

Package ‘sdmTMB’

February 29, 2024

Type Package

Title Spatial and Spatiotemporal SPDE-Based GLMMs with 'TMB'

Version 0.4.3

Description Implements spatial and spatiotemporal GLMMs (Generalized Linear Mixed Effect Models) using 'TMB', 'fmesher', and the SPDE (Stochastic Partial Differential Equation) Gaussian Markov random field approximation to Gaussian random fields. One common application is for spatially explicit species distribution models (SDMs).
See Anderson et al. (2022) <[doi:10.1101/2022.03.24.485545](https://doi.org/10.1101/2022.03.24.485545)>.

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URL <https://pbs-assess.github.io/sdmTMB/>,
<https://github.com/pbs-assess/sdmTMB>

BugReports <https://github.com/pbs-assess/sdmTMB/issues>

Depends R (>= 3.5.0)

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add_utm_columns	<i>Add UTM coordinates to a data frame</i>
-----------------	--

Description

Add UTM (Universal Transverse Mercator) coordinates to a data frame. This is useful since geo-statistical modeling should generally be performed in an equal-distance projection. You can do this yourself separately with the [sf::st_as_sf\(\)](#), [sf::st_transform\(\)](#), and [sf::st_coordinates\(\)](#) functions in the **sf** package.

Usage

```
add_utm_columns(
  dat,
  ll_names = c("longitude", "latitude"),
  ll_crs = 4326,
  utm_names = c("X", "Y"),
  utm_crs = get_crs(dat, ll_names),
  units = c("km", "m")
)

get_crs(dat, ll_names = c("longitude", "latitude"))
```

Arguments

<code>dat</code>	Data frame that contains longitude and latitude columns.
<code>ll_names</code>	Longitude and latitude column names. Note the order.
<code>ll_crs</code>	Input CRS value for <code>ll_names</code> .
<code>utm_names</code>	Output column names for the UTM columns.
<code>utm_crs</code>	Output CRS value for the UTM zone; tries to detect with <code>get_crs()</code> but can be specified manually.
<code>units</code>	UTM units.

Details

Note that longitudes west of the prime meridian should be encoded as running from -180 to 0 degrees.

You may wish to work in km's rather than the standard UTM meters so that the range parameter estimate is not too small, which can cause computational issues. This depends on the the scale of your data.

Value

A copy of the input data frame with new columns for UTM coordinates.

Examples

```
d <- data.frame(lat = c(52.1, 53.4), lon = c(-130.0, -131.4))
get_crs(d, c("lon", "lat"))
add_utm_columns(d, c("lon", "lat"))
```

Effect.sdmTMB	<i>Calculate effects</i>
---------------	--------------------------

Description

Used by effects package

Usage

```
Effect.sdmTMB(focal.predictors, mod, ...)
```

Arguments

<code>focal.predictors</code>	a character vector of one or more predictors in the model in any order.
<code>mod</code>	a regression model object. If no specific method exists for the class of <code>mod</code> , <code>Effect.default</code> will be called.
<code>...</code>	arguments to be passed down.

Value

Output from `effects::effect()`. Can then be plotted with with associated `plot()` method.

Examples

```
fit <- sdmTMB(present ~ depth_scaled, data = pcod_2011, family = binomial(),
  spatial = "off")
effects::effect("depth_scaled", fit)
plot(effects::effect("depth_scaled", fit))
```

emmeans.sdmTMB	<i>Estimated marginal means with the emmeans package with sdmTMB</i>
----------------	--

Description

Methods for using the **emmeans** package with **sdmTMB**. The **emmeans** package computes estimated marginal means for the fixed effects.

References

<https://aosmith.rbind.io/2019/03/25/getting-started-with-emmeans/>

Examples

```
mesh <- make_mesh(pcod_2011, c("X", "Y"), cutoff = 20)
fit <- sdmTMB(
  present ~ as.factor(year),
  data = pcod_2011, mesh = mesh,
  family = binomial()
)
fit
emmeans::emmeans(fit, ~ year)
emmeans::emmeans(fit, pairwise ~ year)
emmeans::emmeans(fit, pairwise ~ year, type = "response")
emmeans::emmeans(fit, pairwise ~ year, adjust = "none")

e <- emmeans::emmeans(fit, ~ year)
plot(e)

e <- emmeans::emmeans(fit, pairwise ~ year)
confint(e)
summary(e, infer = TRUE)
as.data.frame(e)

# interaction of factor with continuous predictor:
fit2 <- sdmTMB(
```

```

present ~ depth_scaled * as.factor(year),
data = pcod_2011, mesh = mesh,
family = binomial()
)
fit2
# slopes for each level:
emmeans::emtrends(fit2, ~ year, var = "depth_scaled")
# test difference in slopes:
emmeans::emtrends(fit2, pairwise ~ year, var = "depth_scaled")
emmeans::emmip(fit2, year ~ depth_scaled,
  at = list(depth_scaled = seq(-2.5, 2.5, length.out = 50)), CIs = TRUE)

```

get_index

*Extract a relative biomass/abundance index or a center of gravity***Description**

Extract a relative biomass/abundance index or a center of gravity

Usage

```

get_index(
  obj,
  bias_correct = FALSE,
  level = 0.95,
  area = 1,
  silent = TRUE,
  ...
)

get_cog(
  obj,
  bias_correct = FALSE,
  level = 0.95,
  format = c("long", "wide"),
  area = 1,
  silent = TRUE,
  ...
)

```

Arguments

obj	Output from <code>predict.sdmTMB()</code> with <code>return_tmb_object = TRUE</code> .
bias_correct	Should bias correction be implemented <code>TMB::sdreport()</code> ?
level	The confidence level.
area	Grid cell area. A vector of length newdata from <code>predict.sdmTMB()</code> or a value of length 1, which will be repeated internally to match.

silent	Silent?
...	Passed to <code>TMB::sdreport()</code> .
format	Long or wide.

Value

For `get_index()`: A data frame with a columns for time, estimate, lower and upper confidence intervals, log estimate, and standard error of the log estimate.

For `get_cog()`: A data frame with a columns for time, estimate (center of gravity in x and y coordinates), lower and upper confidence intervals, and standard error of center of gravity coordinates.

References

Geostatistical random-field model-based indices of abundance (along with many newer papers):

Shelton, A.O., Thorson, J.T., Ward, E.J., and Feist, B.E. 2014. Spatial semiparametric models improve estimates of species abundance and distribution. *Canadian Journal of Fisheries and Aquatic Sciences* 71(11): 1655–1666. doi:[10.1139/cjfas20130508](https://doi.org/10.1139/cjfas20130508)

Thorson, J.T., Shelton, A.O., Ward, E.J., and Skaug, H.J. 2015. Geostatistical delta-generalized linear mixed models improve precision for estimated abundance indices for West Coast groundfishes. *ICES J. Mar. Sci.* 72(5): 1297–1310. doi:[10.1093/icesjms/fsu243](https://doi.org/10.1093/icesjms/fsu243)

Geostatistical model-based centre of gravity:

Thorson, J.T., Pinsky, M.L., and Ward, E.J. 2016. Model-based inference for estimating shifts in species distribution, area occupied and centre of gravity. *Methods Ecol Evol* 7(8): 990–1002. doi:[10.1111/2041210X.12567](https://doi.org/10.1111/2041210X.12567)

Bias correction:

Thorson, J.T., and Kristensen, K. 2016. Implementing a generic method for bias correction in statistical models using random effects, with spatial and population dynamics examples. *Fisheries Research* 175: 66–74. doi:[10.1016/j.fishres.2015.11.016](https://doi.org/10.1016/j.fishres.2015.11.016)

See Also

[get_index_sims\(\)](#)

Examples

```
# Use a small number of knots for this example to make it fast:
pcod_spde <- make_mesh(pcod, c("X", "Y"), n_knots = 60, type = "kmeans")
m <- sdmTMB(
  data = pcod,
  formula = density ~ 0 + as.factor(year),
  time = "year", mesh = pcod_spde, family = tweedie(link = "log")
)

# make prediction grid:
nd <- replicate_df(qcs_grid, "year", unique(pcod$year))

# Note `return_tmb_object = TRUE` and the prediction grid:
```

```

predictions <- predict(m, newdata = nd, return_tmb_object = TRUE)
ind <- get_index(predictions)

if (require("ggplot2", quietly = TRUE)) {
  ggplot(ind, aes(year, est)) + geom_line() +
    geom_ribbon(aes(ymin = lwr, ymax = upr), alpha = 0.4)
}

cog <- get_cog(predictions)
cog

```

get_index_sims	<i>Calculate a population index via simulation from the joint precision matrix</i>
----------------	--

Description

[Experimental]

Calculate a population index via simulation from the joint precision matrix. Compared to [get_index\(\)](#), this version can be faster if bias correction was turned on in [get_index\(\)](#) while being approximately equivalent. **This is an experimental function.** This function usually works reasonably well, but we make no guarantees. It is recommended to use [get_index\(\)](#) with `bias_correct = TRUE` for final inference.

Usage

```

get_index_sims(
  obj,
  level = 0.95,
  return_sims = FALSE,
  area = rep(1, nrow(obj)),
  est_function = stats::median,
  area_function = function(x, area) x + log(area),
  agg_function = function(x) sum(exp(x))
)

```

Arguments

obj	predict.sdmTMB() output with <code>nsim > 0</code> .
level	The confidence level.
return_sims	Logical. Return simulation draws? The default (FALSE) is a quantile summary of those simulation draws.
area	A vector of grid cell/polygon areas for each year-grid cell (row of data) in obj. Adjust this if cells are not of unit area or not all the same area (e.g., some cells are partially over land/water). Note that the area vector is added as <code>log(area)</code>

	to the raw values in obj. In other words, the function assumes a log link, which typically makes sense.
est_function	Function to summarize the estimate (the expected value). <code>mean()</code> would be an alternative to <code>median()</code> .
area_function	Function to apply area weighting. Assuming a log link, the function(x, area) $x + \log(\text{area})$ default makes sense. If in natural space, function(x, area) $x * \text{area}$ makes sense.
agg_function	Function to aggregate samples within each time slice. Assuming a log link, the function(x) <code>sum(exp(x))</code> default makes sense. If in natural space, function(x) <code>sum(x)</code> makes sense.

Details

Can also be used to produce an index from a model fit with **tmbstan**.

This function does nothing more than summarize and reshape the matrix of simulation draws into a data frame.

Value

A data frame. If `return_sims = FALSE`:

- name of column (e.g. year) that was supplied to `sdmTMB()` time argument
- est: estimate
- lwr: lower confidence interval value
- upr: upper confidence interval value
- log_est: log estimate
- se: standard error on the log estimate

If `return_sims = TRUE`, samples from the index values in a long-format data frame:

- name of column (e.g. year) that was supplied to `sdmTMB()` time argument
- .value: sample value
- .iteration: sample number

See Also

[get_index\(\)](#)

Examples

```
m <- sdmTMB(density ~ 0 + as.factor(year),
  data = pcod_2011, mesh = pcod_mesh_2011, family = tweedie(link = "log"),
  time = "year"
)
qcs_grid_2011 <- replicate_df(qcs_grid, "year", unique(pcod_2011$year))
p <- predict(m, newdata = qcs_grid_2011, nsim = 100)
x <- get_index_sims(p)
```

```

x_sims <- get_index_sims(p, return_sims = TRUE)

if (require("ggplot2", quietly = TRUE)) {
  ggplot(x, aes(year, est, ymin = lwr, ymax = upr)) +
    geom_line() +
    geom_ribbon(alpha = 0.4)
  ggplot(x_sims, aes(as.factor(year), .value)) +
    geom_violin()
}

# Demo custom functions if working in natural space:
ind <- get_index_sims(
  exp(p),
  agg_function = function(x) sum(x),
  area_function = function(x, area) x * area
)

```

get_pars

Get TMB parameter list

Description

Get TMB parameter list

Usage

```
get_pars(object)
```

Arguments

object Fit from [sdmTMB\(\)](#)

Value

A named list of parameter values

Examples

```

fit <- sdmTMB(present ~ 1, data = pcod_2011, family = binomial(), spatial = "off")
pars <- get_pars(fit)
names(pars)

```

make_mesh	<i>Construct an SPDE mesh for sdmTMB</i>
-----------	--

Description

Construct an SPDE mesh for use with sdmTMB.

