Package ‘MultiscaleDTM’

October 12, 2022

Title Multi-Scale Geomorphometric Terrain Attributes

Version 0.5.3

Description Calculates multi-scale geomorphometric terrain attributes from regularly gridded digital terrain models using a variable focal windows size (Misiuk et al. (2021) <doi:10.1080/01490419.2021.1925789>; Wilson et al. (2007) <doi:10.1080/01490410701295962>; Wood (1996) <https://hdl.handle.net/2381/34503>).

License GPL (>= 3)

Encoding UTF-8

RoxygenNote 7.2.1

Depends terra

LinkingTo Rcpp, RcppArmadillo

Imports Rcpp, raster, dplyr, shiny, rgl, stats, utils

Suggests knitr, rmarkdown

NeedsCompilation yes

Author Alexander Ilich [aut, cre] (<https://orcid.org/0000-0003-1758-8499>),
Vincent Lecours [aut],
Benjamin Misiuk [aut],
Steven Murawski [aut]

Maintainer Alexander Ilich <ailich@usf.edu>

Repository CRAN

Date/Publication 2022-10-04 08:00:02 UTC

R topics documented:

`AdjSD` *Calculates standard deviation of bathymetry (a measure of rugosity) adjusted for slope*

Description

Calculates standard deviation of bathymetry (a measure of rugosity). Using a sliding rectangular window a plane is fit to the data and the standard deviation of the residuals is calculated.

Usage

```
AdjSD(
  r,
  w = c(3, 3),
  na.rm = FALSE,
  include_scale = FALSE,
  filename = NULL,
  overwrite = FALSE,
  wopt = list()
)
```

Arguments

`r`	DTM as a SpatRaster or RasterLayer in a projected coordinate system where map units match elevation/depth units
`w`	A vector of length 2 specifying the dimensions of the rectangular window to use where the first number is the number of rows and the second number is the number of columns. Window size must be an odd number.
`na.rm`	A logical indicating whether or not to remove NA values before calculations

include_scale	logical indicating whether to append window size to the layer names (default = FALSE)
filename	character Output filename.
overwrite	logical. If TRUE, filename is overwritten (default is FALSE).
wopt	list with named options for writing files as in writeRaster

Value

a SpatRaster or RasterLayer of adjusted rugosity

Examples

```
r<- rast(volcano, extent= ext(2667400, 2667400 +
ncol(volcano)*10, 6478700, 6478700 + nrow(volcano)*10),
crs = "EPSG:27200")
adjsd<- AdjSD(r, w=c(5,5), na.rm = TRUE)
plot(adjsd)
```

---

annulus_window *Creates annulus focal window*

Description

Creates annulus focal window around central pixel.

Usage

```
annulus_window(radius, unit = "cell", resolution, return_dismat = FALSE)
```

Arguments

radius	radius of inner annulus c(inner,outer)
unit	unit for radius. Either "cell" (number of cells, the default) or "map" for map units (e.g. meters).
resolution	resolution of intended raster layer (one number or a vector of length 2). Only necessary if unit= "map"
return_dismat	logical, if TRUE return a matrix of distances from focal cell instead of a matrix to pass to terra::focal (default FALSE)

Value

if a matrix of 1's and NA's showing which cells to include and exclude respectively in focal calculations, or if return_dismat=TRUE, a matrix indicating the distance from the focal cell.

BPI *Calculates Bathymetric Position Index*

Description

Calculates Bathymetric Position Index (BPI). This is the value of the focal pixel minus the mean of the surrounding pixels contained within an annulus shaped window.

Usage

```
BPI(
  r,
  radius = NULL,
  unit = "cell",
  w = NULL,
  na.rm = FALSE,
  include_scale = FALSE,
  filename = NULL,
  overwrite = FALSE,
  wopt = list()
)
```

Arguments

r	DTM as a SpatRaster or RasterLayer
radius	a vector of length 2 specifying the inner and outer radii of the annulus c(inner,outer). This is ignored if w is provided.
unit	unit for radius. Either "cell" (number of cells, the default) or "map" for map units (e.g. meters). This is ignored if w is provided.
w	A focal weights matrix specifying which cells to include and exclude in the annulus focal window which can be created using MultiscaleDTM::annulus_window.
na.rm	A logical vector indicating whether or not to remove NA values before calculations
include_scale	logical indicating whether to append window size to the layer names (default = FALSE). If unit="map" then window size will have "MU" after the number indicating that the number represents the window size in map units.
filename	character Output filename.
overwrite	logical. If TRUE, filename is overwritten (default is FALSE).
wopt	list with named options for writing files as in writeRaster

