Package ‘sad’

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Title Verify the Scale, Anisotropy and Direction of Weather Forecasts

Version 0.1.3

Description Implementation of the wavelet-based spatial verification method of Buschow and Friederichs ``SAD: Verifying the Scale, Anisotropy and Direction of precipitation forecasts'' (2020, submitted to QJRMS). Forecasts and Observations are transformed by a decimated or redundant dual-tree complex wavelet transform to analyze the spatial scale, degree of anisotropy and preferred direction in each field. These structural attributes are compared by a series of scores. An experimental algorithm for the correction of these errors is included as well.

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Imports emdist

Depends dualtrees

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getpareto *Find the pareto set*

Description

Determine the set of pareto optimal forecasts in a matrix of scores

Usage

```
getpareto(scores)
```

Arguments

`scores`	a matrix of negatively oriented scores where the rows correspond to different forecasts and the columns denote different scores.

Details

The Pareto set contains all those forecasts for which no other forecast is better in every respect. In this function, we assume that all scores are negatively oriented, "better" therefore means lower values.

Value

a vector of indices indicating all members of the pareto set.

Note

This function becomes very memory hungry if you have more than 1000 forecasts, be careful.

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hemd *histogram emd*

Description

Earth Mover's Distance between two histograms, given as vectors

Usage

```
hemd(h1, h2, mids = NULL)
```

Arguments

`h1, h2`	vectors of non-negtaive numbers representing two histograms
`mids`	the bin mids corresponding to the histograms. Can also be given via the names of `h1`.

Value

the value of the EMD

`prepare_sad` *prepare a sad forecast for verification*

Description

remove small values, apply log-transform, smooth borders, handle boundary conditions

Usage

```
prepare_sad(x, xmin = 0.1, log = TRUE, rsm = 0, Nx = NULL,
  Ny = NULL, boundaries = "pad")
```

Arguments

`x`	a list of 2 or more 2D matrices with equal sizes and no missing or inifinite values, as required by `as.sadforecast`
`xmin`	values smaller than `xmin` are set to zero
`log`	logical, do you want to log-transfrom the data? (recommended for precipitation)
`rsm`	number of pixels which are linearly smoothed at the edge
`Nx`	size to which the data is extended in x-direction
`Ny`	size to which the data is extended in y-direction
`boundaries`	how to handle the boundary conditions, either "pad", "mirror" or "periodic"

Details

the positions within the extended field where the original field resides are output as attributes "px", "py" of the result. The other input parameters are saved as attributes of the result as well.

Value

an object of class `sadforecast` which has been prepared in the desired way.

Examples

```
data( rrain )
ra <- list( rrain[2,4,,], rrain[3,9,,] )
ra <- prepare_sad( ra, rsm=0, Nx=256, boundaries="mirror", log=FALSE )
plot(ra)
```

`raincols` *rain color scale*

Description

eight shades of blue used in `plot.sadforecast`

Usage

```
raincols
```

Format

An object of class `character` of length 8.

`rrain` *Random Rain*

Description

Randomly simulated synthetic rain fields with Matern covariances

Usage

```
data(rrain)
```

Format

A `4x10x128x128` matrix

Details

These fields were used in Buschow et al. (2019) <doi:10.5194/gmd-12-3401-2019>. The first array corresponds to the four model configurations from that paper (different roughness nu and scale sc), the second dimension contains ten realizations for each model.

Source

simulated using the 'RandomFields' package, code available at <10.5281/zenodo.3257511>

Examples

```
data(rrain)
```

`sadcorrect` *correct structure errors*

Description

use the inverse 'dtcwt' to correct errors in scale, anisotropy and direction

Usage

```
sadcorrect(x, xmin = 0.1, log = TRUE, rsm = 0, Nx = NULL,
  Ny = NULL, J = NULL, boundaries = "pad", direction = TRUE)
```

Arguments

`x`	a list of equally sized matrices, the first element is assumed to be the observation
`xmin`	values smaller than `xmin` are set to zero
`log`	logical, do you want to log-transfrom the data? (recommended for precipitation)
`rsm`	number of pixels which are linearly smoothed at the edge
`Nx`	size to which the data is extended in x-direction, has to be a whole power of 2
`Ny`	size to which the data is extended in y-direction, has to be a whole power of 2
`J`	largest scale considered
`boundaries`	how to handle the boundary conditions, either "pad", "mirror" or "periodic"
`direction`	if `TRUE`, scale and direction are corrected, otherwise only scale

Details

The algorithm performs the following steps:

