

# Package ‘EFDR’

July 21, 2025

**Type** Package

**Title** Wavelet-Based Enhanced FDR for Detecting Signals from Complete or Incomplete Spatially Aggregated Data

**Version** 1.3

**Date** 2023-08-23

**Suggests** knitr, rmarkdown, markdown, ggplot2, RCurl, fields, gridExtra, animation

**Description** Enhanced False Discovery Rate (EFDR) is a tool to detect anomalies in an image. The image is first transformed into the wavelet domain in order to decorrelate any noise components, following which the coefficients at each resolution are standardised. Statistical tests (in a multiple hypothesis testing setting) are then carried out to find the anomalies. The power of EFDR exceeds that of standard FDR, which would carry out tests on every wavelet coefficient: EFDR choose which wavelets to test based on a criterion described in Shen et al. (2002). The package also provides elementary tools to interpolate spatially irregular data onto a grid of the required size. The work is based on Shen, X., Huang, H.-C., and Cressie, N. 'Nonparametric hypothesis testing for a spatial signal.' Journal of the American Statistical Association 97.460 (2002): 1122-1140.

**Imports** copula, Matrix, methods, foreach ( $\geq 1.4.2$ ), doParallel ( $\geq 1.0.8$ ), waveslim ( $\geq 1.7.5$ ), parallel, gstat ( $\geq 1.0-19$ ), tidyr ( $\geq 0.1.0.9000$ ), dplyr ( $\geq 0.3.0.2$ ), sp ( $\geq 1.0-15$ )

**URL** <https://github.com/andrewzm/EFDR/>

**Depends** R ( $\geq 3.5.0$ )

**VignetteBuilder** knitr

**License** GPL ( $\geq 2$ )

**Encoding** UTF-8

**NeedsCompilation** no

**RoxygenNote** 7.2.0

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**Repository** CRAN  
**Date/Publication** 2023-08-22 22:20:02 UTC

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EFDR-package	<i>Wavelet-Based Enhanced FDR for Signal Detection in Noisy Images</i>
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Description

Enhanced False Discovery Rate (EFDR) is a tool to detect anomalies in an image. The image is first transformed into the wavelet domain in order to decorrelate any noise components, following which the coefficients at each resolution are standardised. Statistical tests (in a multiple hypothesis testing setting) are then carried out to find the anomalies. The power of EFDR exceeds that of standard FDR, which would carry out tests on every wavelet coefficient: EFDR choose which wavelets to test based on a criterion described in Shen et al. (2002). The package also provides elementary tools to interpolate spatially irregular data onto a grid of the required size. The work is based on Shen, X., Huang, H.-C., and Cressie, N. 'Nonparametric hypothesis testing for a spatial signal.' Journal of the American Statistical Association 97.460 (2002): 1122-1140.

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See Also

Useful links:  
• <https://github.com/andrewzm/EFDR/>

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df.to.mat	<i>Change xyz data-frame into a Z image</i>
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**Description**

Given a data frame with fields x, y and z, df.to.mat uses the x and y coordinates to rearrange z into a rectangular matrix image Z.

**Usage**

```
df.to.mat(df)
```

**Arguments**

df                      data frame with fields x, y and z

**Details**

This function requires that *all* pixels in the image are defined, that is df\$x and df\$y must be the column outputs of the function expand.grid(x0,y0) where x0, y0 are axes values. Note that x0 and y0 do not need to be regularly spaced.

**Value**

matrix image

**Examples**

```
df <- data.frame(expand.grid(1:10,1:10))
names(df) <- c("x","y")
df$z <- rnorm(nrow(df))
Z <- df.to.mat(df)
```

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diagnostic.table	<i>2x2 diagnostic table</i>
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**Description**

Returns the a 2x2 table resulting from diagnostic evaluation. The cells contain the number of true negatives, true positives, false negatives and false positives.

**Usage**

```
diagnostic.table(reject.true, reject, n)
```

**Arguments**

<code>reject.true</code>	indices of the true alternative hypotheses
<code>reject</code>	indices of the rejected null hypotheses
<code>n</code>	total number of tests

**Value**

2x2 matrix

**References**

Noel Cressie and Sandy Burden (2015). "Evaluation of diagnostics for hierarchical spatial statistical models." Contribution to K. V. Mardia Festschrift, Wiley, Chichester, forthcoming.