Value

a SpatRaster or RasterLayer

References

Lundblad, E.R., Wright, D.J., Miller, J., Larkin, E.M., Rinehart, R., Naar, D.F., Donahue, B.T., Anderson, S.M., Battista, T., 2006. A benthic terrain classification scheme for American Samoa. Marine Geodesy 29, 89–111. https://doi.org/10.1080/01490410600738021

Examples

```
r<- rast(volcano, extent= ext(2667400, 2667400 +
ncol(volcano)*10, 6478700, 6478700 + nrow(volcano)*10),
crs = "EPSG:27200")
bpi<- BPI(r, radius = c(2,4), unit = "cell", na.rm = TRUE)
plot(bpi)
```

---

circle_window *Creates circular focal window*

Description

Creates circular focal window around central pixel.

Usage

```
circle_window(radius, unit = "cell", resolution, return_dismat = FALSE)
```

Arguments

radius	radius of circular window
unit	unit for radius. Either "cell" (number of cells, the default) or "map" for map units (e.g. meters).
resolution	resolution of intended raster layer (one number or a vector of length 2). Only necessary if unit= "map"
return_dismat	logical, if TRUE return a matrix of distances from focal cell instead of a matrix to pass to terra::focal.

Value

if a matrix of 1's and NA's showing which cells to include and exclude respectively in focal calculations, or if return_dismat=TRUE, a matrix indicating the distance from the focal cell.

classify_features_ff *Helper function factory to classify morphometric features*

Description

Helper function factory to classify morphometric features according to a modified version of Wood 1996 page 120

Usage

```
classify_features_ff(slope_tolerance = 1, curvature_tolerance = 1e-04)
```

Arguments

`slope_tolerance`
: Slope tolerance that defines a 'flat' surface (degrees; default is 1.0). Relevant for the features layer.

`curvature_tolerance`
: Curvature tolerance that defines 'planar' surface (default is 0.0001). Relevant for the features layer.

Value

A function that can be passed to raster::overlay to classify morphometric features

References

Wood, J., 1996. The geomorphological characterisation of digital elevation models (Ph.D.). University of Leicester.

explore_terrain *Interactive Shiny app to look at terrain attributes*

Description

Interactive Shiny app to look at terrain attributes based on a surface fit using a Wood/Evans Quadratic Equation: Z =ax^2+by^2+cxy+dx+ey(+f)

Usage

```
explore_terrain()
```

Value

No return value, launches Shiny app.

References

Evans, I.S., 1980. An integrated system of terrain analysis and slope mapping. Zeitschrift f˙ur Geomorphologic Suppl-Bd 36, 274–295.

Wood, J., 1996. The geomorphological characterisation of digital elevation models (Ph.D.). University of Leicester.

Minár, J., Evans, I.S., Jenčo, M., 2020. A comprehensive system of definitions of land surface (topographic) curvatures, with implications for their application in geoscience modelling and prediction. Earth-Science Reviews 211, 103414. https://doi.org/10.1016/j.earscirev.2020.103414

`kmax` *Calculate max curvature*

Description

Calculate max curvature, kmax, from the equation Z =ax^2+by^2+cxy+dx+ey(+f).

Usage

```
kmax(a, b, c, d, e)
```

Arguments

`a`	regression coefficient
`b`	regression coefficient
`c`	regression coefficient
`d`	regression coefficient
`e`	regression coefficient

References

Evans, I.S., 1980. An integrated system of terrain analysis and slope mapping. Zeitschrift f˙ur Geomorphologic Suppl-Bd 36, 274–295.

Wood, J., 1996. The geomorphological characterisation of digital elevation models (Ph.D.). University of Leicester.

Minár, J., Evans, I.S., Jenčo, M., 2020. A comprehensive system of definitions of land surface (topographic) curvatures, with implications for their application in geoscience modelling and prediction. Earth-Science Reviews 211, 103414. https://doi.org/10.1016/j.earscirev.2020.103414

`kmean` *Calculate mean curvature*

Description

Calculate mean curvature, kmean, from the equation Z =ax^2+by^2+cxy+dx+ey(+f).

Usage

```
kmean(a, b, c, d, e)
```

Arguments

`a`	regression coefficient
`b`	regression coefficient
`c`	regression coefficient
`d`	regression coefficient
`e`	regression coefficient

References

Evans, I.S., 1980. An integrated system of terrain analysis and slope mapping. Zeitschrift f˙ur Geomorphologic Suppl-Bd 36, 274–295.

Wood, J., 1996. The geomorphological characterisation of digital elevation models (Ph.D.). University of Leicester.