Usage

```
make_mesh(
  data,
  xy_cols,
  type = c("kmeans", "cutoff", "cutoff_search"),
  cutoff,
  n_knots,
  seed = 42,
  mesh = NULL,
  fmesher_func = fmesher::fm_rcdt_2d_inla,
  convex = NULL,
  concave = convex,
  ...
)

## S3 method for class 'sdmTMBmesh'
plot(x, ...)
```

Arguments

data	A data frame.
xy_cols	A character vector of x and y column names contained in data. These should likely be in an equal distance projection. For a helper function to convert to UTM, see add_utm_columns() .
type	Method to create the mesh. Also see mesh argument to supply your own mesh.
cutoff	An optional cutoff if type is "cutoff". The minimum allowed triangle edge length.
n_knots	The number of desired knots if type is not "cutoff".
seed	Random seed. Affects stats::kmeans() determination of knot locations if type = "kmeans".
mesh	An optional mesh created via fmesher instead of using the above convenience options.
fmesher_func	Which fmesher function to use. Options include fmesher::fm_rcdt_2d_inla() and fmesher::fm_mesh_2d_inla() along with version without the <code>_inla</code> on the end.
convex	If specified, passed to fmesher::fm_nonconvex_hull() . Distance to extend non-convex hull from data.

concave	If specified, passed to <code>fmesher::fm_nonconvex_hull()</code> . "Minimum allowed reentrant curvature". Defaults to convex.
...	Passed to <code>graphics::plot()</code> .
x	Output from <code>make_mesh()</code> .

Value

`make_mesh()`: A list of class `sdmTMBmesh`. The element `mesh` is the output from `fmesher_func` (default is `fmesher::fm_mesh_2d_inla()`). See `mesh$mesh$n` for the number of vertices.

`plot.sdmTMBmesh()`: A plot of the mesh and data points. If **ggplot2** is installed, a **ggplot2** object is returned, otherwise a base graphics R plot is returned. To make your own, pass `your_mesh$mesh` to `inlabru::gg()`.

Examples

```
# Extremely simple cutoff:
mesh <- make_mesh(pcod, c("X", "Y"), cutoff = 5, type = "cutoff")
plot(mesh)

# Using a k-means algorithm to assign vertices:
mesh <- make_mesh(pcod, c("X", "Y"), n_knots = 50, type = "kmeans")
plot(mesh)

# But, it's better to develop more tailored meshes:

# Pass arguments via '...' to fmesher::fm_mesh_2d_inla():
mesh <- make_mesh(
  pcod, c("X", "Y"),
  fmesher_func = fmesher::fm_mesh_2d_inla,
  cutoff = 8, # minimum triangle edge length
  max.edge = c(20, 40), # inner and outer max triangle lengths
  offset = c(5, 40) # inner and outer border widths
)
plot(mesh)

# Or define a mesh directly with fmesher (formerly in INLA):
inla_mesh <- fmesher::fm_mesh_2d_inla(
  loc = cbind(pcod$X, pcod$Y), # coordinates
  max.edge = c(25, 50), # max triangle edge length; inner and outer meshes
  offset = c(5, 25), # inner and outer border widths
  cutoff = 5 # minimum triangle edge length
)
mesh <- make_mesh(pcod, c("X", "Y"), mesh = inla_mesh)
plot(mesh)
```

pcod	<i>Example fish survey data</i>
------	---------------------------------

Description

Various fish survey datasets.

Usage

pcod
pcod_2011
pcod_mesh_2011
qcs_grid
dogfish
yelloweye
hbll_s_grid
wcvi_grid

Format

pcod: Trawl survey data for Pacific Cod in Queen Charlotte Sound. A data frame.
pcod_2011: A version of pcod for years 2011 and after (smaller for speed). A data frame.
pcod_mesh_2011: A mesh pre-built for pcod_2011 for examples. A list of class sdmTMBmesh.
qcs_grid A 2x2km prediction grid for Queen Charlotte Sound. A data frame.
dogfish: Trawl survey data for Pacific Spiny Dogfish on West Coast Vancouver Island. A data frame.
yelloweye: Survey data for Yelloweye Rockfish from the Hard Bottom Longline Survey (South) off West Coast Vancouver Island.
hbll_s_grid: A survey domain grid to go with yelloweye. A data frame.
wcvi_grid: A survey domain grid to go with dogfish. A data frame.

plot_anisotropy	<i>Plot anisotropy from an sdmTMB model</i>
-----------------	---

Description

Anisotropy is when spatial correlation is directionally dependent. In `sdmTMB()`, the default spatial correlation is isotropic, but anisotropy can be enabled with `anisotropy = TRUE`. These plotting functions help visualize that estimated anisotropy.

Usage

```
plot_anisotropy(object, return_data = FALSE)
```

```
plot_anisotropy2(object, model = 1)
```

Arguments

<code>object</code>	An object from <code>sdmTMB()</code> .
<code>return_data</code>	Logical. Return a data frame? <code>plot_anisotropy()</code> only.
<code>model</code>	Which model if a delta model (only for <code>plot_anisotropy2()</code> ; <code>plot_anisotropy()</code> always plots both).

Value

`plot_anisotropy()`: One or more ellipses illustrating the estimated anisotropy. The ellipses are centered at coordinates of zero in the space of the X-Y coordinates being modeled. The ellipses show the spatial and/or spatiotemporal range (distance at which correlation is effectively independent) in any direction from zero. Uses **ggplot2**. If anisotropy was turned off when fitting the model, NULL is returned instead of a **ggplot2** object.

`plot_anisotropy2()`: A plot of eigenvectors illustrating the estimated anisotropy. A list of the plotted data is invisibly returned. Uses base graphics. If anisotropy was turned off when fitting the model, NULL is returned instead of a plot object.

References

Code adapted from VAST R package

Examples

```
mesh <- make_mesh(pcod_2011, c("X", "Y"), n_knots = 80, type = "kmeans")
fit <- sdmTMB(
  data = pcod_2011,
  formula = density ~ 1,
  mesh = mesh,
  family = tweedie(),
  share_range = FALSE,
```

```

    time = "year",
    anisotropy = TRUE #<
)
plot_anisotropy(fit)
plot_anisotropy2(fit)

```

plot_pc_matern	<i>Plot PC Matérn priors</i>
----------------	------------------------------

Description

Plot PC Matérn priors

Usage

```

plot_pc_matern(
  range_gt,
  sigma_lt,
  range_prob = 0.05,
  sigma_prob = 0.05,
  range_lims = c(range_gt * 0.1, range_gt * 10),
  sigma_lims = c(0, sigma_lt * 2),
  plot = TRUE
)

```

Arguments

range_gt	A value one expects the spatial or spatiotemporal range is greater than with 1 - range_prob probability.
sigma_lt	A value one expects the spatial or spatiotemporal marginal standard deviation (sigma_0 or sigma_E internally) is less than with 1 - sigma_prob probability.
range_prob	Probability. See description for range_gt.
sigma_prob	Probability. See description for sigma_lt.
range_lims	Plot range variable limits.
sigma_lims	Plot sigma variable limits.
plot	Logical controlling whether plot is drawn (defaults to TRUE).

Value

A plot from [image\(\)](#). Invisibly returns the underlying matrix data. The rows are the sigmas. The columns are the ranges. Column and row names are provided.

See Also

[pc_matern\(\)](#)

Examples

```
plot_pc_matern(range_gt = 5, sigma_lt = 1)
plot_pc_matern(range_gt = 5, sigma_lt = 10)
plot_pc_matern(range_gt = 5, sigma_lt = 1, sigma_prob = 0.2)
plot_pc_matern(range_gt = 5, sigma_lt = 1, range_prob = 0.2)
```

plot_smooth

*Plot a smooth term from an sdmTMB model***Description**

Deprecated: use `visreg::visreg()`. See [visreg_delta\(\)](#) for examples.

Usage

```
plot_smooth(
  object,
  select = 1,
  n = 100,
  level = 0.95,
  ggplot = FALSE,
  rug = TRUE,
  return_data = FALSE
)
```

Arguments

<code>object</code>	An sdmTMB() model.
<code>select</code>	The smoother term to plot.
<code>n</code>	The number of equally spaced points to evaluate the smoother along.
<code>level</code>	The confidence level.
<code>ggplot</code>	Logical: use the ggplot2 package?
<code>rug</code>	Logical: add rug lines along the lower axis?
<code>return_data</code>	Logical: return the predicted data instead of making a plot?

Details

Note:

- Any numeric predictor is set to its mean
- Any factor predictor is set to its first-level value
- The time element (if present) is set to its minimum value
- The x and y coordinates are set to their mean values

Value

A plot of a smoother term.

Examples

```
d <- subset(pcod, year >= 2000 & density > 0)
pcod_spde <- make_mesh(d, c("X", "Y"), cutoff = 30)
m <- sdmTMB(
  data = d,
  formula = log(density) ~ s(depth_scaled) + s(year, k = 5),
  mesh = pcod_spde
)
plot_smooth(m)
```

predict.sdmTMB	<i>Predict from an sdmTMB model</i>
----------------	-------------------------------------

Description

Make predictions from an **sdmTMB** model; can predict on the original or new data.

Usage

```
## S3 method for class 'sdmTMB'
predict(
  object,
  newdata = NULL,
  type = c("link", "response"),
  se_fit = FALSE,
  re_form = NULL,
  re_form_iid = NULL,
  nsim = 0,
  sims_var = "est",
  model = c(NA, 1, 2),
  offset = NULL,
  mcmc_samples = NULL,
  return_tmb_object = FALSE,
  return_tmb_report = FALSE,
  return_tmb_data = FALSE,
  tmbstan_model = deprecated(),
  sims = deprecated(),
  area = deprecated(),
  ...
)
```

Arguments

object	A model fitted with <code>sdmTMB()</code> .
newdata	A data frame to make predictions on. This should be a data frame with the same predictor columns as in the fitted data and a time column (if this is a spatiotemporal model) with the same name as in the fitted data.
type	Should the est column be in link (default) or response space?
se_fit	Should standard errors on predictions at the new locations given by newdata be calculated? Warning: the current implementation can be slow for large data sets or high-resolution projections unless <code>re_form = NA</code> (omitting random fields). A faster option to approximate point-wise uncertainty is to use the <code>nsim</code> argument.
re_form	NULL to specify including all spatial/spatiotemporal random effects in predictions. <code>~0</code> or NA for population-level predictions. Likely to be used in conjunction with <code>se_fit = TRUE</code> . This does not affect <code>get_index()</code> calculations.
re_form_iid	NULL to specify including all random intercepts in the predictions. <code>~0</code> or NA for population-level predictions. No other options (e.g., some but not all random intercepts) are implemented yet. Only affects predictions with newdata. This <i>does</i> affect <code>get_index()</code> .
nsim	If > 0 , simulate from the joint precision matrix with <code>nsim</code> draws. Returns a matrix of <code>nrow(data)</code> by <code>nsim</code> representing the estimates of the linear predictor (i.e., in link space). Can be useful for deriving uncertainty on predictions (e.g., <code>apply(x, 1, sd)</code>) or propagating uncertainty. This is currently the fastest way to characterize uncertainty on predictions in space with <code>sdmTMB</code> .
sims_var	Experimental: Which TMB reported variable from the model should be extracted from the joint precision matrix simulation draws? Defaults to link-space predictions. Options include: "omega_s", "zeta_s", "epsilon_st", and "est_rf" (as described below). Other options will be passed verbatim.
model	Type of prediction if a delta/hurdle model <i>and</i> <code>nsim > 0</code> or <code>mcmc_samples</code> is supplied: NA returns the combined prediction from both components on the link scale for the positive component; 1 or 2 return the first or second model component only on the link or response scale depending on the argument type. For regular prediction from delta models, both sets of predictions are returned.
offset	A numeric vector of optional offset values. If left at default NULL, the offset is implicitly left at 0.
mcmc_samples	See <code>extract_mcmc()</code> in the <code>sdmTMBextra</code> package for more details and the Bayesian vignette . If specified, the predict function will return a matrix of a similar form as if <code>nsim > 0</code> but representing Bayesian posterior samples from the Stan model.
return_tmb_object	Logical. If TRUE, will include the TMB object in a list format output. Necessary for the <code>get_index()</code> or <code>get_cog()</code> functions.
return_tmb_report	Logical: return the output from the TMB report? For regular prediction, this is all the reported variables at the MLE parameter values. For <code>nsim > 0</code> or when <code>mcmc_samples</code> is supplied, this is a list where each element is a sample and the contents of each element is the output of the report for that sample.

return_tmb_data	Logical: return formatted data for TMB? Used internally.
tmbstan_model	Deprecated. See mcmc_samples.
sims	Deprecated. Please use nsim instead.
area	Deprecated. Please use area in get_index() .
...	Not implemented.

