# Supplementary Data S1 - R code for the variance components model
# Accompanies xxx_full_citation_xxx to come here
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chlorophyll_driver_model <- "data{
// HERE WE DEFINE THE DATA THAT WE INPUT INTO STAN
  int<lower=0> N;
  // number of observations for chlorophyll fluorescence
  int<lower=0> Nlakes;
  // total number of lakes
  int<lower=0> Nlakecars;
  // total number of lake-specific characteristics inputted to the model
  vector[N] y;
  // observed chlorophyll fluorescence
  int lake[N];
  // lake ID associated with each chlorophyll fluorescence observation
  int month[N];
  // month ID associated with each chlorophyll fluorescence observation
  int day[N];
  // day ID associated with each chlorophyll fluorescence observation
  int<lower=0> surf_wtemps_N;
  // number of observations for surface water temperatures
  vector[surf_wtemps_N] surf_wtemps_y;
  // observed surface water temperatures
  int surf_wtemps_lake[surf_wtemps_N];
  // lake ID associated with each surface water temperature observation
  int surf_wtemps_month[surf_wtemps_N];
  // month ID associated with each surface water temperature observation
  int surf_wtemps_day[surf_wtemps_N];
  // day ID associated with each surface water temperature observation
  int<lower=0> wind_spds_N;
  // number of wind speed observations
  vector<lower=0>[wind_spds_N] wind_spds_y;
  // observed wind speeds
  int wind_spds_lake[wind_spds_N];
  // lake ID associated with each wind speed observation
  int wind_spds_month[wind_spds_N];
  // month ID associated with each wind speed observation
  int wind_spds_day[wind_spds_N];
  // day ID associated with each wind speed observation
  int<lower=0> par_N;
  // number of PAR observations
  vector[par_N] par_y;
  // observed PAR
  int par_lake[par_N];
  // lake ID associated with each PAR observation
  int par_month[par_N];
  // month ID associated with each PAR observation
  int par_day[par_N];
  // day ID associated with each PAR observation
  matrix[Nlakes,Nlakecars] lakechars;
  // matrix of lake-specific characteristics, such as depth, area, and trophic state
  matrix[Nlakecars+12,Nlakecars+12] Imat;
  // identity matrix used to setup prior for correlation matrix
"
vector[Nlakecars] mvn_known_mu;
// means calculated across lakes for each lake-specific characteristic
vector[Nlakecars] mvn_known_sd;
// standard deviations calculated across lakes for each lake-specific characteristic
int thetamax;
// index in vector of wind speeds with the largest value
int thetamin;
// index in vector of wind speeds with the smallest value
int theta_id[par_N-2];
// indices in the vector of wind speeds that do not include thetamax or thetamin
}
parameters{
// HERE WE DEFINE THE PARAMETERS THAT WE ESTIMATE IN STAN
corr_matrix[Nlakecars+12] Omega;
// correlation matrix
real betaINT[Nlakes];
// lake-specific intercepts for chlorophyll fluorescence
matrix[Nlakes,12] betaLAKEMONTH;
// variation in chlorophyll fluorescence associated with each month in each lake
matrix[Nlakes,366] betaLAKEDAY;
// variation in chlorophyll fluorescence associated with each day in each lake
real surf_wtemps_betaINT[Nlakes];
// lake-specific intercepts for surface water temperatures
matrix[Nlakes,12] surf_wtemps_betaLAKEMONTH;
// variation in surface water temperatures associated with each month in each lake
matrix[Nlakes,366] surf_wtemps_betaLAKEDAY;
// variation in surface water temperatures associated with each day in each lake
real wind_spds_betaINT[Nlakes];
// lake-specific intercepts for wind speed