Minár, J., Evans, I.S., Jenčo, M., 2020. A comprehensive system of definitions of land surface (topographic) curvatures, with implications for their application in geoscience modelling and prediction. Earth-Science Reviews 211, 103414. https://doi.org/10.1016/j.earscirev.2020.103414

`kmin` *Calculate min curvature*

Description

Calculate min curvature, kmin, from the equation Z =ax^2+by^2+cxy+dx+ey(+f).

Usage

```
kmin(a, b, c, d, e)
```

Arguments

a	regression coefficient
b	regression coefficient
c	regression coefficient
d	regression coefficient
e	regression coefficient

References

Evans, I.S., 1980. An integrated system of terrain analysis and slope mapping. Zeitschrift f¨ur Geomorphologic Suppl-Bd 36, 274–295.

Wood, J., 1996. The geomorphological characterisation of digital elevation models (Ph.D.). University of Leicester.

Minár, J., Evans, I.S., Jenčo, M., 2020. A comprehensive system of definitions of land surface (topographic) curvatures, with implications for their application in geoscience modelling and prediction. Earth-Science Reviews 211, 103414. https://doi.org/10.1016/j.earscirev.2020.103414

---

knc *Calculate normal contour curvature*

Description

Calculate normal contour curvature (kn)c, which is the principal representative of the plan curvature group based on regression coefficients from the equation Z =ax^2+by^2+cxy+dx+ey(+f).

Usage

```
knc(a, b, c, d, e)
```

Arguments

a	regression coefficient
b	regression coefficient
c	regression coefficient
d	regression coefficient
e	regression coefficient

References

Evans, I.S., 1980. An integrated system of terrain analysis and slope mapping. Zeitschrift f¨ur Geomorphologic Suppl-Bd 36, 274–295.

Wood, J., 1996. The geomorphological characterisation of digital elevation models (Ph.D.). University of Leicester.

Minár, J., Evans, I.S., Jenčo, M., 2020. A comprehensive system of definitions of land surface (topographic) curvatures, with implications for their application in geoscience modelling and prediction. Earth-Science Reviews 211, 103414. https://doi.org/10.1016/j.earscirev.2020.103414

kns *Calculate normal slope line curvature*

Description

Calculate normal slope line curvature (kn)s, which is the principal representative of the profile curvature group based on regression coefficients from the equation Z =ax^2+by^2+cxy+dx+ey(+f).

Usage

```
kns(a, b, c, d, e)
```

Arguments

a	regression coefficient
b	regression coefficient
c	regression coefficient
d	regression coefficient
e	regression coefficient

References

Evans, I.S., 1980. An integrated system of terrain analysis and slope mapping. Zeitschrift f˙ur Geomorphologic Suppl-Bd 36, 274–295.

Wood, J., 1996. The geomorphological characterisation of digital elevation models (Ph.D.). University of Leicester.

Minár, J., Evans, I.S., Jenčo, M., 2020. A comprehensive system of definitions of land surface (topographic) curvatures, with implications for their application in geoscience modelling and prediction. Earth-Science Reviews 211, 103414. https://doi.org/10.1016/j.earscirev.2020.103414

ku *Calculate unsphericity curvature*

Description

Calculate unsphericity curvature, ku, from the equation Z =ax^2+by^2+cxy+dx+ey(+f).

Usage

```
ku(a, b, c, d, e)
```

Arguments

a	regression coefficient
b	regression coefficient
c	regression coefficient
d	regression coefficient
e	regression coefficient

References

Evans, I.S., 1980. An integrated system of terrain analysis and slope mapping. Zeitschrift f˙ur Geomorphologic Suppl-Bd 36, 274–295.

Wood, J., 1996. The geomorphological characterisation of digital elevation models (Ph.D.). University of Leicester.

Minár, J., Evans, I.S., Jenčo, M., 2020. A comprehensive system of definitions of land surface (topographic) curvatures, with implications for their application in geoscience modelling and prediction. Earth-Science Reviews 211, 103414. https://doi.org/10.1016/j.earscirev.2020.103414

---

outlier_filter — *Helper function to filter outliers from regression parameters using interquartile range*

Description

Helper function to filter outliers from regression parameters using interquartile range

Usage

```
outlier_filter(params, outlier_quantile, wopt = list())
```

Arguments

params	regression parameters for fitted surface
outlier_quantile	vector of length 2 specifying the quantiles used for filtering outliers
wopt	list with named options for writing files as in writeRaster

Qfit *Calculates multiscale slope, aspect, curvature, and morphometric features using a local quadratic fit*

Description

Calculates multiscale slope, aspect, curvature, and morphometric features of a DTM over a sliding rectangular window using a local quadratic fit to the surface (Evans, 1980; Wood, 1996).

