Package ‘wflo’

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Title  Data Set and Helper Functions for Wind Farm Layout Optimization Problems
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Description Provides a convenient data set, a set of helper functions, and a benchmark function for economically (profit) driven wind farm layout optimization. This enables researchers in the field of the NP-hard (non-deterministic polynomial-time hard) problem of wind farm layout optimization to focus on their optimization methodology contribution and also provides a realistic benchmark setting for comparability among contributions. See Croonenbroeck, Carsten & Hennecke, David (2020) <doi:10.1016/j.energy.2020.119244>.

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Author Carsten Croonenbroeck [aut, cre],
    David Hennecke [ctb]

Maintainer Carsten Croonenbroeck <carsten.croonenbroeck@uni-rostock.de>
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AcquireData

Downloads the larger data set for entire Germany.

Description

Convenience function that downloads the larger data set covering the entire area of Germany and saves it to the specified directory. This data set can replace the smaller sub sample data set that is part of this package.
AirDensity

Usage

AcquireData(Folder)

Arguments

Folder must be a character string containing the folder location to where the file will be saved. For instance, use `getwd` to save to the current working directory.

Details

This function will interactively lead the user through the downloading process and also gives advice on how to use the larger data set. Make sure that R can write to the specified directory.

Value

AcquireData returns nothing.

Author(s)

Carsten Croonenbroeck

See Also

Use `FarmVars` for the settings object and `FarmData` for the smaller, built-in data set that is part of this package.

Examples

```r
## Not run:
AcquireData(tempdir())
# Will download the data file to the specified directory.
## End(Not run)
```

AirDensity Provides convenient computations for air density.

Description

Implements a set of computations and constants to compute air density as a function of altitude (a.s.l.), temperature and relative humidity.

Usage

AirDensity(Altitude = 0, Temperature = 20, phi = 0.76)
### Arguments

- **Altitude** altitude in meters above sea level.
- **Temperature** temperature in degrees Celsius.
- **phi** relative humidity, must be within [0, 1].

### Details

The function first computes air pressure at user provided target altitude based on the barometric formula. Then, saturation vapor pressure is computed using the Magnus formula. With both, the density of air is computed afterward.

### Value

`AirDensity` returns a single value representing air density in kg per cubic meter.

### Note

This function returns valid values for negative altitudes, but only for temperature values between -45 and +60 degrees Celsius.

### Author(s)

Carsten Croonenbroeck

### See Also

- `WindspeedLog` and `WindspeedHellmann` to compute wind speed at target heights using two slightly different established models.

### Examples

```r
AirDensity()
AirDensity(300, 25, 0.6)
AirDensity(0, 0, 0) # Standard conditions according to DIN 1343:1990,
                  # returns the expected value of 1.292.
```

### Description

The partial Jensen wake model requires the overlap area of the rotor disc at the downwind location with the wake disc. This function computes it.

### Usage

```r
Area(a, b, d)
```
Cost

Arguments

a must be a single value. Provide the radius of the first circle in meters.
b must be a single value. Provide the radius of the second circle in meters.
d must be a single value. Provide the distance between the two circles’ centers.

Details

If a turbine is downwind another turbine, the wake cone of that upwind turbine may only partially cover the rotor disc of the second turbine. For the partial wake model it is necessary to compute the covered area.

Value

Area returns covered area in square meters.

Author(s)

Carsten Croonenbroeck

See Also

JensenTrapezoid to check whether there are wake effects present. FarmVars for the data object.

Examples

Area(60, 40, 50)
# Returns 2930.279.

Cost

Stub for a turbine’s cost function.

Description

A function that returns the yearly installation costs for a given set of turbines (provide x and y for the turbines’ locations). In its present form it only returns the 'UnitCost' value from the FarmVars settings object per turbine.

Usage

Cost(x, y)

Arguments

x can be a single value or a numeric vector of values, contains the ’x’ location(s) of turbines.
y can be a single value or a numeric vector of values, contains the ’y’ location(s) of turbines.
Details

Note that \(x\) and \(y\) should both be of length \(n\), i.e. the numbers of values they contain should match the number of turbines in the current wind farm layout problem. This function is a stub and can and should be replaced by something reasonable in an actual wind farm layout problem.

Value

\(\text{Cost}\) returns a vector of values. The number of elements matches the length of \(x\) and \(y\).

Author(s)

Carsten Croonenbroeck

See Also

\(\text{Profit}\) to see where to use \(\text{Cost}\), \(\text{Yield}\) for a similar function for yearly yield.