Value

If return_tmb_object = FALSE (and nsim = 0 and mcmc_samples = NULL):

A data frame:

- est: Estimate in link space (everything is in link space)
- est_non_rf: Estimate from everything that isn't a random field
- est_rf: Estimate from all random fields combined
- omega_s: Spatial (intercept) random field that is constant through time
- zeta_s: Spatial slope random field
- epsilon_st: Spatiotemporal (intercept) random fields, could be off (zero), IID, AR1, or random walk

If return_tmb_object = TRUE (and nsim = 0 and mcmc_samples = NULL):

A list:

- data: The data frame described above
- report: The TMB report on parameter values
- obj: The TMB object returned from the prediction run
- fit_obj: The original TMB model object

In this case, you likely only need the data element as an end user. The other elements are included for other functions.

If nsim > 0 or mcmc_samples is not NULL:

A matrix:

- Columns represent samples
- Rows represent predictions with one row per row of newdata

Examples

```
d <- pcod_2011
mesh <- make_mesh(d, c("X", "Y"), cutoff = 30) # a coarse mesh for example speed
m <- sdmTMB(
  data = d, formula = density ~ 0 + as.factor(year) + depth_scaled + depth_scaled2,
  time = "year", mesh = mesh, family = tweedie(link = "log")
)
```

```

# Predictions at original data locations -----

predictions <- predict(m)
head(predictions)

predictions$resids <- residuals(m) # randomized quantile residuals

library(ggplot2)
ggplot(predictions, aes(X, Y, col = resids)) + scale_colour_gradient2() +
  geom_point() + facet_wrap(~year)
hist(predictions$resids)
qqnorm(predictions$resids);abline(a = 0, b = 1)

# Predictions onto new data -----

qcs_grid_2011 <- replicate_df(qcs_grid, "year", unique(pcod_2011$year))
predictions <- predict(m, newdata = qcs_grid_2011)

# A short function for plotting our predictions:
plot_map <- function(dat, column = est) {
  ggplot(dat, aes(X, Y, fill = {{ column }})) +
    geom_raster() +
    facet_wrap(~year) +
    coord_fixed()
}

plot_map(predictions, exp(est)) +
  scale_fill_viridis_c(trans = "sqrt") +
  ggtitle("Prediction (fixed effects + all random effects)")

plot_map(predictions, exp(est_non_rf)) +
  ggtitle("Prediction (fixed effects and any time-varying effects)") +
  scale_fill_viridis_c(trans = "sqrt")

plot_map(predictions, est_rf) +
  ggtitle("All random field estimates") +
  scale_fill_gradient2()

plot_map(predictions, omega_s) +
  ggtitle("Spatial random effects only") +
  scale_fill_gradient2()

plot_map(predictions, epsilon_st) +
  ggtitle("Spatiotemporal random effects only") +
  scale_fill_gradient2()

# Visualizing a marginal effect -----

# See the visreg package or the ggeffects::ggeffect() or
# ggeffects::ggpredict() functions
# To do this manually:

```

```

nd <- data.frame(depth_scaled =
  seq(min(d$depth_scaled), max(d$depth_scaled), length.out = 100))
nd$depth_scaled2 <- nd$depth_scaled^2

# Because this is a spatiotemporal model, you'll need at least one time
# element. If time isn't also a fixed effect then it doesn't matter what you pick:
nd$year <- 2011L # L: integer to match original data
p <- predict(m, newdata = nd, se_fit = TRUE, re_form = NA)
ggplot(p, aes(depth_scaled, exp(est),
  ymin = exp(est - 1.96 * est_se), ymax = exp(est + 1.96 * est_se))) +
  geom_line() + geom_ribbon(alpha = 0.4)

# Plotting marginal effect of a spline -----

m_gam <- sdmTMB(
  data = d, formula = density ~ 0 + as.factor(year) + s(depth_scaled, k = 5),
  time = "year", mesh = mesh, family = tweedie(link = "log")
)
if (require("visreg", quietly = TRUE)) {
  visreg::visreg(m_gam, "depth_scaled")
}

# or manually:
nd <- data.frame(depth_scaled =
  seq(min(d$depth_scaled), max(d$depth_scaled), length.out = 100))
nd$year <- 2011L
p <- predict(m_gam, newdata = nd, se_fit = TRUE, re_form = NA)
ggplot(p, aes(depth_scaled, exp(est),
  ymin = exp(est - 1.96 * est_se), ymax = exp(est + 1.96 * est_se))) +
  geom_line() + geom_ribbon(alpha = 0.4)

# Forecasting -----
mesh <- make_mesh(d, c("X", "Y"), cutoff = 15)

unique(d$year)
m <- sdmTMB(
  data = d, formula = density ~ 1,
  spatiotemporal = "AR1", # using an AR1 to have something to forecast with
  extra_time = 2019L, # `L` for integer to match our data
  spatial = "off",
  time = "year", mesh = mesh, family = tweedie(link = "log")
)

# Add a year to our grid:
grid2019 <- qcs_grid_2011[qcs_grid_2011$year == max(qcs_grid_2011$year), ]
grid2019$year <- 2019L # `L` because `year` is an integer in the data
qcsgrid_forecast <- rbind(qcs_grid_2011, grid2019)

predictions <- predict(m, newdata = qcsgrid_forecast)
plot_map(predictions, exp(est)) +
  scale_fill_viridis_c(trans = "log10")
plot_map(predictions, epsilon_st) +

```

```

scale_fill_gradient2()

# Estimating local trends -----

d <- pcod
d$year_scaled <- as.numeric(scale(d$year))
mesh <- make_mesh(pcod, c("X", "Y"), cutoff = 25)
m <- sdmTMB(data = d, formula = density ~ depth_scaled + depth_scaled2,
  mesh = mesh, family = tweedie(link = "log"),
  spatial_varying = ~ 0 + year_scaled, time = "year", spatiotemporal = "off")
nd <- replicate_df(qcs_grid, "year", unique(pcod$year))
nd$year_scaled <- (nd$year - mean(d$year)) / sd(d$year)
p <- predict(m, newdata = nd)

plot_map(subset(p, year == 2003), zeta_s_year_scaled) + # pick any year
  ggtitle("Spatial slopes") +
  scale_fill_gradient2()

plot_map(p, est_rf) +
  ggtitle("Random field estimates") +
  scale_fill_gradient2()

plot_map(p, exp(est_non_rf)) +
  ggtitle("Prediction (fixed effects only)") +
  scale_fill_viridis_c(trans = "sqrt")

plot_map(p, exp(est)) +
  ggtitle("Prediction (fixed effects + all random effects)") +
  scale_fill_viridis_c(trans = "sqrt")

```

replicate_df

Replicate a prediction data frame over time

Description

Useful for replicating prediction grids across time slices used in model fitting.

Usage

```
replicate_df(dat, time_name, time_values)
```

Arguments

dat	Data frame.
time_name	Name of time column in output.
time_values	Time values to replicate dat over.

Value

A data frame replicated over `time_values` with a new column based on `time_name`.

Examples

```
df <- data.frame(variable = c("a", "b"))
replicate_df(df, time_name = "year", time_values = 1:3)

head(qcs_grid)
nd <- replicate_df(qcs_grid, "year", unique(pcod$year))
head(nd)
table(nd$year)
```

residuals.sdmTMB

Residuals method for sdmTMB models

Description

See the residual-checking vignette: `browseVignettes("sdmTMB")` or [on the documentation site](#).
 See notes about types of residuals in 'Details' section below.

Usage

```
## S3 method for class 'sdmTMB'
residuals(
  object,
  type = c("mle-laplace", "mle-mcmc", "mvn-laplace", "response", "pearson"),
  model = c(1, 2),
  mcmc_samples = NULL,
  qres_func = NULL,
  ...
)
```

Arguments

<code>object</code>	An <code>sdmTMB()</code> model
<code>type</code>	Type of residual. See details.
<code>model</code>	Which delta/hurdle model component?
<code>mcmc_samples</code>	A vector of MCMC samples of the linear predictor in link space. See the sdmTMBextra package.
<code>qres_func</code>	A custom quantile residuals function. Function should take the arguments <code>object</code> , <code>y</code> , <code>mu</code> , ... and return a vector of length <code>length(y)</code> .
...	Passed to residual function. Only <code>n</code> works for binomial.

Details

Types of residuals currently supported:

"mle-laplace" refers to randomized quantile residuals (Dunn & Smyth 1996), which are also known as probability integral transform (PIT) residuals (Smith 1985). Under model assumptions, these should be distributed as standard normal with the following caveat: the Laplace approximation used for the latent/random effects can cause these residuals to deviate from the standard normal assumption even if the model is consistent with the data (Thygesen et al. 2017). Therefore, **these residuals are fast to calculate but can be unreliable.**

"mle-mcmc" refers to randomized quantile residuals where the fixed effects are fixed at their MLE (maximum likelihood estimate) values and the random effects are sampled with MCMC via tmbstan/Stan. As proposed in Thygesen et al. (2017) and used in Rufener et al. (2021). Under model assumptions, these should be distributed as standard normal. **These residuals are theoretically preferred over the regular Laplace approximated randomized-quantile residuals, but will be considerably slower to calculate.**

See the **sdmTMBextra** package for the function `predict_mle_mcmc()`, which can generate the MCMC samples to pass to the `mcmc_samples` argument. Ideally MCMC is run until convergence and then the last iteration can be used for residuals. MCMC samples are defined by `mcmc_iter - mcmc_warmup`. The Stan model can be printed with `print_stan_model = TRUE` to check. The defaults may not be sufficient for many models.

"mvn-laplace" is the same as "mle-laplace" except the parameters are based on simulations drawn from the assumed multivariate normal distribution (using the joint precision matrix).

"response" refers to response residuals: observed minus predicted.

Value

A vector of residuals.