matrix[Nlakes,12] wind_spds_betaLAKEMONTH;
// variation in wind speed associated with each month in each lake
matrix[Nlakes,366] wind_spds_betaLAKEDAY;
// variation in wind speed associated with each day in each lake
matrix[Nlakes,2] par_betaINT;
// lake-specific intercepts for PAR
matrix[Nlakes,12] par_betaLAKEMONTH;
// variation in PAR associated with each month in each lake
matrix[Nlakes,366] par_betaLAKEDAY;
// variation in PAR associated with each day in each lake
real<lower=0,upper=1> theta[par_N-2];
// probability of membership into one of two groups for PAR mixing model for all but two observations for which we define groups to improve fitting
vector[12] mvn_est_mu;
// means calculated across lakes for each variance component on log-scale
vector[lower=0][12] mvn_est_sd;
// standard deviations calculated across lakes for each variance component on log-scale
matrix[Nlakes,12] log_varcomp;
// estimated variance component at each of 3 time scales for each of 4 high-resolution variables in each lake
real<lower=0> int_sd;
// hyper-standard deviation for lake-specific intercepts for chlorophyll fluorescence
real int_mu;
// hyper-mean for lake-specific intercepts for chlorophyll fluorescence
real<lower=0> int_sd_surfwtemps;
// hyper-standard deviation for lake-specific intercepts for surface water temperature
real int_mu_surfwtemps;
// hyper-mean for lake-specific intercepts for surface water temperature
real<lower=0> int_sd_wind_spds;
// hyper-standard deviation for lake-specific intercepts for wind speed
real int_mu_wind_spds;
// hyper-mean for lake-specific intercepts for wind speed
real<lower=0> int_sd_par[2];
// hyper-standard deviation for lake-specific intercepts for PAR
real int_mu_par[2];
// hyper-mean for lake-specific intercepts for PAR
}
transformed parameters{
// HERE WE DEFINE THE PARAMETERS THAT WE CALCULATE IN STAN
matrix[Nlakecars+12,Nlakecars+12] LL;
// Cholesky deocmposed covariance matrix
vector[N] mu;
// mean chlorophyll fluorescence
vector[N] si;
// standard deviation in chlorophyll fluorescence
vector[surf_wtemps_N] surf_wtemps_mu;
// mean surface water temperature
vector[surf_wtemps_N] surf_wtemps_si;
// standard deviation in surface water temperature
vector[wind_spds_N] wind_spds_mu;
// mean wind speed
ordered[2] par_mu[par_N];
// mean PAR in each of two groups
row_vector[Nlakecars+12] lakeparams[Nlakes];
// transformed matrix of lake-specific characteristics and variance components in each lake for each of estimation
matrix[Nlakes,Nlakecars+12] lakeparams_tmp;
// concatenated matrix of lake-specific characteristics and variance components
matrix<lower=0>[Nlakes,12] varcomp;
// exponentiated log_varcomp, i.e. estimated variance component at each of 3 time scales for each of 4 high-resolution variables in each lake
vector[Nlakecars+12] mvn_append_mu;
// concatenated means of lake-specific characteristics and variance components averaged across all lakes
vector[Nlakecars+12] mvn_append_sd;
// concatenated standard deviations of lake-specific characteristics and variance components averaged across all lakes
real<lower=0,upper=1> theta_N[par_N];
// concatenated probability of group membership
lakeparams_tmp = append_col(log_varcomp,lakechars);
// concatenate logged variance components with lake-specific characteristics
for (i in 1:18)
// this transforms for ease of estimation
lakeparams[i] = lakeparams_tmp[i];
varcomp = exp(log_varcomp);
// back-transform logged variance components onto normal scale
mvn_append_mu = append_row(mvn_est_mu, mvn_known_mu);