1. remove values below `xmin`
2. if `log=TRUE` log-transform all fields
3. set all fields to zero mean, unit variance
4. apply `dtcwt` to all fields
5. loop over forecasts and scales. If `direction=TRUE` loop over the six directions. Multiply forecast energy at each location by the ratio of total observed energy to total forecast energy at that scale (and possibly direction)
6. apply `idtcwt` to all forecasts
7. reset means and variance of the forecasts to their original values
8. if `log=TRUE` invert the log-transform
9. return the list of corrected fields

Value

an object of class `sadforecast`

Examples

```
data(rrain)
ra   <- as.sadforecast( list( rrain[2,1,,], rrain[3,1,,], rrain[3,2,,], rrain[3,3,,] ) )
ra_c <- sadcorrect( ra, rsm=10 )
plot(ra_c)
```

---

sadforecast — *class for a list of forecasts*

Description

check that a list of forecasts fulfills all requirements to be verified by our method

Usage

```
as.sadforecast(x)

## S3 method for class 'sadforecast'
plot(x, mfrow = NULL, col = NULL, ...)
```

Arguments

x	a list of 2 or more 2D matrices with equal sizes and no missing or inifinite values
mfrow	vector with the number of rows and columns you would like in the plot
col	color scale for the plot
...	further arguments passed to image

Details

as.sadforecast does nothing except check that everything is as it should be, add the attributes that can be changed by prepare_sad and provide a method for quick plots of the data.

Value

an object of class sadforecast

Examples

```
data( rrain )
ra <- list( rrain[1,1,,], rrain[4,5,,], rrain[2,7,,] )
ra <- as.sadforecast(ra)
plot(ra)
```

`sadverif` *dual-tree verification*

Description

verify the scale, anisotropy and direction of a number of forecasts

Usage

```
sadverif(x, dec = TRUE, xmin = 0.1, log = TRUE, a = 1, nbr = 33,
  rsm = 0, Nx = NULL, Ny = NULL, J = NULL, boundaries = "pad",
  return_specs = FALSE)

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

## S3 method for class 'sadverif'
summary(object, ...)
```

Arguments

`x`	a list of equally sized matrices, the first element is assumed to be the observation
`dec`	logical, do you want to use the decimated transform
`xmin`	values smaller than `xmin` are set to zero
`log`	logical, do you want to log-transfrom the data? (recommended for precipitation)
`a`	relative weight of directional errors compared to scale errors in `semdd`
`nbr`	number of breaks for the scale histograms, has no effect if `dec=TRUE`
`rsm`	number of pixels which are linearly smoothed at the edge
`Nx`	size to which the data is extended in x-direction
`Ny`	size to which the data is extended in y-direction
`J`	largest scale considered
`boundaries`	how to handle the boundary conditions, either "pad", "mirror" or "periodic"
`return_specs`	if `TRUE`, the spatial mean spectra are returned as well
`...`	further arguments, currently ignored.
`object`	object of class sadverif

Details

each element of `x` is transformed via `dtcwt` from the 'dualtrees' package. Scores and centres based on the mean spectra are calculated. If `dec=FALSE`, scale histograms and the corresponding score `hemd` are calcualted as well.

Value

an object of class `sadverif`, containing the following elements

settings a dataframe containing the parameters that were originally passed to dtverif

centres a matrix cotaining the anisotropy `rho`, angle `phi` and central scale `z` derived from the mean spectra. Rain area and sum are included as well.

detscores a matrix containing the differences in centre components, the direction/anisotropy score `dxy`, the emd between direction-averaged spectra (`semd`) and the emd between the directional spectra (`semdd`). If `dec=FALSE`, the emd between the scale histograms, hemd, is included as well.

time the time the calculation took in seconds

if there is more than one forecast, the ensemble scores SpEn and (if available), hemd are computed as well, treating all forecasts as members of the ensemble to be verified.

References

Selesnick, I.W., R.G. Baraniuk, and N.C. Kingsbury (2005) <doi:10.1109/MSP.2005.1550194> Buschow et al. (2019) <doi:10.5194/gmd-12-3401-2019> Buschow and Friederichs (2020) <doi:10.5194/ascmo-6-13-2020>

Examples

```
oldpar <- par(no.readonly=TRUE)
on.exit(par(oldpar))
data(rrain)
ra <- as.sadforecast( list( rrain[1,1,,], rrain[1,2,,], rrain[2,1,,], rrain[3,1,,] ) )
plot(ra)
verif <- sadverif( ra, log=FALSE, xmin=0 )
summary(verif)
par( mfrow=c(2,2) )
plot( verif )
```

`semd` *spectral emd*

Description

earth mover's distance between dual-tree wavelet spectra

Usage

```
semd(dt1, dt2, a = 1, dir = TRUE)
```

Arguments

`dt1, dt2`	forecast and observed spectrum
`a`	ratio between scale- and directional component
`dir`	whether or not to include direction information

Value

a single value, the emd. If `dir=FALSE`, the value is signed, indicating the direction of the scale error.

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