References

- Dunn, P.K. & Smyth, G.K. (1996). Randomized Quantile Residuals. *Journal of Computational and Graphical Statistics*, 5, 236–244.
- Smith, J.Q. (1985). Diagnostic checks of non-standard time series models. *Journal of Forecasting*, 4, 283–291.
- Rufener, M.-C., Kristensen, K., Nielsen, J.R., and Bastardie, F. 2021. Bridging the gap between commercial fisheries and survey data to model the spatiotemporal dynamics of marine species. *Ecological Applications*. e02453. [doi:10.1002/eap.2453](https://doi.org/10.1002/eap.2453)
- Thygesen, U.H., Albertsen, C.M., Berg, C.W., Kristensen, K., and Nielsen, A. 2017. Validation of ecological state space models using the Laplace approximation. *Environ Ecol Stat* 24(2): 317–339. [doi:10.1007/s1065101703724](https://doi.org/10.1007/s1065101703724)

Examples

```
mesh <- make_mesh(pcod_2011, c("X", "Y"), cutoff = 10)
fit <- sdmTMB(
  present ~ as.factor(year) + poly(depth, 3),
```



```

    data = pcod_2011, mesh = mesh,
    family = binomial()
  )

  # response residuals will be not be normally distributed unless
  # the family is Gaussian:
  r0 <- residuals(fit, type = "response")
  qqnorm(r0)
  qqline(r0)

  # quick but can have issues because of Laplace approximation:
  r1 <- residuals(fit, type = "mle-laplace")
  qqnorm(r1)
  qqline(r1)

  # see also "mle-mcmc" residuals with the help of the sdmTMBextra package

```

run_extra_optimization

Run extra optimization on an already fitted object

Description

[Experimental]

Usage

```
run_extra_optimization(object, nlminb_loops = 0, newton_loops = 1)
```

Arguments

object	An object from <code>sdmTMB()</code> .
nlminb_loops	How many extra times to run <code>stats::nlminb()</code> optimization. Sometimes restarting the optimizer at the previous best values aids convergence.
newton_loops	How many extra Newton optimization loops to try with <code>stats::optimHess()</code> . Sometimes aids convergence.

Value

An updated model fit of class `sdmTMB`.

Examples

```

# Run extra optimization steps to help convergence:
# (Not typically needed)
fit <- sdmTMB(density ~ 0 + poly(depth, 2) + as.factor(year),
  data = pcod_2011, mesh = pcod_mesh_2011, family = tweedie())
fit_1 <- run_extra_optimization(fit, newton_loops = 1)
max(fit$gradients)
max(fit_1$gradients)

```

sanity

*Sanity check of an sdmTMB model***Description**

Sanity check of an sdmTMB model

Usage

```
sanity(object, big_sd_log10 = 2, gradient_thresh = 0.001, silent = FALSE)
```

Arguments

object	Fitted model from <code>sdmTMB()</code> .
big_sd_log10	Value to check size of standard errors against. A value of 2 would indicate that standard errors greater than 10^2 (i.e., 100) should be flagged.
gradient_thresh	Gradient threshold to issue warning.
silent	Logical: suppress messages? Useful to set to TRUE if running large numbers of models and just interested in returning sanity list objects.

Details

If object is NA, NULL, or of class "try-error", `sanity()` will return FALSE. This is to facilitate using `sanity()` on models with `try()` or `tryCatch()`. See the examples section.

Value

An invisible named list of checks.

Examples

```
fit <- sdmTMB(
  present ~ s(depth),
  data = pcod_2011, mesh = pcod_mesh_2011,
  family = binomial()
)
sanity(fit)

s <- sanity(fit)
s

# If fitting many models in a loop, you may want to wrap
# sdmTMB() in try() to handle errors. sanity() will take an object
# of class "try-error" and return FALSE.
# Here, we will use stop() to simulate a failed sdmTMB() fit:
failed_fit <- try(stop())
s2 <- sanity(failed_fit)
```

```
all(unlist(s))
all(unlist(s2))
```

sdmTMB

Fit a spatial or spatiotemporal GLMM with TMB

Description

Fit a spatial or spatiotemporal generalized linear mixed effects model (GLMM) with the TMB (Template Model Builder) R package and the SPDE (stochastic partial differential equation) approximation to Gaussian random fields.

Usage

```
sdmTMB(
  formula,
  data,
  mesh,
  time = NULL,
  family = gaussian(link = "identity"),
  spatial = c("on", "off"),
  spatiotemporal = c("iid", "ar1", "rw", "off"),
  share_range = TRUE,
  time_varying = NULL,
  time_varying_type = c("rw", "rw0", "ar1"),
  spatial_varying = NULL,
  weights = NULL,
  offset = NULL,
  extra_time = NULL,
  reml = FALSE,
  silent = TRUE,
  anisotropy = FALSE,
  control = sdmTMBcontrol(),
  priors = sdmTMBpriors(),
  knots = NULL,
  bayesian = FALSE,
  previous_fit = NULL,
  do_fit = TRUE,
  do_index = FALSE,
  predict_args = NULL,
  index_args = NULL,
  experimental = NULL
)
```

Arguments

formula	Model formula. IID random intercepts are possible using lme4 syntax, e.g., <code>+(1 g)</code> where <code>g</code> is a column of class character or factor representing groups. Penalized splines are possible via mgcv with <code>s()</code> . Optionally a list for delta (hurdle) models. See examples and details below.
data	A data frame.
mesh	An object from <code>make_mesh()</code> .
time	An optional time column name (as character). Can be left as <code>NULL</code> for a model with only spatial random fields; however, if the data are actually spatiotemporal and you wish to use <code>get_index()</code> or <code>get_cog()</code> downstream, supply the time argument.
family	The family and link. Supports <code>gaussian()</code> , <code>Gamma()</code> , <code>binomial()</code> , <code>poisson()</code> , <code>Beta()</code> , <code>nbinom2()</code> , <code>truncated_nbinom2()</code> , <code>nbinom1()</code> , <code>truncated_nbinom1()</code> , <code>censored_poisson()</code> , <code>gamma_mix()</code> , <code>lognormal_mix()</code> , <code>student()</code> , and <code>tweedie()</code> . Supports the delta/hurdle models: <code>delta_beta()</code> , <code>delta_gamma()</code> , <code>delta_gamma_mix()</code> , <code>delta_lognormal_mix()</code> , <code>delta_lognormal()</code> , and <code>delta_truncated_nbinom2()</code> . For binomial family options, see 'Binomial families' in the Details section below.
spatial	Estimate spatial random fields? Options are 'on' / 'off' or <code>TRUE</code> / <code>FALSE</code> . Optionally, a list for delta models, e.g. <code>list('on', 'off')</code> .
spatiotemporal	Estimate the spatiotemporal random fields as 'iid' (independent and identically distributed; default), stationary 'ar1' (first-order autoregressive), a random walk ('rw'), or fixed at 0 'off'. Will be set to 'off' if <code>time = NULL</code> . If a delta model, can be a list. E.g., <code>list('off', 'ar1')</code> . Note that the spatiotemporal standard deviation represents the marginal steady-state standard deviation of the process in the case of the AR1. I.e., it is scaled according to the correlation. See the TMB documentation . If the AR1 correlation coefficient (ρ) is estimated close to 1, say > 0.99 , then you may wish to switch to the random walk 'rw'. Capitalization is ignored. <code>TRUE</code> gets converted to 'iid' and <code>FALSE</code> gets converted to 'off'.
share_range	Logical: estimate a shared spatial and spatiotemporal range parameter (<code>TRUE</code> , default) or independent range parameters (<code>FALSE</code>). If a delta model, can be a list. E.g., <code>list(TRUE, FALSE)</code> .
time_varying	An optional one-sided formula describing covariates that should be modelled as a time-varying process. Set the type of process with <code>time_varying_type</code> . See the help for <code>time_varying_type</code> for warnings about modelling the first time step. Structure shared in delta models.
time_varying_type	Type of time-varying process to apply to <code>time_varying</code> formula. 'rw' indicates a random walk with the first time step estimated independently (included for legacy reasons), 'rw0' indicates a random walk with the first time step estimated with a mean-zero normal prior, 'ar1' indicates a stationary first-order autoregressive process with the first time step estimated with a mean-zero prior. In the case of 'rw', be careful not to include covariates (including the intercept) in both the main and time-varying formula since the first time step is estimated

independently. I.e., in this case, at least one should have ~ 0 or ~ -1 . Structure shared in delta models.

spatial_varying

An optional one-sided formula of coefficients that should vary in space as random fields. Note that you likely want to include a fixed effect for the same variable to improve interpretability since the random field is assumed to have a mean of 0. If a (scaled) time column is used, it will represent a local-time-trend model. See [doi:10.1111/ecog.05176](https://doi.org/10.1111/ecog.05176) and the [spatial trends vignette](#). Note this predictor should usually be centered to have mean zero and have a standard deviation of approximately 1. **The spatial intercept is controlled by the spatial argument**; therefore, include or exclude the spatial intercept by setting `spatial = 'on'` or `'off'`. The only time when it matters whether `spatial_varying` excludes an intercept is in the case of factor predictors. In this case, if `spatial_varying` excludes the intercept (~ 0 or ~ -1), you should set `spatial = 'off'` to match. Structure must be shared in delta models.

weights

A numeric vector representing optional likelihood weights for the conditional model. Implemented as in **glmmTMB**: weights do not have to sum to one and are not internally modified. Can also be used for trials with the binomial family; the `weights` argument needs to be a vector and not a name of the variable in the data frame. See the Details section below.

offset

A numeric vector representing the model offset *or* a character value representing the column name of the offset. In delta/hurdle models, this applies only to the positive component. Usually a log transformed variable.

extra_time

Optional extra time slices (e.g., years) to include for interpolation or forecasting with the predict function. See the Details section below.

reml

Logical: use REML (restricted maximum likelihood) estimation rather than maximum likelihood? Internally, this adds the fixed effects to the list of random effects to integrate over.

silent

Silent or include optimization details? Helpful to set to FALSE for models that take a while to fit.

anisotropy

Logical: allow for anisotropy (spatial correlation that is directionally dependent)? See [plot_anisotropy\(\)](#). Must be shared across delta models.

control

Optimization control options via [sdmTMBcontrol\(\)](#).

priors

Optional penalties/priors via [sdmTMBpriors\(\)](#). Must currently be shared across delta models.

knots

Optional named list containing knot values to be used for basis construction of smoothing terms. See [mgcv::gam\(\)](#) and [mgcv::gamm\(\)](#). E.g., `s(x, bs = 'cc', k = 4)`, `knots = list()`.

bayesian

Logical indicating if the model will be passed to **tmbstan**. If TRUE, Jacobian adjustments are applied to account for parameter transformations when priors are applied.

previous_fit

A previously fitted sdmTMB model to initialize the optimization with. Can greatly speed up fitting. Note that the model must be set up *exactly* the same way. However, the data and weights arguments can change, which can be useful for cross-validation.

do_fit

Fit the model (TRUE) or return the processed data without fitting (FALSE)?

do_index	Do index standardization calculations while fitting? Saves memory and time when working with large datasets or projection grids since the TMB object doesn't have to be rebuilt with <code>predict.sdmTMB()</code> and <code>get_index()</code> . If TRUE, then <code>predict_args</code> must have a <code>newdata</code> element supplied and <code>area</code> can be supplied to <code>index_args</code> . Most users can ignore this option. The fitted object can be passed directly to <code>get_index()</code> .
predict_args	A list of arguments to pass to <code>predict.sdmTMB()</code> if <code>do_index = TRUE</code> . Most users can ignore this option.
index_args	A list of arguments to pass to <code>get_index()</code> if <code>do_index = TRUE</code> . Currently, only <code>area</code> is supported. Bias correction can be done when calling <code>get_index()</code> on the resulting fitted object. Most users can ignore this option.
experimental	A named list for esoteric or in-development options. Here be dragons.

Details

Model description

See the [model description](#) vignette or the relevant appendix of the preprint on sdmTMB: [doi:10.1101/2022.03.24.485545](#)

Binomial families

Following the structure of `stats::glm()` and `glmmTMB`, a binomial family can be specified in one of 4 ways: (1) the response may be a factor (and the model classifies the first level versus all others), (2) the response may be binomial (0/1), (3) the response can be a matrix of form `cbind(success, failure)`, and (4) the response may be the observed proportions, and the 'weights' argument is used to specify the Binomial size (N) parameter (`prob ~ ..., weights = N`).

