial cycle

 b10 = 0.741362443) ## ditto decadal cycle

fit1 <- stan(model\_code = scode, data = data1, iter = 4000, verbose = TRUE) ## invokes Stan

print(fit1) ## prints summary for the fitted model