// concatenate means of lake-specific characteristics and variance components averaged across all lakes
mvn_append_sd = append_row(mvn_est_sd, mvn_known_sd);
// concatenate standard deviations of lake-specific characteristics and variance components averaged across all lakes
LL = cholesky_decompose(quad_form_diag(Omega,mvn_append_sd));
// Cholesky decompose of correlation matrix Omega and estimated hyper-standard
deviations for each variance component
for (i in 1:N){
  // calculate mean chlorophyll fluorescence
  mu[i] = int_mu + betaINT[lake[i]]*int_sd +
  betaLAKEDAY[lake[i],day[i]]*varcomp[lake[i],2] +
  betaLAKEMONTH[lake[i],month[i]]*varcomp[lake[i],1];
  si[i] = varcomp[lake[i],3];
}
for (i in 1:surf_wtemps_N){
  // calculate mean surface water temperature
  surf_wtemps_mu[i] = int_mu_surfwtemps +
  surf_wtemps_betaINT[surf_wtemps_lake[i]]*int_sd_surfwtemps +
  surf_wtemps_betaLAKEDAY[surf_wtemps_lake[i],surf_wtemps_day[i]]*varcomp[surf_wtemps_lake[i],5] +
  surf_wtemps_betaLAKEMONTH[surf_wtemps_lake[i],surf_wtemps_month[i]]*varcomp[surf_wtemps_lake[i],4];
  surf_wtemps_si[i] = varcomp[surf_wtemps_lake[i],6];
}
for (i in 1:wind_spds_N)
  // calculate mean wind speed
  wind_spds_mu[i] = int_mu_wind_spds +
  int_sd_wind_spds*wind_spds_betaINT[wind_spds_lake[i]] +
  wind_spds_betaLAKEDAY[wind_spds_lake[i],wind_spds_day[i]]*varcomp[wind_spds_lake[i],8] +
  wind_spds_betaLAKEMONTH[wind_spds_lake[i],wind_spds_month[i]]*varcomp[wind_spds_lake[i],7];
theta_N[thetamax] <- 0;
// assign group membership to largest and smallest wind speed values to help
fitting and avoid chains converging on opposing membership
theta_N[thetamin] <- 1;
for (i in 1:(par_N-2))
  theta_N[theta_id[i]] <- theta[i];
// fill vector of theta values with estimated values
for (i in 1:par_N){
  // calculate mean PAR in each group of the mixture
  par_mu[i,1] = int_mu_par[1]+int_sd_par[1]*par_betaINT[par_lake[i],1] +
  par_betaLAKEDAY[par_lake[i], par_day[i]]*varcomp[par_lake[i],11] +
  par_betaLAKEMONTH[par_lake[i], par_month[i]]*varcomp[par_lake[i],10];
  par_betaLAKEDAY[par_lake[i], par_day[i]]*varcomp[par_lake[i],11] +
  par_betaLAKEMONTH[par_lake[i], par_month[i]]*varcomp[par_lake[i],10];
}
model{
  // HERE WE DEFINE THE PRIOR LIKELIHOODS THAT WE ESTIMATE IN STAN
  mvn_est_mu ~ normal(0,1);
  mvn_est_sd ~ normal(0,5);
  int_mu ~ normal(0,5);
  int_sd ~ normal(0,1);
  int_mu_surfwtemps ~ normal(0,10);
  int_sd_surfwtemps ~ normal(0,5);
  int_sd_wind_spds ~ normal(0,1);
  int_mu_par ~ normal(0,5);
  int_sd_par ~ normal(0,1);
  Omega ~ inv_wishart(Nlakecars+12+1, Imat);
  lakeparams ~ multi_normal_cholesky(mvn_append_mu, LL);
  betaINT ~ normal(0,1);
to_vector(betaLAKEMONTH) ~ normal(0,1);
to_vector(betaLAKEDAY) ~ normal(0,1);
surf_wtemps_betaINT ~ normal(0,1);
to_vector(surf_wtemps_betaLAKEMONTH) ~ normal(0,1);
to_vector(surf_wtemps_betaLAKEDAY) ~ normal(0,1);
wind_spds_betaINT ~ normal(0,1);
to_vector(wind_spds_betaLAKEMONTH) ~ normal(0,1);
to_vector(wind_spds_betaLAKEDAY) ~ normal(0,1);
to_vector(par_betaINT) ~ normal(0,100);
to_vector(par_betaLAKEMONTH) ~ normal(0,1);
to_vector(par_betaLAKEDAY) ~ normal(0,1);
y ~ normal(mu, si);
surf_wtemps_y ~ normal(surf_wtemps_mu, surf_wtemps_si);
for (i in 1:wind_spds_N)
  wind_spds_y[i] ~ normal(wind_spds_mu[i], varcomp[wind_spds_lake[i],9])
T[0,];
theta ~ beta(5,5);
for (n in 1:par_N)
  target += log_mix(theta_N[n], normal_lpdf(par_y[n] | par_mu[n,1],
                 varcomp[par_lake[n],12]), normal_lpdf(par_y[n] | par_mu[n,2],
                 varcomp[par_lake[n],12]));
"