Smooth terms

Smooth terms can be included following GAMs (generalized additive models) using `+ s(x)`, which implements a smooth from `mgcv::s()`. `sdmTMB` uses penalized smooths, constructed via `mgcv::smooth2random()`. This is a similar approach implemented in `gamm4` and `brms`, among other packages. Within these smooths, the same syntax commonly used in `mgcv::s()` or `mgcv::t2()` can be applied, e.g. 2-dimensional smooths may be constructed with `+ s(x, y)` or `+ t2(x, y)`; smooths can be specific to various factor levels, `+ s(x, by = group)`; the basis function dimensions may be specified, e.g. `+ s(x, k = 4)`; and various types of splines may be constructed such as cyclic splines to model seasonality (perhaps with the `knots` argument also be supplied).

Threshold models

A linear break-point relationship for a covariate can be included via `+ breakpoint(variable)` in the formula, where `variable` is a single covariate corresponding to a column in data. In this case, the relationship is linear up to a point and then constant (hockey-stick shaped).

Similarly, a logistic-function threshold model can be included via `+ logistic(variable)`. This option models the relationship as a logistic function of the 50% and 95% values. This is similar to length- or size-based selectivity in fisheries, and is parameterized by the points at which $f(x) = 0.5$ or 0.95. See the [threshold vignette](#).

Note that only a single threshold covariate can be included and the same covariate is included in both components for the delta families.

Extra time: forecasting or interpolating

Extra time slices (e.g., years) can be included for interpolation or forecasting with the `predict` function via the `extra_time` argument. The `predict` function requires all time slices to be defined when fitting the model to ensure the various time indices are set up correctly. Be careful if including extra time slices that the model remains identifiable. For example, including `+ as.factor(year)` in formula will render a model with no data to inform the expected value in a missing year. `sdmTMB()` makes no attempt to determine if the model makes sense for forecasting or interpolation. The options `time_varying`, `spatiotemporal = "rw"`, `spatiotemporal = "ar1"`, or a smoother on the time column provide mechanisms to predict over missing time slices with process error.

`extra_time` can also be used to fill in missing time steps for the purposes of a random walk or AR(1) process if the gaps between time steps are uneven.

Regularization and priors

You can achieve regularization via penalties (priors) on the fixed effect parameters. See `sdmTMBpriors()`. You can fit the model once without penalties and look at the output of `print(your_model)` or `tidy(your_model)` or fit the model with `do_fit = FALSE` and inspect `head(your_modeltm_dataX_ij[[1]])` if you want to see how the formula is translated to the fixed effect model matrix. Also see the [Bayesian vignette](#).

Delta/hurdle models

Delta models (also known as hurdle models) can be fit as two separate models or at the same time by using an appropriate delta family. E.g.: `delta_gamma()`, `delta_beta()`, `delta_lognormal()`, and `delta_truncated_nbinom2()`. If fit with a delta family, by default the formula, spatial, and spatiotemporal components are shared. Some elements can be specified independently for the two models using a list format. These include `formula`, `spatial`, `spatiotemporal`, and `share_range`. The first element of the list is for the binomial component and the second element is for the positive component (e.g., Gamma). Other elements must be shared for now (e.g., spatially varying coefficients, time-varying coefficients). Furthermore, there are currently limitations if specifying two formulas as a list: the two formulas cannot have smoothers, threshold effects, or random intercepts. For now, these must be specified through a single formula that is shared across the two models.

The main advantage of specifying such models using a delta family (compared to fitting two separate models) is (1) coding simplicity and (2) calculation of uncertainty on derived quantities such as an index of abundance with `get_index()` using the generalized delta method within TMB. Also, selected parameters can be shared across the models.

See the [delta-model vignette](#).

Index standardization

For index standardization, you may wish to include `0 + as.factor(year)` (or whatever the time column is called) in the formula. See a basic example of index standardization in the relevant [package vignette](#). You will need to specify the `time` argument. See `get_index()`.

Value

An object (list) of class `sdmTMB`. Useful elements include:

- `sd_report`: output from `TMB::sdreport()`
- `gradients`: marginal log likelihood gradients with respect to each fixed effect
- `model`: output from `stats::nlminb()`
- `data`: the fitted data

- mesh: the object that was supplied to the mesh argument
- family: the family object, which includes the inverse link function as `family$linkinv()`
- tmb_params: The parameters list passed to `TMB::MakeADFun()`
- tmb_map: The 'map' list passed to `TMB::MakeADFun()`
- tmb_data: The data list passed to `TMB::MakeADFun()`
- tmb_obj: The TMB object created by `TMB::MakeADFun()`

References

Main reference introducing the package to cite when using sdmTMB:

Anderson, S.C., E.J. Ward, P.A. English, L.A.K. Barnett. 2022. sdmTMB: an R package for fast, flexible, and user-friendly generalized linear mixed effects models with spatial and spatiotemporal random fields. *bioRxiv* 2022.03.24.485545; doi:10.1101/2022.03.24.485545.

Reference for local trends:

Barnett, L.A.K., E.J. Ward, S.C. Anderson. 2021. Improving estimates of species distribution change by incorporating local trends. *Ecography*. 44(3):427-439. doi:10.1111/ecog.05176.

Further explanation of the model and application to calculating climate velocities:

English, P., E.J. Ward, C.N. Rooper, R.E. Forrest, L.A. Rogers, K.L. Hunter, A.M. Edwards, B.M. Connors, S.C. Anderson. 2021. Contrasting climate velocity impacts in warm and cool locations show that effects of marine warming are worse in already warmer temperate waters. *Fish and Fisheries*. 23(1) 239-255. doi:10.1111/faf.12613.

Discussion of and illustration of some decision points when fitting these models:

Commander, C.J.C., L.A.K. Barnett, E.J. Ward, S.C. Anderson, T.E. Essington. 2022. The shadow model: how and why small choices in spatially explicit species distribution models affect predictions. *PeerJ* 10: e12783. doi:10.7717/peerj.12783.

Application and description of threshold/break-point models:

Essington, T.E., S.C. Anderson, L.A.K. Barnett, H.M. Berger, S.A. Siedlecki, E.J. Ward. 2022. Advancing statistical models to reveal the effect of dissolved oxygen on the spatial distribution of marine taxa using thresholds and a physiologically based index. *Ecography*. 2022: e06249 doi:10.1111/ecog.06249.

Application to fish body condition:

Lindmark, M., S.C. Anderson, M. Gogina, M. Casini. Evaluating drivers of spatiotemporal individual condition of a bottom-associated marine fish. *bioRxiv* 2022.04.19.488709. doi:10.1101/2022.04.19.488709.

Several sections of the original TMB model code were adapted from the VAST R package:

Thorson, J.T. 2019. Guidance for decisions using the Vector Autoregressive Spatio-Temporal (VAST) package in stock, ecosystem, habitat and climate assessments. *Fish. Res.* 210:143–161. doi:10.1016/j.fishres.2018.10.013.

Code for the family R-to-TMB implementation, selected parameterizations of the observation likelihoods, general package structure inspiration, and the idea behind the TMB prediction approach were adapted from the glmmTMB R package:

Brooks, M.E., K. Kristensen, K.J. van Benthem, A. Magnusson, C.W. Berg, A. Nielsen, H.J. Skaug, M. Maechler, B.M. Bolker. 2017. glmmTMB Balances Speed and Flexibility Among Packages for

Zero-inflated Generalized Linear Mixed Modeling. The R Journal, 9(2):378-400. doi:10.32614/rj2017066.

Implementation of geometric anisotropy with the SPDE and use of random field GLMMs for index standardization:

Thorson, J.T., A.O. Shelton, E.J. Ward, H.J. Skaug. 2015. Geostatistical delta-generalized linear mixed models improve precision for estimated abundance indices for West Coast groundfishes. ICES J. Mar. Sci. 72(5): 1297–1310. doi:10.1093/icesjms/fsu243.

Examples

```
library(sdmTMB)

# Build a mesh to implement the SPDE approach:
mesh <- make_mesh(pcod_2011, c("X", "Y"), cutoff = 20)

# - this example uses a fairly coarse mesh so these examples run quickly
# - 'cutoff' is the minimum distance between mesh vertices in units of the
#   x and y coordinates
# - 'cutoff = 10' might make more sense in applied situations for this dataset
# - or build any mesh in 'fmesher' and pass it to the 'mesh' argument in make_mesh()
# - the mesh is not needed if you will be turning off all
#   spatial/spatiotemporal random fields

# Quick mesh plot:
plot(mesh)

# Fit a Tweedie spatial random field GLMM with a smoother for depth:
fit <- sdmTMB(
  density ~ s(depth),
  data = pcod_2011, mesh = mesh,
  family = tweedie(link = "log")
)
fit

# Extract coefficients:
tidy(fit, conf.int = TRUE)
tidy(fit, effects = "ran_par", conf.int = TRUE)

# Perform several 'sanity' checks:
sanity(fit)

# Predict on the fitted data; see ?predict.sdmTMB
p <- predict(fit)

# Predict on new data:
p <- predict(fit, newdata = qcs_grid)
head(p)

# Visualize the depth effect with ggeffects:
ggeffects::ggpredict(fit, "depth [all]") |> plot()
```

```

# Visualize depth effect with visreg: (see ?visreg_delta)
visreg::visreg(fit, xvar = "depth") # link space; randomized quantile residuals
visreg::visreg(fit, xvar = "depth", scale = "response")
visreg::visreg(fit, xvar = "depth", scale = "response", gg = TRUE, rug = FALSE)

# Add spatiotemporal random fields:
fit <- sdmTMB(
  density ~ 0 + as.factor(year),
  time = "year", #<
  data = pcod_2011, mesh = mesh,
  family = tweedie(link = "log")
)
fit

# Make the fields AR1:
fit <- sdmTMB(
  density ~ s(depth),
  time = "year",
  spatial = "off",
  spatiotemporal = "ar1", #<
  data = pcod_2011, mesh = mesh,
  family = tweedie(link = "log")
)
fit

# Make the fields a random walk:
fit <- sdmTMB(
  density ~ s(depth),
  time = "year",
  spatial = "off",
  spatiotemporal = "rw", #<
  data = pcod_2011, mesh = mesh,
  family = tweedie(link = "log")
)
fit

# Depth smoothers by year:
fit <- sdmTMB(
  density ~ s(depth, by = as.factor(year)), #<
  time = "year",
  spatial = "off",
  spatiotemporal = "rw",
  data = pcod_2011, mesh = mesh,
  family = tweedie(link = "log")
)
fit

# 2D depth-year smoother:
fit <- sdmTMB(
  density ~ s(depth, year), #<
  spatial = "off",
  data = pcod_2011, mesh = mesh,

```

```

    family = tweedie(link = "log")
  )
  fit

# Turn off spatial random fields:
fit <- sdmTMB(
  present ~ poly(log(depth)),
  spatial = "off", #<
  data = pcod_2011, mesh = mesh,
  family = binomial()
)
fit

# Which, matches glm():
fit_glm <- glm(
  present ~ poly(log(depth)),
  data = pcod_2011,
  family = binomial()
)
summary(fit_glm)
AIC(fit, fit_glm)

# Delta/hurdle binomial-Gamma model:
fit_dg <- sdmTMB(
  density ~ poly(log(depth), 2),
  data = pcod_2011, mesh = mesh,
  spatial = "off",
  family = delta_gamma() #<
)
fit_dg

# Delta model with different formulas and spatial structure:
fit_dg <- sdmTMB(
  list(density ~ depth_scaled, density ~ poly(depth_scaled, 2)), #<
  data = pcod_2011, mesh = mesh,
  spatial = list("off", "on"), #<
  family = delta_gamma()
)
fit_dg

# Delta/hurdle truncated NB2:
pcod_2011$count <- round(pcod_2011$density)
fit_nb2 <- sdmTMB(
  count ~ s(depth),
  data = pcod_2011, mesh = mesh,
  spatial = "off",
  family = delta_truncated_nbinom2() #<
)
fit_nb2

# Regular NB2:
fit_nb2 <- sdmTMB(
  count ~ s(depth),

```

```

    data = pcod_2011, mesh = mesh,
    spatial = "off",
    family = nbinom2() #<
  )
  fit_nb2

# IID random intercepts by year:
pcod_2011$year <- as.factor(pcod_2011$year)
fit <- sdmTMB(
  density ~ s(depth) + (1 | fyear), #<
  data = pcod_2011, mesh = mesh,
  family = tweedie(link = "log")
)
fit

# Spatially varying coefficient of year:
pcod_2011$year_scaled <- as.numeric(scale(pcod_2011$year))
fit <- sdmTMB(
  density ~ year_scaled,
  spatial_varying = ~ 0 + year_scaled, #<
  data = pcod_2011, mesh = mesh, family = tweedie(), time = "year"
)
fit

# Time-varying effects of depth and depth squared:
fit <- sdmTMB(
  density ~ 0 + as.factor(year),
  time_varying = ~ 0 + depth_scaled + depth_scaled2, #<
  data = pcod_2011, time = "year", mesh = mesh,
  family = tweedie()
)
print(fit)
# Extract values:
est <- as.list(fit$sd_report, "Estimate")
se <- as.list(fit$sd_report, "Std. Error")
est$b_rw_t[, , 1]
se$b_rw_t[, , 1]

# Linear break-point effect of depth:
fit <- sdmTMB(
  density ~ breakpt(depth_scaled), #<
  data = pcod_2011,
  mesh = mesh,
  family = tweedie()
)
fit

```

Description

`sdmTMB()` and `stats::nlminb()` control options.