Usage

```
Qfit(
  r,
  w = c(3, 3),
  unit = "degrees",
  metrics = c("elev", "qslope", "qaspect", "qeastness", "qnorthness", "profc", "planc",
    "twistc", "meanc", "maxc", "minc", "features"),
  slope_tolerance = 1,
  curvature_tolerance = 1e-04,
  outlier_quantile = c(0.01, 0.99),
  na.rm = FALSE,
  force_center = FALSE,
  include_scale = FALSE,
  mask_aspect = TRUE,
  return_params = FALSE,
  as_derivs = FALSE,
  filename = NULL,
  overwrite = FALSE,
  wopt = list()
)
```

Arguments

r	DTM as a SpatRaster (terra) or RasterLayer (raster) in a projected coordinate system where map units match elevation/depth units (up is assumed to be north for calculations of aspect, northness, and eastness).
w	Vector of length 2 specifying the dimensions of the rectangular window to use where the first number is the number of rows and the second number is the number of columns. Window size must be an odd number. Default is 3x3.
unit	"degrees" or "radians".
metrics	Character vector specifying which terrain attributes to return. The default is to return all available metrics, c("elev", "qslope", "qaspect", "qeastness", "qnorthness", "profc", "planc", "twistc", "meanc", "maxc", "minc", "features"). Slope, aspect, eastness, and northness are preceded with a 'q' to differentiate them from the measures calculated by SlpAsp() where the 'q' indicates that a quadratic

surface was used for the calculation. 'elev' is the predicted elevation at the central cell (i.e. the intercept term of the regression) and is only relevant when force_center=FALSE. 'profc' is the profile curvature, 'planc' is the plan curvature, 'meanc' is the mean curvature, 'minc' is minimum curvature, and 'features' are morphometric features. See details.

`slope_tolerance`
: Slope tolerance that defines a 'flat' surface (degrees; default = 1.0). Relevant for the features layer.

`curvature_tolerance`
: Curvature tolerance that defines 'planar' surface (default = 0.0001). Relevant for the features layer.

`outlier_quantile`
: vector of length 2 specifying the quantiles used for filtering outliers

`na.rm`
: Logical indicating whether or not to remove NA values before calculations.

`force_center`
: Logical specifying whether the constrain the model through the central cell of the focal window

`include_scale`
: Logical indicating whether to append window size to the layer names (default = FALSE).

`mask_aspect`
: Logical. If TRUE (default), aspect will be set to NA and northness and eastness will be set to 0 when slope = 0. If FALSE, aspect is set to 270 degrees or 3*pi/2 radians ((-pi/2)- atan2(0,0)+2*pi) and northness and eastness will be calculated from this.

`return_params`
: Logical indicating whether to return Wood/Evans regression parameters (default = FALSE).

`as_derivs`
: Logical indicating whether parameters should be formatted as partial derivatives instead of regression coefficients (default = FALSE) (Minár et al., 2020).

`filename`
: character Output filename. Can be a single filename, or as many filenames as there are layers to write a file for each layer

`overwrite`
: logical. If TRUE, filename is overwritten (default is FALSE).

`wopt`
: list with named options for writing files as in writeRaster

Details

This function calculates slope, aspect, eastness, northness, profile curvature, plan curvature, mean curvature, twisting curvature, maximum curvature, minimum curvature, morphometric features, and a smoothed version of the elevation surface using a quadratic surface fit from Z = aX^2+bY^2+cXY+dX+eY+f, where Z is the elevation or depth values, X and Y are the xy coordinates relative to the central cell in the focal window, and a-f are parameters to be estimated (Evans, 1980; Minár et al. 2020; Wood, 1996). For aspect, 0 degrees represents north (or if rotated, the direction that increases as you go up rows in your data) and increases clockwise. For calculations of northness (cos(asp)) and eastness (sin(asp)), up in the y direction is assumed to be north, and if this is not true for your data (e.g. you are using a rotated coordinate system), you must adjust accordingly. All curvature formulas are adapted from Minár et al 2020. Therefore all curvatures are measured in units of 1/length (e.g. m^-1) except twisting curvature which is measured in radians/length (i.e. change in angle per unit distance), and we adopt a geographic sign convention where convex is positive and concave is negative (i.e., hills are considered convex with positive. Naming convention for curvatures is not consistent across the literature, however Minár et al (2020) has suggested a framework in which the reported measures of curvature translate to profile curvature = (kn)s, plan curvature = (kn)c, twisting curvature (Tg)c, mean curvature = kmean, maximum curvature = kmax, minimum curvature = kmin. For morphometric features cross-sectional curvature (zcc) was replaced by planc (kn)c, z”min was replaced by kmax, and z”max was replaced by kmin as these are more robust ways to measures the same types of curvature (Minár et al., 2020). Additionally, the planar feature from Wood (1996) was split into planar flat and slope depending on whether the slope threshold is exceeded or not.