**Examples**

```
set.seed(1)
wf = "la8"
J = 3
n = 64
h = 0.5
Z <- test_image(h = h, r = 14, n1 = n)$z
sig <- wav_th(Z, wf=wf, J=J, th = h)

Z <- Z + rnorm(n^2)*0.5
m1 <- test.bonferroni(Z, wf="la8",J=3, alpha = 0.05)
m2 <- test.fdr(Z, wf="la8",J=3, alpha = 0.05)

cat("Bonferroni diagnostic table: ",sep="\n")
diagnostic.table(sig,m1$reject_coeff,n = n^2)
cat("FDR diagnostic table: ",sep="\n")
diagnostic.table(sig,m2$reject_coeff,n = n^2)
```

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fdrpower

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*Power function*


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**Description**

Returns the power of the multiple hypothesis test, by finding the proportion of the correctly rejected null hypotheses.

**Usage**

```
fdrpower(reject.true, reject)
```

**Arguments**

<code>reject.true</code>	indices of the true alternative hypotheses
<code>reject</code>	indices of the rejected null hypotheses

**Value**

Single value (proportion)

**References**

Shen, X., Huang, H.-C., and Cressie, N. 'Nonparametric hypothesis testing for a spatial signal.' Journal of the American Statistical Association 97.460 (2002): 1122-1140.

**Examples**

```
set.seed(1)
wf = "la8"
J = 3
n = 64
h = 0.5
Z <- test_image(h = h, r = 14, n1 = n)$z
sig <- wav_th(Z, wf=wf, J=J, th = h)

Z <- Z + rnorm(n^2)*0.5
m1 <- test.bonferroni(Z, wf="la8", J=3, alpha = 0.05)
m2 <- test.fdr(Z, wf="la8", J=3, alpha = 0.05)

cat(paste0("Bonferroni power: ", fdrpower(sig, m1$reject_coeff)))
cat(paste0("FDR power: ", fdrpower(sig, m2$reject_coeff)))
```

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nei.efdr

*Find wavelet neighbourhood*


---

**Description**

Given an image, this function first computes the 2d DWT and then returns a matrix of size N by b where N is the number of wavelets and b is the number of neighbours per wavelet. Two wavelets are deemed to be neighbours according to the metric of Shen, Huang and Cressie (2002). The distance metric is a function of the spatial separation, the resolution and the orientation.

**Usage**

```
nei.efdr(Z, wf = "la8", J = 2, b = 11, parallel = 1L)
```

**Arguments**

Z	image of size n1 by n2 where both n1, n2 have to be powers of two
wf	type of wavelet to employ. Please see <code>waveslim::wave.filter</code> for a full list of wavelet names
J	number of resolutions to employ in the wavelet decomposition
b	number of neighbours to consider in EFDR
parallel	number of cores to use with parallel backend; needs to be an integer less than the number of available cores

Value

matrix of size N by b

References

Shen, X., Huang, H.-C., and Cressie, N. 'Nonparametric hypothesis testing for a spatial signal.' Journal of the American Statistical Association 97.460 (2002): 1122-1140.

Examples

```
image <- matrix(rnorm(64),8,8)
```

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regrid	<i>Regrid ir/regular data</i>
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Description

Given a data frame with fields x, y and z, regrid returns a data frame with fields x, y and z, this time with x, y arranged on a regular grid of size n2 by n1.

Usage

```
regrid(  
  df,  
  n1 = 128,  
  n2 = n1,  
  method = "idw",  
  idp = 0.5,  
  nmax = 7,  
  model = "Exp"  
)
```

Arguments

df	data frame with fields x, y and z
n1	image length in pixels
n2	image height in pixels
method	method to be used, see details
idp	inverse distance power
nmax	when using inverse distance weighting, the number of nearest neighbours to consider when interpolating using idw. When using conditional simulation, the number of nearest observations to used for a kriging simulation
model	the model type when using conditional simulation (use gstat::vgm() to list all possible models)

## Details

There are three supported methods for regridding. The first, "idw", is the inverse-distance-weighting method. The function overlays a grid over the data. The cells are constructed evenly within the bounding box of the data and filled with interpolated values using the inverse weighting distance metric with power `idp`. `nmax` determines the maximum number of neighbours when using the distance weighting. With this method, interpolation uses the inverse distance weight function `gstat` in the `gstat` package. Refer to the package `gstat` for more details and formulae.

The second method "cond\_sim" uses conditional simulation to generate a realisation of the unobserved process at the grid points. This is a model-based approach, and the variogram model may be selected through the parameter `model`. The exponential variogram is used by default. For a complete list of possible models use `gstat::vgm()`. For a tutorial on how the conditional simulation is carried out see the `gstat` vignette.

The third method "median\_polishing" applies a median polish to the data. First, a grid is overlayed. If more than one data point is present in each grid box, the mean of the data is taken. Where there is no data, the grid box is assigned a value of NA. This gridded image is then passed to the function `medpolish` which carried out Tukey's median polish procedure to obtain an interpolant of the form  $z(s) = \mu + a(s1) + b(s2)$  where  $s1$  is the x-axis and  $s2$  is the y-axis. Missing points in the gridded image are then replaced with  $z(s)$  evaluated at these points. This method cannot be used if all rows and columns do not contain at least one data point.