Usage

```
sdmTMBcontrol(
  eval.max = 2000L,
  iter.max = 1000L,
  normalize = FALSE,
  nlminb_loops = 1L,
  newton_loops = 1L,
  mgcv = deprecated(),
  quadratic_roots = FALSE,
  start = NULL,
  map_rf = deprecated(),
  map = NULL,
  lower = NULL,
  upper = NULL,
  censored_upper = NULL,
  multiphase = TRUE,
  profile = FALSE,
  get_joint_precision = TRUE,
  parallel = getOption("sdmTMB.cores", 1L),
  ...
)
```

Arguments

<code>eval.max</code>	Maximum number of evaluations of the objective function allowed.
<code>iter.max</code>	Maximum number of iterations allowed.
<code>normalize</code>	Logical: use <code>TMB::normalize()</code> to normalize the process likelihood using the Laplace approximation? Can result in a substantial speed boost in some cases. This used to default to FALSE prior to May 2021. Currently not working for models fit with REML or random intercepts.
<code>nlminb_loops</code>	How many times to run <code>stats::nlminb()</code> optimization. Sometimes restarting the optimizer at the previous best values aids convergence. If the maximum gradient is still too large, try increasing this to 2.
<code>newton_loops</code>	How many Newton optimization steps to try after running <code>stats::nlminb()</code> . This sometimes aids convergence by further reducing the log-likelihood gradient with respect to the fixed effects. This calculates the Hessian at the current MLE with <code>stats::optimHess()</code> using a finite-difference approach and uses this to update the fixed effect estimates.
<code>mgcv</code>	Deprecated Parse the formula with <code>mgcv::gam()</code> ?
<code>quadratic_roots</code>	Experimental feature for internal use right now; may be moved to a branch. Logical: should quadratic roots be calculated? Note: on the sdmTMB side, the first two coefficients are used to generate the quadratic parameters. This means

	that if you want to generate a quadratic profile for depth, and depth and depth^2 are part of your formula, you need to make sure these are listed first and that an intercept isn't included. For example, <code>formula = cpue ~ 0 + depth + depth2 + as.factor(year)</code> .
<code>start</code>	A named list specifying the starting values for parameters. You can see the necessary structure by fitting the model once and inspecting <code>your_model\$tmb_obj\$env\$parList()</code> . Elements of <code>start</code> that are specified will replace the default starting values.
<code>map_rf</code>	Deprecated use <code>spatial = 'off'</code> , <code>spatiotemporal = 'off'</code> in <code>sdmTMB()</code> .
<code>map</code>	A named list with factor NAs specifying parameter values that should be fixed at a constant value. See the documentation in <code>TMB::MakeADFun()</code> . This should usually be used with <code>start</code> to specify the fixed value.
<code>lower</code>	An optional named list of lower bounds within the optimization. Parameter vectors with the same name (e.g., <code>b_j</code> or <code>ln_kappa</code> in some cases) can be specified as a numeric vector. E.g. <code>lower = list(b_j = c(-5, -5))</code> .
<code>upper</code>	An optional named list of upper bounds within the optimization.
<code>censored_upper</code>	An optional vector of upper bounds for <code>sdmTMBcontrol()</code> . Values of NA indicate an unbounded right-censored to distribution, values greater than the observation indicate an upper bound, and values equal to the observation indicate no censoring.
<code>multiphase</code>	Logical: estimate the fixed and random effects in phases? Phases are usually faster and more stable.
<code>profile</code>	Logical: should population-level/fixed effects be profiled out of the likelihood? These are then appended to the random effects vector without the Laplace approximation. See <code>TMB::MakeADFun()</code> . <i>This can dramatically speed up model fit if there are many fixed effects but is experimental at this stage.</i>
<code>get_joint_precision</code>	Logical. Passed to <code>getJointPrecision</code> in <code>TMB::sdreport()</code> . Must be TRUE to use simulation-based methods in <code>predict.sdmTMB()</code> or <code>[get_index_sims()]</code> . If not needed, setting this FALSE will reduce object size.
<code>parallel</code>	Argument currently ignored. For parallel processing with 3 cores, as an example, use <code>TMB::openmp(n = 3, DLL = "sdmTMB")</code> . But be careful, because it's not always faster with more cores and there is definitely an upper limit.
<code>...</code>	Anything else. See the 'Control parameters' section of <code>stats::nlminb()</code> .

Details

Usually used within `sdmTMB()`. For example:

```
sdmTMB(..., control = sdmTMBcontrol(newton_loops = 2))
```

Value

A list of control arguments

Examples

```
sdmTMBcontrol()
```

Description

[Experimental]

Optional priors/penalties on model parameters. This results in penalized likelihood within TMB or can be used as priors if the model is passed to **tmbstan** (see the Bayesian vignette).

Note that Jacobian adjustments are only made if `bayesian = TRUE` when the `sdmTMB()` model is fit. I.e., the final model will be fit with **tmbstan** and priors are specified then `bayesian` should be set to `TRUE`. Otherwise, leave `bayesian = FALSE`.

`pc_matern()` is the Penalized Complexity prior for the Matern covariance function.

Usage

```
sdmTMBpriors(
  matern_s = pc_matern(range_gt = NA, sigma_lt = NA),
  matern_st = pc_matern(range_gt = NA, sigma_lt = NA),
  phi = halfnormal(NA, NA),
  ar1_rho = normal(NA, NA),
  tweedie_p = normal(NA, NA),
  b = normal(NA, NA),
  sigma_G = halfnormal(NA, NA)
)

normal(location = 0, scale = 1)

halfnormal(location = 0, scale = 1)

mvnormal(location = 0, scale = diag(length(location)))

pc_matern(range_gt, sigma_lt, range_prob = 0.05, sigma_prob = 0.05)
```

Arguments

<code>matern_s</code>	A PC (Penalized Complexity) prior (<code>pc_matern()</code>) on the spatial random field Matérn parameters.
<code>matern_st</code>	Same as <code>matern_s</code> but for the spatiotemporal random field. Note that you will likely want to set <code>share_fields = FALSE</code> if you choose to set both a spatial and spatiotemporal Matérn PC prior since they both include a prior on the spatial range parameter.
<code>phi</code>	A <code>halfnormal()</code> prior for the dispersion parameter in the observation distribution.
<code>ar1_rho</code>	A <code>normal()</code> prior for the AR1 random field parameter. Note the parameter has support $-1 < \text{ar1_rho} < 1$.

tweedie_p	A normal() prior for the Tweedie power parameter. Note the parameter has support $1 < \text{tweedie_p} < 2$ so choose a mean appropriately.
b	normal() priors for the main population-level 'beta' effects.
sigma_G	halfnormal() priors for the random intercept SDs.
location	Location parameter(s).
scale	Scale parameter. For normal()/halfnormal(): standard deviation(s). For mvnormal(): variance-covariance matrix.
range_gt	A value one expects the spatial or spatiotemporal range is greater than with $1 - \text{range_prob}$ probability.
sigma_lt	A value one expects the spatial or spatiotemporal marginal standard deviation (sigma_0 or sigma_E internally) is less than with $1 - \text{sigma_prob}$ probability.
range_prob	Probability. See description for range_gt.
sigma_prob	Probability. See description for sigma_lt.

Details

Meant to be passed to the priors argument in `sdmTMB()`.

normal() and halfnormal() define normal and half-normal priors that, at this point, must have a location (mean) parameter of 0. halfnormal() is the same as normal() but can be used to make the syntax clearer. It is intended to be used for parameters that have support > 0 .

See <https://arxiv.org/abs/1503.00256> for a description of the PC prior for Gaussian random fields. Quoting the discussion (and substituting the argument names in pc_matern()): "In the simulation study we observe good coverage of the equal-tailed 95% credible intervals when the prior satisfies $P(\text{sigma} > \text{sigma_lt}) = 0.05$ and $P(\text{range} < \text{range_gt}) = 0.05$, where sigma_lt is between 2.5 to 40 times the true marginal standard deviation and range_gt is between 1/10 and 1/2.5 of the true range."

Keep in mind that the range is dependent on the units and scale of the coordinate system. In practice, you may choose to try fitting the model without a PC prior and then constraining the model from there. A better option would be to simulate from a model with a given range and sigma to choose reasonable values for the system or base the prior on knowledge from a model fit to a similar system but with more spatial information in the data.

Value

A named list with values for the specified priors.

References

- Fuglstad, G.-A., Simpson, D., Lindgren, F., and Rue, H. (2016) Constructing Priors that Penalize the Complexity of Gaussian Random Fields. arXiv:1503.00256
- Simpson, D., Rue, H., Martins, T., Riebler, A., and Sørbye, S. (2015) Penalising model component complexity: A principled, practical approach to constructing priors. arXiv:1403.4630

See Also

`plot_pc_matern()`

Examples

```

normal(0, 1)
halfnormal(0, 1)
mvnormal(c(0, 0))
pc_matern(range_gt = 5, sigma_lt = 1)
plot_pc_matern(range_gt = 5, sigma_lt = 1)

d <- subset(pcod, year > 2011)
pcod_spde <- make_mesh(d, c("X", "Y"), cutoff = 30)

# - no priors on population-level effects (`b`)
# - halfnormal(0, 10) prior on dispersion parameter `phi`
# - Matern PC priors on spatial `matern_s` and spatiotemporal
#   `matern_st` random field parameters
m <- sdmTMB(density ~ s(depth, k = 3),
  data = d, mesh = pcod_spde, family = tweedie(),
  share_range = FALSE, time = "year",
  priors = sdmTMBpriors(
    phi = halfnormal(0, 10),
    matern_s = pc_matern(range_gt = 5, sigma_lt = 1),
    matern_st = pc_matern(range_gt = 5, sigma_lt = 1)
  )
)

# - no prior on intercept
# - normal(0, 1) prior on depth coefficient
# - no prior on the dispersion parameter `phi`
# - Matern PC prior
m <- sdmTMB(density ~ depth_scaled,
  data = d, mesh = pcod_spde, family = tweedie(),
  spatiotemporal = "off",
  priors = sdmTMBpriors(
    b = normal(c(NA, 0), c(NA, 1)),
    matern_s = pc_matern(range_gt = 5, sigma_lt = 1)
  )
)

# You get a prior, you get a prior, you get a prior!
# (except on the annual means; see the `NA`s)
m <- sdmTMB(density ~ 0 + depth_scaled + depth_scaled2 + as.factor(year),
  data = d, time = "year", mesh = pcod_spde, family = tweedie(link = "log"),
  share_range = FALSE, spatiotemporal = "AR1",
  priors = sdmTMBpriors(
    b = normal(c(0, 0, NA, NA, NA), c(2, 2, NA, NA, NA)),
    phi = halfnormal(0, 10),
    tweedie_p = normal(1.5, 2),
    ar1_rho = normal(0, 1),
    matern_s = pc_matern(range_gt = 5, sigma_lt = 1),
    matern_st = pc_matern(range_gt = 5, sigma_lt = 1)
  )
)

```

Description

Facilitates cross validation with sdmTMB models. Returns the log likelihood of left-out data, which is similar in spirit to the ELPD (expected log pointwise predictive density). The function has an option for leave-future-out cross validation. By default, the function creates folds randomly but folds can be manually assigned via the `fold_ids` argument.