Value

a SpatRaster (terra) or RasterStack/RasterLayer (raster)

References

Evans, I.S., 1980. An integrated system of terrain analysis and slope mapping. Zeitschrift f¨ur Geomorphologic Suppl-Bd 36, 274–295.

Minár, J., Evans, I.S., Jenčo, M., 2020. A comprehensive system of definitions of land surface (topographic) curvatures, with implications for their application in geoscience modelling and prediction. Earth-Science Reviews 211, 103414. https://doi.org/10.1016/j.earscirev.2020.103414

Wilson, M.F., O’Connell, B., Brown, C., Guinan, J.C., Grehan, A.J., 2007. Multiscale Terrain Analysis of Multibeam Bathymetry Data for Habitat Mapping on the Continental Slope. Marine Geodesy 30, 3-35. https://doi.org/10.1080/01490410701295962

Wood, J., 1996. The geomorphological characterisation of digital elevation models (Ph.D.). University of Leicester.

Examples

```
r<- rast(volcano, extent= ext(2667400, 2667400 +
ncol(volcano)*10, 6478700, 6478700 + nrow(volcano)*10),
crs = "EPSG:27200")
qmetrics<- Qfit(r, w = c(5,5), unit = "degrees", na.rm = TRUE)
plot(qmetrics)

# To get only the regression coefficients, set "metrics=c()" and "return_params=TRUE"
reg_coefs<- Qfit(r, w = c(5,5), metrics=c(), unit = "degrees", na.rm = TRUE, return_params=TRUE)
plot(reg_coefs)
```

RDMV *Calculates Relative Difference from Mean Value (RDMV)*

Description

Calculates Relative Difference from Mean Value (RDMV). RDMV = (focal_value - local_mean)/local_range or RDMV = (focal_value - local_mean)/local_sd.

Usage

```
RDMV(
  r,
  w = c(3, 3),
  method = "range",
  na.rm = FALSE,
  include_scale = FALSE,
  filename = NULL,
  overwrite = FALSE,
  wopt = list()
)
```

Arguments

`r`	DTM as a SpatRaster, RasterLayer, RasterStack, or RasterBrick
`w`	A vector of length 2 specifying the dimensions of the rectangular window to use where the first number is the number of rows and the second number is the number of columns. Window size must be an odd number. Default is 3x3.
`method`	standardization method. Either "range" (the default) or "sd".
`na.rm`	A logical indicating whether or not to remove NA values before calculations
`include_scale`	logical indicating whether to append window size to the layer names (default = FALSE)
`filename`	character Output filename.
`overwrite`	logical. If TRUE, filename is overwritten (default is FALSE).
`wopt`	list with named options for writing files as in writeRaster

Value

a SpatRaster or RasterLayer

References

Lecours, V., Devillers, R., Simms, A.E., Lucieer, V.L., Brown, C.J., 2017. Towards a Framework for Terrain Attribute Selection in Environmental Studies. Environmental Modelling & Software 89, 19-30. https://doi.org/10.1016/j.envsoft.2016.11.027

Examples

```
r<- rast(volcano, extent= ext(2667400, 2667400 +
ncol(volcano)*10, 6478700, 6478700 + nrow(volcano)*10),
crs = "EPSG:27200")
rdmv<- RDMV(r, w=c(5,5), na.rm = TRUE, method="range")
plot(rdmv)
```

RIE *Calculates Roughness Index-Elevation*

Description

Calculates Roughness Index-Elevation. This is the standard deviation of residual topography in a focal window where residual topography is calculated as the focal pixel minus the focal mean.

Usage

```
RIE(
  r,
  w = c(3, 3),
  na.rm = FALSE,
  include_scale = FALSE,
  filename = NULL,
  overwrite = FALSE,
  wopt = list()
)
```

Arguments

r	DTM as a SpatRaster or RasterLayer
w	A vector of length 2 specifying the dimensions of the rectangular window to use where the first number is the number of rows and the second number is the number of columns. Window size must be an odd number. Default is 3x3.
na.rm	A logical indicating whether or not to remove NA values before calculation of SD
include_scale	logical indicating whether to append window size to the layer names (default = FALSE)
filename	character Output filename.
overwrite	logical. If TRUE, filename is overwritten (default is FALSE).
wopt	list with named options for writing files as in writeRaster

Details

Note the original paper by Cavalli et al (2008) uses a fixed 5x5 window and uses 25 as the denominator indicating use of the population standard deviation. This implementation provides a flexible window size and istead calculates the sample standard deviation which uses a denominator of n-1.