## Value

data frame with fields `x`, `y`, `z`

## Examples

```
df <- data.frame(x = runif(200), y = runif(200), z = rnorm(200))
df.gridded <- regrid(df, n1=10)
```

---

test.efdr.condsim	<i>Test for anomalies in wavelet space via conditional simulation</i>
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## Description

Test for anomalies using EFDR and conditional simulation. The noisy image can be partially observed, or/and aggregated at different resolutions

## Usage

```
test.efdr.condsim(
  Zvec,
  H,
  n1,
  n2,
  rho_est_method = c("CPL", "MOM"),
  iter.cs = 100,
```

```

wf = "la8",
J = 2,
alpha = 0.05,
n.hyp = 100,
b = 11,
iteration = 200,
parallel = 1L
)

```

### Arguments

<code>Zvec</code>	vector of observations such that $Z_{tilde} = H.Z$
<code>H</code>	matrix mapping the fine-resolution image $Z$ in vector form to $Z_{tilde}$ . Must have as many rows as $Z_{tilde}$ and $n1 \times n2$ columns
<code>n1</code>	number of rows in fine-resolution image
<code>n2</code>	number of columns in fine-resolution image
<code>rho_est_method</code>	method with which to estimate the level of exchangeability $\rho$ ; can be either "CPL" (copula model) or "MOM" (method of moments)
<code>iter.cs</code>	number of conditional simulations to carry out
<code>wf</code>	type of wavelet to employ. Defaults to 'la8', the Daubechies orthonormal compactly supported wavelet of length $L = 8$ (Daubechies, 1992), least asymmetric family. Other options include 'haar' (Haar wavelet), 'fk8' (Fejer-Korovkin wavelet with $L=8$ ) and 'mb8' (minimum-bandwidth wavelet with $L=8$ ). Please type 'waveslim::wave.filter' in the console for a full list of wavelet names
<code>J</code>	number of resolutions to employ in wavelet decomposition
<code>alpha</code>	significance level at which tests are carried out
<code>n.hyp</code>	number of hypotheses tests to carry out with EFDR. If a vector is supplied, the optimal one from the set of proposed number of tests is chosen
<code>b</code>	the number of neighbours to consider in EFDR
<code>iteration</code>	number of Monte Carlo iterations to employ when determining which of the proposed number of tests in <code>n.hyp</code> is the optimal number of tests
<code>parallel</code>	number of cores to use with parallel backend; needs to be an integer less than or equal to the number of available cores

### Value

List with three fields:

`filtered` the discrete wavelet transform containing the anomalous wavelet coefficients in the signal

`Z` the image containing the anomalous wavelets in the signal

`reject_coeff` indices of wavelets under which the null hypothesis of no anomaly was rejected

`pvalue_ordered` ordered p-values under the null hypothesis. The column names indicate the wavelet to which the p-value belongs

`nhat` the number of tests carried out.



## References

- Daubechies, I. (1992) Ten Lectures on Wavelets, CBMS-NSF Regional Conference Series in Applied Mathematics, SIAM: Philadelphia.
- Shen, X., Huang, H.-C., and Cressie, N. 'Nonparametric hypothesis testing for a spatial signal.' Journal of the American Statistical Association 97.460 (2002): 1122-1140.

## Examples

```
## Set up experiment
n <- 32      # 32 x 32 images
r <- 10      # signal of size 10 x 10
h <- 5       # intensity of 5
grid <- 8    # aggregated to 8 x 8 image
parallel <- 4 # use 4 cores

## Simulate the pixel-level data
raw_grid <- expand.grid(x = seq(1, n), y = seq(1, n))
df <- data.frame(raw_grid)          # spatial grid
dd <- as.matrix(dist(raw_grid, diag = TRUE)) # distance matrix
Sigma <- exp(-dd/5)                 # cov. fn.
diag(Sigma) <- 1                    # fix diagonal
L <- t(chol(Sigma))                 # lower Cholesky factor
mu <- matrix(0, n, n)               # zero mean
mu[(n/2-r/2):(n/2+r/2), (n/2-r/2):(n/2+r/2)] <- h # add signal
Z <- mu + matrix(L %*% rnorm(n^2), n, n) # simulate data

## Construct H (aggregation) matrix
H <- matrix(0, grid^2, n^2)
for(i in 1:grid^2) {
  ind <- rep(rep(c(0L, 1L, 0L),
    c((n/grid)*((i-1)%grid), n/grid, (n-n/grid-n/grid*((i-1)%grid)))),
    n/grid)
  H[i, which(c(rep(0L, (ceiling(i/grid)-1)*n^2/grid), ind) == TRUE)] <- 1/(n/grid)^2
}

## Aggregate the signal
z_tilde <- c(H %*% c(Z))

## Run EFDR using conditional simulation
## Not run: out2 <- test.efdr.condsim(Zvec = z_tilde, H = H, n1 = n, n2 = n,
parallel = parallel)

## End(Not run)
```

---

test\_image

---

*Create a test image*


---

## Description

This function generates an image for test purposes. The image is that of a filled circle at the centre.