Usage

```
sdmTMB_cv(
  formula,
  data,
  mesh_args,
  mesh = NULL,
  time = NULL,
  k_folds = 8,
  fold_ids = NULL,
  lfo = FALSE,
  lfo_forecast = 1,
  lfo_validations = 5,
  parallel = TRUE,
  use_initial_fit = FALSE,
  future_globals = NULL,
  spde = deprecated(),
  ...
)
```

Arguments

<code>formula</code>	Model formula.
<code>data</code>	A data frame.
<code>mesh_args</code>	Arguments for <code>make_mesh()</code> . If supplied, the mesh will be reconstructed for each fold.
<code>mesh</code>	Output from <code>make_mesh()</code> . If supplied, the mesh will be constant across folds.
<code>time</code>	The name of the time column. Leave as <code>NULL</code> if this is only spatial data.
<code>k_folds</code>	Number of folds.
<code>fold_ids</code>	Optional vector containing user fold IDs. Can also be a single string, e.g. "fold_id" representing the name of the variable in data. Ignored if <code>lfo</code> is <code>TRUE</code>
<code>lfo</code>	Whether to implement leave-future-out (LFO) cross validation where data are used to predict future folds. <code>time</code> argument in <code>sdmTMB()</code> must be specified. See Details section below.

lfo_forecast	If lfo = TRUE, number of time steps to forecast. Time steps 1, ..., T are used to predict T + lfo_forecast and the last forecasted time step is used for validation. See Details section below.
lfo_validations	If lfo = TRUE, number of times to step through the LFOCV process. Defaults to 5. See Details section below.
parallel	If TRUE and a <code>future::plan()</code> is supplied, will be run in parallel.
use_initial_fit	Fit the first fold and use those parameter values as starting values for subsequent folds? Can be faster with many folds.
future_globals	A character vector of global variables used within arguments if an error is returned that future.apply can't find an object. This vector is appended to TRUE and passed to the argument <code>future_globals</code> in <code>future.apply::future_lapply()</code> . Useful if global objects are used to specify arguments like priors, families, etc.
spde	Deprecated. Use mesh instead.
...	All other arguments required to run <code>sdmTMB()</code> model with the exception of weights, which are used to define the folds.

Details

Parallel processing

Parallel processing can be used by setting a `future::plan()`.

For example:

```
library(future)
plan(multisession)
# now use sdmTMB_cv() ...
```

Leave-future-out cross validation (LFOCV)

An example of LFOCV with 9 time steps, `lfo_forecast = 1`, and `lfo_validations = 2`:

- Fit data to time steps 1 to 7, predict and validate step 8.
- Fit data to time steps 1 to 8, predict and validate step 9.

An example of LFOCV with 9 time steps, `lfo_forecast = 2`, and `lfo_validations = 3`:

- Fit data to time steps 1 to 5, predict and validate step 7.
- Fit data to time steps 1 to 6, predict and validate step 8.
- Fit data to time steps 1 to 7, predict and validate step 9.

See example below.

Value

A list:

- data: Original data plus columns for fold ID, CV predicted value, and CV log likelihood.
- models: A list of models; one per fold.
- fold_loglik: Sum of left-out log likelihoods per fold. More positive values are better.
- sum_loglik: Sum of fold_loglik across all left-out data. More positive values are better.
- pdHess: Logical vector: Hessian was invertible each fold?
- converged: Logical: all pdHess TRUE?
- max_gradients: Max gradient per fold.

Prior to **sdmTMB** version '0.3.0.9002', elpd was incorrectly returned as the log average likelihood, which is another metric you could compare models with, but not ELPD. For maximum likelihood, **ELPD is equivalent in spirit to the sum of the log likelihoods**.

Examples

```
mesh <- make_mesh(pcod, c("X", "Y"), cutoff = 25)

# Set parallel processing first if desired with the future package.
# See the Details section above.

m_cv <- sdmTMB_cv(
  density ~ 0 + depth_scaled + depth_scaled2,
  data = pcod, mesh = mesh,
  family = tweedie(link = "log"), k_folds = 2
)

m_cv$fold_loglik
m_cv$sum_loglik

head(m_cv$data)
m_cv$models[[1]]
m_cv$max_gradients

# Create mesh each fold:
m_cv2 <- sdmTMB_cv(
  density ~ 0 + depth_scaled + depth_scaled2,
  data = pcod, mesh_args = list(xy_cols = c("X", "Y"), cutoff = 20),
  family = tweedie(link = "log"), k_folds = 2
)

# Use fold_ids:
m_cv3 <- sdmTMB_cv(
  density ~ 0 + depth_scaled + depth_scaled2,
  data = pcod, mesh = mesh,
  family = tweedie(link = "log"),
  fold_ids = rep(seq(1, 3), nrow(pcod))[seq(1, nrow(pcod))]
)
```

```

# LFOCV:
m_lfocv <- sdmTMB_cv(
  present ~ s(year, k = 4),
  data = pcod,
  mesh = mesh,
  lfo = TRUE,
  lfo_forecast = 2,
  lfo_validations = 3,
  family = binomial(),
  spatiotemporal = "off",
  time = "year" # must be specified
)

# See how the LFOCV folds were assigned:
example_data <- m_lfocv$models[[1]]$data
table(example_data$cv_fold, example_data$year)

```

sdmTMB_simulate

Simulate from a spatial/spatiotemporal model

Description

sdmTMB_simulate() uses TMB to simulate *new* data given specified parameter values. [simulate.sdmTMB\(\)](#), on the other hand, takes an *existing* model fit and simulates new observations and optionally new random effects.

Usage

```

sdmTMB_simulate(
  formula,
  data,
  mesh,
  family = gaussian(link = "identity"),
  time = NULL,
  B = NULL,
  range = NULL,
  rho = NULL,
  sigma_0 = NULL,
  sigma_E = NULL,
  sigma_Z = NULL,
  phi = NULL,
  tweedie_p = NULL,
  df = NULL,
  threshold_coefs = NULL,
  fixed_re = list(omega_s = NULL, epsilon_st = NULL, zeta_s = NULL),
  previous_fit = NULL,

```

```

    seed = sample.int(1e+06, 1),
    ...
)

```

Arguments

formula	A <i>one-sided</i> formula describing the fixed-effect structure. Random intercepts are not (yet) supported. Fixed effects should match the corresponding B argument vector of coefficient values.
data	A data frame containing the predictors described in formula and the time column if time is specified.
mesh	Output from make_mesh() .
family	Family as in sdmTMB() . Delta families are not supported. Instead, simulate the two component models separately and combine.
time	The time column name.
B	A vector of beta values (fixed-effect coefficient values).
range	Parameter that controls the decay of spatial correlation. If a vector of length 2, share_range will be set to FALSE and the spatial and spatiotemporal ranges will be unique.
rho	Spatiotemporal correlation between years; should be between -1 and 1.
sigma_0	SD of spatial process (Omega).
sigma_E	SD of spatiotemporal process (Epsilon).
sigma_Z	SD of spatially varying coefficient field (Zeta).
phi	Observation error scale parameter (e.g., SD in Gaussian).
tweedie_p	Tweedie p (power) parameter; between 1 and 2.
df	Student-t degrees of freedom.
threshold_coefs	An optional vector of threshold coefficient values if the formula includes breakpt() or logistic() . If breakpt() , these are slope and cut values. If logistic() , these are the threshold at which the function is 50% of the maximum, the threshold at which the function is 95% of the maximum, and the maximum. See the model description vignette for details.
fixed_re	A list of optional random effects to fix at specified (e.g., previously estimated) values. Values of NULL will result in the random effects being simulated.
previous_fit	(Deprecated) ; please use simulate.sdmTMB() . An optional previous sdmTMB() fit to pull parameter values. Will be over-ruled by any non-NULL specified parameter arguments.
seed	Seed number.
...	Any other arguments to pass to sdmTMB() .

Value

A data frame where:

- The 1st column is the time variable (if present).
- The 2nd and 3rd columns are the spatial coordinates.
- omega_s represents the simulated spatial random effects (only if present).
- zeta_s represents the simulated spatial varying covariate field (only if present).
- epsilon_st represents the simulated spatiotemporal random effects (only if present).
- eta is the true value in link space
- mu is the true value in inverse link space.
- observed represents the simulated process with observation error.
- The remaining columns are the fixed-effect model matrix.

See Also

[simulate.sdmTMB\(\)](#)

Examples

```
set.seed(123)

# make fake predictor(s) (a1) and sampling locations:
predictor_dat <- data.frame(
  X = runif(300), Y = runif(300),
  a1 = rnorm(300), year = rep(1:6, each = 50)
)
mesh <- make_mesh(predictor_dat, xy_cols = c("X", "Y"), cutoff = 0.1)

sim_dat <- sdmTMB_simulate(
  formula = ~ 1 + a1,
  data = predictor_dat,
  time = "year",
  mesh = mesh,
  family = gaussian(),
  range = 0.5,
  sigma_E = 0.1,
  phi = 0.1,
  sigma_0 = 0.2,
  seed = 42,
  B = c(0.2, -0.4) # B0 = intercept, B1 = a1 slope
)
head(sim_dat)

if (require("ggplot2", quietly = TRUE)) {
  ggplot(sim_dat, aes(X, Y, colour = observed)) +
    geom_point() +
    facet_wrap(~year) +
    scale_color_gradient2()
}
```

```
# fit to the simulated data:
fit <- sdmTMB(observed ~ a1, data = sim_dat, mesh = mesh, time = "year")
fit
```

sdmTMB_stacking

Perform stacking with log scores on sdmTMB_cv() output

Description

[Experimental]

This approach is described in Yao et al. (2018) [doi:10.1214/17BA1091](https://doi.org/10.1214/17BA1091). The general method minimizes (or maximizes) some quantity across models. For simple models with normal error, this may be the root mean squared error (RMSE), but other approaches include the log score. We adopt the latter here, where log scores are used to generate the stacking of predictive distributions

Usage

```
sdmTMB_stacking(model_list, include_folds = NULL)
```

Arguments

model_list	A list of models fit with sdmTMB_cv() to generate estimates of predictive densities. You will want to set the seed to the same value before fitting each model or manually construct the fold IDs so that they are the same across models.
include_folds	An optional numeric vector specifying which folds to include in the calculations. For example, if 5 folds are used for k-fold cross validation, and the first 4 are needed to generate these weights, include_folds = 1:4.

Value

A vector of model weights.