Value

a SpatRaster or RasterLayer

References

Cavalli, M., Tarolli, P., Marchi, L., Dalla Fontana, G., 2008. The effectiveness of airborne LiDAR data in the recognition of channel-bed morphology. CATENA 73, 249–260. https://doi.org/10.1016/j.catena.2007.11.001

Examples

```
r<- rast(volcano, extent= ext(2667400, 2667400 +
ncol(volcano)*10, 6478700, 6478700 + nrow(volcano)*10),
crs = "EPSG:27200")
rie<- RIE(r, w=c(5,5), na.rm = TRUE)
plot(rie)
```

SAPA *Calculates surface area to planar area rugosity*

Description

Calculates surface area (Jenness, 2004) to planar area rugosity and by default corrects planar area for slope using the arc-chord ratio (Du Preez, 2015). Additionally, the method has been modified to allow for calculations at multiple different window sizes (see details).

Usage

```
SAPA(
  r,
  w = 1,
  slope_correction = TRUE,
  include_scale = FALSE,
  slope_layer = NULL,
  filename = NULL,
  overwrite = FALSE,
  wopt = list()
)
```

Arguments

`r` DTM as a SpatRaster or RasterLayer in a projected coordinate system where map units match elevation/depth units

`w` A single number or a vector of length 2 (row, column) specifying the dimensions of the rectangular window over which surface area will be summed. Window size must be an odd number. 1 refers to "native" scale and surface area and planar area will be calculated per cell (the traditional implementation).

`slope_correction` Whether to use the arc-chord ratio to correct planar area for slope (default is TRUE)

`include_scale` logical indicating whether to append window size to the layer names (default = FALSE)

slope_layer	Optionally specify an appropriate slope layer IN RADIANS to use. If not supplied, it will be calculated using the SlpAsp function based on Misiuk et al (2021). The slope layer should have a window size that is 2 larger than the w specified for SAPA.
filename	character Output filename.
overwrite	logical. If TRUE, filename is overwritten (default is FALSE).
wopt	list with named options for writing files as in writeRaster

Details

Planar area is calculated as the x_dis * y_dis if uncorrected for slope and (x_dis * y_dis)/cos(slope) if corrected for slope. When w=1, this is called "native" scale and is equivalent to what is presented in Du Preez (2015) and available in the ArcGIS Benthic Terrain Modeller add-on. In this case operations are performed on a per cell basis where x_dis is the resolution of the raster in the x direction (left/right) and y_dis is the resolution of the raster in the y direction (up/down) and slope is calculated using the Horn (1981) method. To expand this to multiple scales of analysis, at w > 1 slope is calculated based on Misiuk et al (2021) which provides a modification of the Horn method to extend the matric to multiple spatial scales. Planar area is calculated the same way as for w=1 except that now x_dis is the x resolution of the raster * the number of columns in the focal window, and y_dis is y resolution of the raster * the number of rows. For w > 1, surface area is calculated as the sum of surface areas within the focal window. Although the (modified) Horn slope is used by default to be consistent with Du Preez (2015), slope calculated using a different algorithm (e.g. Wood 1996) could be supplied using the slope_layer argument. Additionally, a slope raster can be supplied if you have already calculated it and do not wish to recalculate it. However, be careful to supply a slope layer measured in radians and calculated at the relevant scale (2 larger than the w of SAPA).

Value

a SpatRaster or RasterLayer

References

Du Preez, C., 2015. A new arc–chord ratio (ACR) rugosity index for quantifying three-dimensional landscape structural complexity. Landscape Ecol 30, 181–192. https://doi.org/10.1007/s10980-014-0118-8

Horn, B.K., 1981. Hill Shading and the Reflectance Map. Proceedings of the IEEE 69, 14-47.

Jenness, J.S., 2004. Calculating landscape surface area from digital elevation models. Wildlife Society Bulletin 32, 829-839.