**Usage**

```
test_image(h = 1, r = 10, n1 = 64, n2 = 64)
```

**Arguments**

h	amplitude of the filled circle
r	radius of the circle (in pixels)
n1	image height in pixels
n2	image width in pixels

**Value**

List with two elements

z the test image

signal.grid the x-y grid in long table format

**References**

Shen, X., Huang, H.-C., and Cressie, N. 'Nonparametric hypothesis testing for a spatial signal.' Journal of the American Statistical Association 97.460 (2002): 1122-1140.

**Examples**

```
Z <- test_image()$z
```

---

wavelet-test

*Test for anomalies in wavelet space*


---

**Description**

Test for anomalies using either bonferroni, FDR, EFDR or LOS in the wavelet domain using the 2D wavelet transform.

**Usage**

```
test.efdr(
  Z,
  wf = "la8",
  J = 2,
  alpha = 0.05,
  n.hyp = 100,
  b = 11,
  iteration = 200,
  parallel = 1L
)
```

```
test.fdr(Z, wf = "la8", J = 2, alpha = 0.05)

test.bonferroni(Z, wf = "la8", J = 2, alpha = 0.05)

test.los(Z, wf = "la8", J = 2, alpha = 0.05)
```

### Arguments

<code>Z</code>	image of size $n_1$ by $2n_2$ where $n_1, n_2$ have to be powers of two
<code>wf</code>	type of wavelet to employ. Defaults to 'la8', the Daubechies orthonormal compactly supported wavelet of length $L = 8$ (Daubechies, 1992), least asymmetric family. Other options include 'haar' (Haar wavelet), 'fk8' (Fejer-Korovkin wavelet with $L=8$ ) and 'mb8' (minimum-bandwidth wavelet with $L=8$ ). Please type 'waveslim::wave.filter' in the console for a full list of wavelet names
<code>J</code>	number of resolutions to employ in wavelet decomposition
<code>alpha</code>	significance level at which tests are carried out
<code>n.hyp</code>	number of hypotheses tests to carry out with EFDR. If a vector is supplied, the optimal one from the set of proposed number of tests is chosen
<code>b</code>	the number of neighbours to consider in EFDR
<code>iteration</code>	number of Monte Carlo iterations to employ when determining which of the proposed number of tests in <code>n.hyp</code> is the optimal number of tests
<code>parallel</code>	number of cores to use with parallel backend; needs to be an integer less than or equal to the number of available cores

### Value

List with three fields:

`filtered` the discrete wavelet transform containing the anomalous wavelet coefficients in the signal

`Z` the image containing the anomalous wavelets in the signal

`reject_coeff` indices of wavelets under which the null hypothesis of no anomaly was rejected

`pvalue_ordered` ordered p-values under the null hypothesis. The column names indicate the wavelet to which the p-value belongs

`nhat` the number of tests carried out.

### References

Daubechies, I. (1992) Ten Lectures on Wavelets, CBMS-NSF Regional Conference Series in Applied Mathematics, SIAM: Philadelphia.

Shen, X., Huang, H.-C., and Cressie, N. 'Nonparametric hypothesis testing for a spatial signal.' Journal of the American Statistical Association 97.460 (2002): 1122-1140.

### Examples

```
## See vignettes by typing vignette("EFDR_vignettes")
```

---

wav_th	<i>Indices of wavelets exceeding a given threshold</i>
--------	--

---

### Description

This function is primarily used for testing the power of a method in the wavelet domain. Given an image, the discrete wavelet transform is found. The indices of the coefficients which exceed a certain threshold are then considered the 'signal' for testing purposes.

### Usage

```
wav_th(Z, wf = "la8", J = 2, th = 1)
```

### Arguments

Z	image of size n1 by n2 where n1, n2 have to be powers of two
wf	type of wavelet to employ. Please see <code>waveslim::wave.filter</code> for a full list of wavelet names
J	number of resolutions to employ in the wavelet decomposition
th	threshold

### Value

Indices of wavelet coefficients in a vector

### References

Shen, X., Huang, H.-C., and Cressie, N. 'Nonparametric hypothesis testing for a spatial signal.' Journal of the American Statistical Association 97.460 (2002): 1122-1140.

### Examples

```
Z <- test_image(h = 0.5, r = 14, n1 = 64)$z
print(wav_th(Z, wf="la8", J=3, th=0.5))
```

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