Examples

```r
## Returns a vector of two, c(100000, 100000).
Cost(c(0.5, 0.7), c(0.2, 0.3))

## Replace the function by another function
## also called 'Cost', embedded in environment e.
## Also, see the vignette.
## Not run:
e$Cost <- function(x, y) #x, y \in R^n
{
  retVal <- rep(e$FarmVars$UnitCost, min(length(x), length(y)))
  retVal[x > 0.5] <- retVal[x > 0.5] * 2
  return(retVal)
}
set.seed(1357)
NumTurbines <- 4 # For example.
Result <- pso::psoptim(par = runif(NumTurbines * 2), fn = Profit,
  lower = rep(0, NumTurbines * 2), upper = rep(1, NumTurbines * 2))
Result
rm(Cost, envir = e)
## End(Not run)
```

---

e

Environment for data and variables.

Description

Environment that contains variables object \(\text{FarmVars}\) and, if downloaded, full data set \(\text{FarmData}\).
FarmData

Usage

e

Details

e contains data and variables, see FarmVars and FarmData.

Value

e returns the environment for FarmVars and FarmData.

Author(s)

Carsten Croonenbroeck

See Also

AcquireData for downloading the full data set.

Examples

```
e
## Gives the environment object.
```

---

FarmData  Data set for wind farm layout optimization.

Description

This list object contains four matrices covering adjusted yield, wind speed, wind direction and standard deviations of wind directions in Germany.

Usage

FarmData

Format

A list object containing seven matrices, each containing 25 x 25 values at a raster resolution of 200 x 200 m (note that for the larger data set downloadable using AcquireData, each matrix contains 4400 x 3250 values):

$\text{AdjustedYield}$: Yield is average annual energy production (AEP). According to FGW technical guidelines, AEP is adjusted due to different location qualities to obtain a better guess at the marketable energy output. Interpret these values directly as "megawatt hours per year".

$\text{WindSpeed}$: Average wind speeds in meters per second.
FarmVars

$\text{WindDirection}$: Average wind directions in degrees (azimuth system).

$\text{SDDirection}$: Standard deviations of wind directions in degrees (azimuth system).

$\text{Elevation}$: Terrain relief (elevation in meters).

$\text{Slope}$: Terrain slope in degrees.

$\text{SlopeDirection}$: Direction of hillside in degrees.

**Note**

If the full mode data set is present, it is loaded into the environment. The built-in data set FarmData contains matrices of dimension 25 x 25, while the full data set eFarmData consists of 4400 x 3250 matrices.

**Author(s)**

Carsten Croonenbroeck
David Hennecke

**Source**


Croonenbroeck, C. & Hennecke, D. Does the German renewable energy act provide a fair incentive system for onshore wind power? - A simulation analysis, Energy Policy, 2020, 114, 111663, 1-15, [https://doi.org/10.1016/j.enpol.2020.111663](https://doi.org/10.1016/j.enpol.2020.111663)

**Examples**

```r
# 'Profit' uses this data set internally:
NumTurbines <- 4
set.seed(1357)
Result <- optim(par = runif(NumTurbines * 2), fn = Profit, method = "L-BFGS-B",
    lower = rep(0, NumTurbines * 2), upper = rep(1, NumTurbines * 2))
Result
PlotResult(Result)
```

**FarmVars**

Variables object for wind farm specifications.
**Description**

This list object collects all necessary variables for wind farm layout optimizations within this package. The object is loaded upon loading the package, embedded into a user writeable environment and provides a set of default values.

**Usage**

FarmVars

**Format**

A list object containing:

$UnitCost: This contains yearly costs per turbine in actual currency. Mostly, this will be installation costs, maintenance cost and others. If, for example, total turbine installation costs are 2 mio. EUR and the projected life span of the turbine is 20 years, then the yearly cost is roughly 100,000 EUR, which is also the default value for this item. Refine the number at will to encompass annuity (taking interest effects into consideration), salvage, or the mentioned maintenance cost.

$Price: This denotes the average sale price of electricity produced at the wind farm per megawatt hour. Defaults to 100, since 100 EUR per megawatt hour is a good (still rough) estimate in the European electricity market.

$StartPoint: Denotes the point at which to start to 'cut out' a sample field from the data set. Since the full data set covers the entire region of Germany at a 200 x 200 meters resolution, the entire area is too big for a wind farm. For an actual wind farm layout optimization problem, a smaller region is indicated. This package will conveniently provide a square area of 5 km x 5 km in size. Note: Concerning the larger data set covering the entire area of Germany (conveniently downloadable using AcquireData), this area can be found at point 2000:2000 (full data covering a range of 4400 x 3250 points) and from there, spans a five kilometers square, i.e. covers the raster at 2000:2024, 2000:2024. Change the default value of 1 to 2000 to find that area or to something else for cross checking your algorithm with data covering a different area. However, for comparability, evaluate your algorithm result at the default of 2000 or using the built-in data set.