Misiuk, B., Lecours, V., Dolan, M.F.J., Robert, K., 2021. Evaluating the Suitability of Multi-Scale Terrain Attribute Calculation Approaches for Seabed Mapping Applications. Marine Geodesy 44, 327-385. https://doi.org/10.1080/01490419.2021.1925789

Examples

```
r<- rast(volcano, extent= ext(2667400, 2667400 +
ncol(volcano)*10, 6478700, 6478700 + nrow(volcano)*10),
crs = "EPSG:27200")
```

```
sapa<- SAPA(r, w=c(5,5), slope_correction = TRUE)
plot(sapa)
```

SlpAsp *Multiscale Slope and Aspect*

Description

Calculates multiscale slope and aspect based on the slope.k/aspect.k algorithm from Misiuk et al (2021) which extends classical formulations of slope restricted to a 3x3 window to multiple scales. The code from Misiuk et al (2021) was modified to allow for rectangular rather than only square windows.

Usage

```
SlpAsp(
  r,
  w = c(3, 3),
  unit = "degrees",
  method = "queen",
  metrics = c("slope", "aspect", "eastness", "northness"),
  include_scale = FALSE,
  mask_aspect = TRUE,
  filename = NULL,
  overwrite = FALSE,
  wopt = list()
)
```

Arguments

r	DTM as a SpatRaster or RasterLayer in a projected coordinate system where map units match elevation/depth units
w	A vector of length 2 specifying the dimensions of the rectangular window to use where the first number is the number of rows and the second number is the number of columns. Window size must be an odd number.
unit	"degrees" or "radians"
method	"queen" or "rook", indicating how many neighboring cells to use to compute slope for any cell. queen uses 8 neighbors (up, down, left, right, and diagonals) and rook uses 4 (up, down, left, right). Alternatively, instead of "queen" or "rook", method can be specified as 8 and 4 respectively.
metrics	a character string or vector of character strings of which terrain atrributes to return ("slope" and/or "aspect"). Default is c("slope", "aspect", "eastness", "northness").
include_scale	logical indicating whether to append window size to the layer names (default = FALSE)

`mask_aspect` A logical. If slope evaluates to 0, aspect will be set to NA when mask_aspect is TRUE (the default). If FALSE, when slope is 0 aspect will be pi/2 radians or 90 degrees which is the behavior of raster::terrain.

`filename` character Output filename. Can be a single filename, or as many filenames as there are layers to write a file for each layer

`overwrite` logical. If TRUE, filename is overwritten (default is FALSE).

`wopt` list with named options for writing files as in writeRaster

Details

When method="rook", slope and aspect are computed according to Fleming and Hoffer (1979) and Ritter (1987). When method="queen", slope and aspect are computed according to Horn (1981). These are the standard slope algorithms found in many GIS packages but are traditionally restricted to a 3 x 3 window size. Misiuk et al (2021) extended these classical formulations to multiple window sizes. This function modifies the code from Misiuk et al (2021) to allow for rectangular rather than only square windows and also added aspect.

Value

a SpatRaster or RasterStack of slope and/or aspect (and components of aspect)

References

Fleming, M.D., Hoffer, R.M., 1979. Machine processing of landsat MSS data and DMA topographic data for forest cover type mapping (No. LARS Technical Report 062879). Laboratory for Applications of Remote Sensing, Purdue University, West Lafayette, Indiana.

Horn, B.K., 1981. Hill Shading and the Reflectance Map. Proceedings of the IEEE 69, 14-47.

Misiuk, B., Lecours, V., Dolan, M.F.J., Robert, K., 2021. Evaluating the Suitability of Multi-Scale Terrain Attribute Calculation Approaches for Seabed Mapping Applications. Marine Geodesy 44, 327-385. https://doi.org/10.1080/01490419.2021.1925789

Ritter, P., 1987. A vector-based slope and aspect generation algorithm. Photogrammetric Engineering and Remote Sensing 53, 1109-1111.

Examples

```
r<- rast(volcano, extent= ext(2667400, 2667400 +
ncol(volcano)*10, 6478700, 6478700 + nrow(volcano)*10),
crs = "EPSG:27200")
slp_asp<- SlpAsp(r = r, w = c(5,5), unit = "degrees",
method = "queen", metrics = c("slope", "aspect",
"eastness", "northness"))
plot(slp_asp)
```

`SurfaceArea` *Calculates surface area of a DTM*

Description

Calculates surface area on a per cell basis of a DTM based on Jenness, 2004.

Usage

```
SurfaceArea(r, filename = NULL, overwrite = FALSE, wopt = list())
```

Arguments

`r`	DTM as a SpatRaster or RasterLayer in a projected coordinate system where map units match elevation/depth units
`filename`	character Output filename.
`overwrite`	logical. If TRUE, filename is overwritten (default is FALSE).
`wopt`	list with named options for writing files as in writeRaster

Value

a SpatRaster or RasterLayer

References

Jenness, J.S., 2004. Calculating landscape surface area from digital elevation models. Wildlife Society Bulletin 32, 829-839.

