

Supporting information

Modelling of vegetation dynamics from satellite time series to determine proglacial primary succession in the course of global warming – A case study in the upper Martell valley (Eastern Italian Alps)

Bettina Knoflach ^{1,*}, [†], Katharina Ramskogler ^{2,*}, [†], Matthew Talluto ³, Florentin Hofmeister ⁴, Florian Haas ⁵, Tobias Heckmann ⁵, Madlene Pfeiffer ⁶, Livia Piermattei ⁷, Camillo Ressl ⁸, Michael H. Wimmer ⁸, Clemens Geitner ¹, Brigitta Erschbamer ² and Johann Stötter ¹

- ¹ Department of Geography, University of Innsbruck, 6020 Innsbruck, Austria; clemens.geitner@uibk.ac.at (C.G.); hans.stoetter@uibk.ac.at (J.S.)
² Department of Botany, University of Innsbruck, 6020 Innsbruck, Austria; katharina.ramskogler@uibk.ac.at (K.R.); brigitta.erschbamer@uibk.ac.at (B.E.)
³ Department of Ecology, University of Innsbruck, 6020 Innsbruck, Austria; matthew.talluto@uibk.ac.at
⁴ Department of Civil, Geo and Environmental Engineering, Technical University of Munich, 80333 Munich, Germany; florentin.hofmeister@tum.de
⁵ Department of Physical Geography, Catholic University of Eichstätt-Ingolstadt, 85072 Eichstätt, Germany; florian.haas@ku.de (F.H.); tobias.heckmann@ku.de (T.H.)
⁶ Institute of Geography, University of Bremen, 28359 Bremen, Germany; madlene.pfeiffer@uni-bremen.de
⁷ Department of Geosciences, University of Oslo, 0316 Oslo, Norway; livia.piermattei@geo.uio.no
⁸ Department of Geodesy and Geoinformation, TU Wien, 1040 Vienna, Austria; camillo.ressl@geo.tuwien.ac.at (C.R.); michael.wimmer@geo.tuwien.ac.at (M.H.W.)
* Correspondence: bettina.knoflach@uibk.ac.at
† These authors contributed equally to this work.

S1 Code of the model for R [1] using RStan [2] – Bayesian beta regression

Model code “betamode.stan” by Talluto, M. & Ramskogler, K.

```
data {  
    int n; // number of data points  
    int k; // number of predictors  
    vector <lower=0, upper=1> [n] cover; // response variable  
    matrix [n, k] x; // predictors  
  
    int n_new;  
    #matrix [n_new, k] x_new;  
}  
parameters {  
    // regression parameters  
    real a;  
    vector [k] B;  
  
    real <lower=0> phi;  
}  
transformed parameters {  
    vector <lower=0> [n] alpha;  
    vector <lower=0> [n] beta;  
    vector <lower=0, upper=1> [n] mu;
```

```

mu = inv_logit(a + x * B);
alpha = mu*phi;
beta = (1-mu) * phi;

}

model {
    // likelihood
    cover ~ beta(alpha, beta);

    // priors, adjust as needed
    // the scales assume X has been transformed to mean=0, sd=1
    a ~ normal(0, 10);
    B ~ normal(0, 5);
    phi ~ cauchy(0, 5);

}

generated quantities {
    vector[n] log_lik;
    vector[n] log_lik_rep;
    vector<lower = 0, upper = 1> [n] cover_rep;
    vector[n_new] cover_new;
    vector[n_new] mu_new;
    mu_new = inv_logit(a + x_new * B);

    for (i in 1:n){
        log_lik[i] = beta_lpdf(cover[i] | alpha[i], beta[i]);
        cover_rep[i] = beta_rng(alpha[i], beta[i]);
        log_lik_rep[i] = beta_lpdf(cover[i] | alpha[i], beta[i]);
    }

    for(i in 1:n_new){
        real alpha_new = mu_new[i]*phi;
        real beta_new = (1-mu_new[i]) * phi;

        cover_new[i] = beta_rng(alpha_new, beta_new);
    }
}

```

load rstan and scale parameters

```

library(rstan)

#prepare x as a matrix and scale the x-variable
x = as.matrix(data1[, c(2)]) #choose the column you need
x = scale(x)

x_2019 = as.matrix(ndvi_datframe[, c(4)]) #choose the column you need
x_2019 = scale(x_2019, center = attr(x, "scaled:center"),
               scale = attr(x, "scaled:scale"))

```

run the code

```

standat = list(n = nrow(x), n_new = nrow(x_2019), k = ncol(x),
               #cover = data1$cover, x = x, x_new = x_2019)
fit = stan("betamod.stan", data = standat, iter = 4000, chains = 4)

```

Table S1. S2 Temperature observation stations in and around the Martell Valley.

Name	Elevation [m a.s.l.]	Temporal coverage	Provider
Hintermartell	1720	2009-2020	Autonomous Province of Bozen/Bolzano - South Tyrol
Zufritt	1851	1972-2020	Autonomous Province of Bozen/Bolzano - South Tyrol
Weissbrunn (Ultental)	1900	1987-2020	Autonomous Province of Bozen/Bolzano - South Tyrol
Sulden (Suldental)	1907	1987-2020	Autonomous Province of Bozen/Bolzano - South Tyrol
Rossbänke (Ultental)	2255	2001-2020	Autonomous Province of Bozen/Bolzano - South Tyrol
Madrisch (Suldental)	2825	2000-2020	Autonomous Province of Bozen/Bolzano - South Tyrol
Langenferner-Felsköpfl	2967	2012-2020	Institute of Atmospheric and Cryospheric Sciences, University of Innsbruck
Weissbrunnspitze	3253	2012-2020	Autonomous Province of Bozen/Bolzano - South Tyrol
Schöntaufspitze	3328	1998-2020	Autonomous Province of Bozen/Bolzano - South Tyrol

References

1. R Core Team. *R: A language and environment for statistical computing. R Foundation for Statistical Computing*; Vienna, Austria, 2020.
2. Stan Development Team. "RStan: the R interface to Stan." *R package version 2.21.2*, 2020.