References

Yao, Y., Vehtari, A., Simpson, D., and Gelman, A. 2018. Using Stacking to Average Bayesian Predictive Distributions (with Discussion). *Bayesian Analysis* 13(3): 917–1007. International Society for Bayesian Analysis. [doi:10.1214/17BA1091](https://doi.org/10.1214/17BA1091)

Examples

```
# Set parallel processing if desired. See 'Details' in ?sdmTMB_cv

# Depth as quadratic:
set.seed(1)
m_cv_1 <- sdmTMB_cv(
  density ~ 0 + depth_scaled + depth_scaled2,
```



```

    data = pcod_2011, mesh = pcod_mesh_2011,
    family = tweedie(link = "log"), k_folds = 2
  )
  # Depth as linear:
  set.seed(1)
  m_cv_2 <- sdmTMB_cv(
    density ~ 0 + depth_scaled,
    data = pcod_2011, mesh = pcod_mesh_2011,
    family = tweedie(link = "log"), k_folds = 2
  )

  # Only an intercept:
  set.seed(1)
  m_cv_3 <- sdmTMB_cv(
    density ~ 1,
    data = pcod_2011, mesh = pcod_mesh_2011,
    family = tweedie(link = "log"), k_folds = 2
  )

  models <- list(m_cv_1, m_cv_2, m_cv_3)
  weights <- sdmTMB_stacking(models)
  weights

```

set_delta_model	Set delta model for <code>ggeffects::ggpredict()</code>
-----------------	---

Description

Set a delta model component to predict from with `ggeffects::ggpredict()`.

Usage

```
set_delta_model(x, model = c(NA, 1, 2))
```

Arguments

<code>x</code>	An <code>sdmTMB()</code> model fit with a delta family such as <code>delta_gamma()</code> .
<code>model</code>	Which delta/hurdle model component to predict/plot with. NA does the combined prediction, 1 does the binomial part, and 2 does the positive part.

Details

A complete version of the examples below would be:

```

fit <- sdmTMB(density ~ poly(depth_scaled, 2), data = pcod_2011,
  spatial = "off", family = delta_gamma())

# binomial part:

```

```

set_delta_model(fit, model = 1) |>
  ggeffects::ggpredict("depth_scaled [all]")

# gamma part:
set_delta_model(fit, model = 2) |>
  ggeffects::ggpredict("depth_scaled [all]")

# combined:
set_delta_model(fit, model = NA) |>
  ggeffects::ggpredict("depth_scaled [all]")

```

But cannot be run on CRAN until a version of **ggeffects** > 1.3.2 is on CRAN. For now, you can install the GitHub version of **ggeffects**. <https://github.com/strengejake/ggeffects>.

Value

The fitted model with a new attribute named `delta_model_predict`. We suggest you use `set_delta_model()` in a pipe (as in the examples) so that this attribute does not persist. Otherwise, `predict.sdmTMB()` will choose this model component by default. You can also remove the attribute yourself after:

```
attr(fit, "delta_model_predict") <- NULL
```

Examples

```

fit <- sdmTMB(density ~ poly(depth_scaled, 2), data = pcod_2011,
  spatial = "off", family = delta_gamma())

# binomial part:
set_delta_model(fit, model = 1)

# gamma part:
set_delta_model(fit, model = 2)

# combined:
set_delta_model(fit, model = NA)

```

simulate.sdmTMB

Simulate from a fitted sdmTMB model

Description

`simulate.sdmTMB` is an S3 method for producing a matrix of simulations from a fitted model. This is similar to `lme4::simulate.merMod()` and `glmmTMB::simulate.glmmTMB()`. It can be used with the **DHARMA** package among other uses.

Usage

```
## S3 method for class 'sdmTMB'
simulate(
  object,
  nsim = 1L,
  seed = sample.int(1e+06, 1L),
  params = c("mle", "mvn"),
  model = c(NA, 1, 2),
  re_form = NULL,
  mcmc_samples = NULL,
  ...
)
```

Arguments

object	sdmTMB model
nsim	Number of response lists to simulate. Defaults to 1.
seed	Random number seed
params	Whether the parameters used in the simulation should come from the Maximum Likelihood Estimate ("mle") or from new draws from the joint precision matrix assuming they are multivariate normal distributed ("mvn").
model	If a delta/hurdle model, which model to simulate from? NA = combined, 1 = first model, 2 = second mdoel.
re_form	NULL to specify a simulation conditional on fitted random effects (this only simulates observation error). ~0 or NA to simulate new random affects (smoothers, which internally are random effects, will not be simulated as new).
mcmc_samples	An optional matrix of MCMC samples. See <code>extract_mcmc()</code> in the sdmTMBextra package.
...	Extra arguments (not used)

Value

Returns a matrix; number of columns is nsim.

See Also

[sdmTMB_simulate\(\)](#)

Examples

```
# start with some data simulated from scratch:
set.seed(1)
predictor_dat <- data.frame(X = runif(300), Y = runif(300), a1 = rnorm(300))
mesh <- make_mesh(predictor_dat, xy_cols = c("X", "Y"), cutoff = 0.1)
dat <- sdmTMB_simulate(
  formula = ~ 1 + a1,
```

```

    data = predictor_dat,
    mesh = mesh,
    family = poisson(),
    range = 0.5,
    sigma_0 = 0.2,
    seed = 42,
    B = c(0.2, -0.4) # B0 = intercept, B1 = a1 slope
  )
fit <- sdmTMB(observed ~ 1 + a1, data = dat, family = poisson(), mesh = mesh)

# simulate from the model:
s1 <- simulate(fit, nsim = 300)
dim(s1)

# test whether fitted models are consistent with the observed number of zeros:
sum(s1 == 0)/length(s1)
sum(dat$observed == 0) / length(dat$observed)

# simulate with the parameters drawn from the joint precision matrix:
s2 <- simulate(fit, nsim = 1, params = "MVN")

# simulate with new random fields:
s3 <- simulate(fit, nsim = 1, re_form = ~ 0)

# simulate with new random fields and new parameter draws:
s3 <- simulate(fit, nsim = 1, params = "MVN", re_form = ~ 0)

```

spread_sims

Extract parameter simulations from the joint precision matrix

Description

spread_sims() returns a wide-format data frame. gather_sims() returns a long-format data frame. The format matches the format in the **tidybayes** spread_draws() and gather_draws() functions.

Usage

```
spread_sims(object, nsim = 200, n_sims = deprecated())
```

```
gather_sims(object, nsim = 200, n_sims = deprecated())
```

Arguments

object	Output from <code>sdmTMB()</code> .
nsim	The number of simulation draws.
n_sims	Deprecated: please use nsim.

Value

A data frame. `gather_sims()` returns a long-format data frame:

- `.iteration`: the sample ID
- `.variable`: the parameter name
- `.value`: the parameter sample value

`spread_sims()` returns a wide-format data frame:

- `.iteration`: the sample ID
- columns for each parameter with a sample per row

Examples

```
m <- sdmTMB(density ~ depth_scaled,
  data = pcod_2011, mesh = pcod_mesh_2011, family = tweedie())
head(spread_sims(m, nsim = 10))
head(gather_sims(m, nsim = 10))
samps <- gather_sims(m, nsim = 1000)

if (require("ggplot2", quietly = TRUE)) {
  ggplot(samps, aes(.value)) + geom_histogram() +
    facet_wrap(~.variable, scales = "free_x")
}
```

tidy.sdmTMB

Turn sdmTMB model output into a tidy data frame

Description

Turn sdmTMB model output into a tidy data frame

Usage

```
## S3 method for class 'sdmTMB'
tidy(
  x,
  effects = c("fixed", "ran_pars", "ran_vals"),
  model = 1,
  conf.int = FALSE,
  conf.level = 0.95,
  exponentiate = FALSE,
  silent = FALSE,
  ...
)
```

Arguments

<code>x</code>	Output from <code>sdmTMB()</code> .
<code>effects</code>	A character value. One of "fixed" ('fixed' or main-effect parameters), "ran_pars" (standard deviations, spatial range, and other random effect and dispersion-related terms), or "ran_vals" (individual random intercepts, if included; behaves like <code>ranef()</code>).
<code>model</code>	Which model to tidy if a delta model (1 or 2).
<code>conf.int</code>	Include a confidence interval?
<code>conf.level</code>	Confidence level for CI.
<code>exponentiate</code>	Whether to exponentiate the fixed-effect coefficient estimates and confidence intervals.
<code>silent</code>	Omit any messages?
<code>...</code>	Extra arguments (not used).

Details

Follows the conventions of the **broom** and **broom.mixed** packages.

Currently, `effects = "ran_pars"` also includes dispersion-related terms (e.g., `phi`), which are not actually associated with random effects.

Standard errors for spatial variance terms fit in log space (e.g., variance terms, range, or parameters associated with the observation error) are omitted to avoid confusion. Confidence intervals are still available.

Value

A data frame

Examples

```
fit <- sdmTMB(density ~ poly(depth_scaled, 2, raw = TRUE),
  data = pcod_2011, mesh = pcod_mesh_2011,
  family = tweedie()
)
tidy(fit)
tidy(fit, conf.int = TRUE)
tidy(fit, "ran_pars", conf.int = TRUE)

pcod_2011$year <- as.factor(pcod_2011$year)
fit <- sdmTMB(density ~ poly(depth_scaled, 2, raw = TRUE) + (1 | year),
  data = pcod_2011, mesh = pcod_mesh_2011,
  family = tweedie()
)
tidy(fit, "ran_vals")
```

visreg_delta

*Plot sdmTMB models with the **visreg** package*

Description

sdmTMB models fit with regular (non-delta) families can be passed to `visreg::visreg()` or `visreg::visreg2d()` directly. Examples are shown below. Delta models can use the helper functions `visreg_delta()` or `visreg2d_delta()` described here.

Usage

```
visreg_delta(object, ..., model = c(1, 2))
```

```
visreg2d_delta(object, ..., model = c(1, 2))
```

Arguments

object	Fit from <code>sdmTMB()</code>
...	Any arguments passed to <code>visreg::visreg()</code> or <code>visreg::visreg2d()</code>
model	1st or 2nd delta model

Details

Note the residuals are currently randomized quantile residuals, *not* deviance residuals as is usual for GLMs with **visreg**.

Value

A plot from the visreg package. Optionally, the data plotted invisibly if `plot = FALSE`. This is useful if you want to make your own plot after.

Examples

```
if (require("ggplot2", quietly = TRUE) &&
    require("visreg", quietly = TRUE)) {

  fit <- sdmTMB(
    density ~ s(depth_scaled),
    data = pcod_2011,
    spatial = "off",
    family = tweedie()
  )
  visreg::visreg(fit, xvar = "depth_scaled")

  visreg::visreg(fit, xvar = "depth_scaled", scale = "response")
  v <- visreg::visreg(fit, xvar = "depth_scaled")
  head(v$fit)
```

```

# now use ggplot2 etc. if desired

# Delta model example:
fit_dg <- sdmTMB(
  density ~ s(depth_scaled, year, k = 8),
  data = pcod_2011, mesh = pcod_mesh_2011,
  spatial = "off",
  family = delta_gamma()
)
visreg_delta(fit_dg, xvar = "depth_scaled", model = 1, gg = TRUE)
visreg_delta(fit_dg, xvar = "depth_scaled", model = 2, gg = TRUE)
visreg_delta(fit_dg,
  xvar = "depth_scaled", model = 1,
  scale = "response", gg = TRUE
)
visreg_delta(fit_dg,
  xvar = "depth_scaled", model = 2,
  scale = "response"
)
visreg_delta(fit_dg,
  xvar = "depth_scaled", model = 2,
  scale = "response", gg = TRUE, rug = FALSE
)
visreg2d_delta(fit_dg,
  xvar = "depth_scaled", yvar = "year",
  model = 2, scale = "response"
)
visreg2d_delta(fit_dg,
  xvar = "depth_scaled", yvar = "year",
  model = 1, scale = "response", plot.type = "persp"
)
visreg2d_delta(fit_dg,
  xvar = "depth_scaled", yvar = "year",
  model = 2, scale = "response", plot.type = "gg"
)
}

```


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