Examples

```
r<- rast(volcano, extent= ext(2667400, 2667400 +
ncol(volcano)*10, 6478700, 6478700 + nrow(volcano)*10),
crs = "EPSG:27200")
sa<- SurfaceArea(r)
plot(sa)
```

`tgc` *Calculate contour geodesic torsion*

Description

Calculate contour geodesic torsion (tg)c, which is the principal representative of the twisting curvature group based on regression coefficients from the equation Z =ax^2+by^2+cxy+dx+ey(+f).

Usage

```
tgc(a, b, c, d, e)
```

Arguments

a	regression coefficient
b	regression coefficient
c	regression coefficient
d	regression coefficient
e	regression coefficient

References

Evans, I.S., 1980. An integrated system of terrain analysis and slope mapping. Zeitschrift f`ur Geomorphologic Suppl-Bd 36, 274–295.

Wood, J., 1996. The geomorphological characterisation of digital elevation models (Ph.D.). University of Leicester.

Minár, J., Evans, I.S., Jenčo, M., 2020. A comprehensive system of definitions of land surface (topographic) curvatures, with implications for their application in geoscience modelling and prediction. Earth-Science Reviews 211, 103414. https://doi.org/10.1016/j.earscirev.2020.103414

`TPI` *Calculates Topographic Position Index*

Description

Calculates Topographic Position Index (TPI). This is the value of the focal pixel minus the mean of the surrounding pixels (i.e. local mean but excluding the value of the focal pixel).

Usage

```
TPI(
  r,
  w = c(3, 3),
  na.rm = FALSE,
  include_scale = FALSE,
  filename = NULL,
  overwrite = FALSE,
  wopt = list()
)
```

Arguments

`r`	DTM as a SpatRaster or RasterLayer
`w`	A vector of length 2 specifying the dimensions of the rectangular window to use where the first number is the number of rows and the second number is the number of columns. Window size must be an odd number. Default is 3x3.
`na.rm`	A logical indicating whether or not to remove NA values before calculations
`include_scale`	logical indicating whether to append window size to the layer names (default = FALSE)
`filename`	character Output filename.
`overwrite`	logical. If TRUE, filename is overwritten (default is FALSE).
`wopt`	list with named options for writing files as in writeRaster

Value

a SpatRaster or RasterLayer

References

Weiss, A., 2001. Topographic Position and Landforms Analysis. Presented at the ESRI user conference, San Diego, CA.

Examples

```
r<- rast(volcano, extent= ext(2667400, 2667400 +
ncol(volcano)*10, 6478700, 6478700 + nrow(volcano)*10),
crs = "EPSG:27200")
tpi<- TPI(r, w=c(5,5), na.rm = TRUE)
plot(tpi)
```

VRM — *Implementation of the Sappington et al., (2007) vector ruggedness measure*

Description

Implementation of the Sappington et al., (2007) vector ruggedness measure, modified from Evans (2021).

Usage

```
VRM(
  r,
  w,
  na.rm = FALSE,
  include_scale = FALSE,
  filename = NULL,
  overwrite = FALSE,
  wopt = list()
)
```

Arguments

`r`	DTM as a SpatRaster or RasterLayer
`w`	A vector of length 2 specifying the dimensions of the rectangular window to use where the first number is the number of rows and the second number is the number of columns. Window size must be an odd number.
`na.rm`	A logical indicating whether or not to remove NA values before calculations
`include_scale`	logical indicating whether to append window size to the layer names (default = FALSE)
`filename`	character Output filename.
`overwrite`	logical. If TRUE, filename is overwritten (default is FALSE).
`wopt`	list with named options for writing files as in writeRaster

Value

a RasterLayer

References

Evans JS (2021). spatialEco. R package version 1.3-6, https://github.com/jeffreyevans/spatialEco.

Sappington, J.M., Longshore, K.M., Thompson, D.B., 2007. Quantifying Landscape Ruggedness for Animal Habitat Analysis: A Case Study Using Bighorn Sheep in the Mojave Desert. The Journal of Wildlife Management 71, 1419-1426. https://doi.org/10.2193/2005-723

Examples

```
r<- rast(volcano, extent= ext(2667400, 2667400 +
ncol(volcano)*10, 6478700, 6478700 + nrow(volcano)*10),
crs = "EPSG:27200")
vrm<- VRM(r, w=c(5,5), na.rm = TRUE)
plot(vrm)
```

Index