$Width: Denotes the width (and, since the test area is a square, also the height) of the test area. Defaults to 25, which leads to a 5 km x 5 km square as a sample wind field, as the raster resolution is 200 x 200 m.

$MeterMinDist: Denotes the minimum distance from one turbine to another in meters. Defaults to 500 meters, which is a rather conservative value.

$EndPoint: The complement to '$StartPoint'. Is computed based on '$StartPoint' and '$Width' as follows: FarmVars$StartPoint + FarmVars$Width - 1. By default, $StartPoint = 1 and $Width = 25, so $EndPoint = 1 + 25 - 1 = 25.

$MeterWidth: Contains the width (and, since the test area is a square, also the height) of the test area in meters. Since by default, FarmVars$Width = 25 and the raster resolution is 200 x 200 m, this defaults to $MeterWidth = 200 * 25 = 5000 meters (5 km).
$\text{MinDist}$: Contains the minimum distance in problem space. Since the problem space in a convenient unit square, this defaults to $\text{MinDist} = \text{MeterMinDist} / \text{MeterWidth} = 500 / 5000 = 0.1$.

$z$: Contains the hub height of the turbine type under investigation. Default value is 100 meters.

$z_0$: Contains the terrain’s roughness length required for Jensen’s wake model. In most studies, a default value of 0.1 is agreed to be a good guess for onshore wind farms, so this is the default value here.

$r_0$: Contains the rotor radius for the turbine type under investigation. For instance, a Vestas V90 turbine has a rotor diameter of 90 meters (hence the name), so the radius is 45 meters, which is also the default value here.

Partial: Selects whether to incorporate partial Jensen wake or not. Defaults to TRUE.

$\text{BenchmarkSolution}$: Contains the best setup for the standard benchmark field at a task of placing 20 turbines. This result has been generated by optimizer genoud() from package rgenoud. It should serve as a benchmark or starting point for improved solutions. e$FarmVars$BenchmarkSolution is taken from Croonenbroeck & Hennecke (2020). Note, however, that the computed profit is a little less than the 12,053,607 EUR reported there, since, starting from version 1.6, wflo by default takes partial Jensen wake effects into account. This does however in no way constrain the representativeness of e$FarmVars$BenchmarkSolution.

Source
Carsten Croonenbroeck

References

Examples

# Inspect the benchmark solution by
Result <- list(par = e$FarmVars$BenchmarkSolution)
Profit(Result$par)
PlotResult(Result)
ShowWakePenalizers(Result)

GaussWS
Convenience function to look-up values from a object returned by GenerateGauss.
**GaussWS**  

**Description**  
Dependent on the resolution at which `GenerateGauss` was set to use, the resolution coordinates (array indices) cannot immediately be interpreted as being measured in meters. This function returns wind speeds from the Gauss object according to x, y, z simply provided in meters.

**Usage**  

```r  
GaussWS(Gauss, x, y, z)  
```

**Arguments**  

- **Gauss** must be an object returned by `GenerateGauss`.
- **x** must be a single value. Provide desired distance in meters.
- **y** must be a single value. Provide desired distance in meters. May be negative.
- **z** must be a single value. Provide desired distance in meters.

**Details**  
The Gaussian wake model is loosely based on the initial contribution by Bastankhah & Porte-Agel (2014).

**Value**  

`GaussWS` returns a single number which can be considered a wind speed in the wake of a turbine at location x, y, and z.

**Author(s)**  
Carsten Croonenbroeck

**References**  

**See Also**  
Use `GenerateGauss` to compute the three-dimensional tensor array object containing the wind speed data. See `QuickGauss3D` for the same algorithm, immediately returning the wind speed at one single point only.

**Examples**  

```r  
## Not run:  
GaussWS(Gauss, 100, 1, 100)  
GaussWS(Gauss, 80, -40, 90)  
GaussWS(Gauss, 200, 40, 150)  
## End(Not run)  
```
GenerateGauss

For an incoming wind speed at reference height, this function computes a 3D tensor object containing Gaussian model based wind speeds.

Description

This function pre-computes Gaussian wind speeds and stores them in a 3D array, similar to voxels. Using that 'table', wind speeds can be looked up very quickly, which makes Gaussian wake feasible during WFLO runs.

Usage

GenerateGauss(u = 8, refHeight = 10, maxX = 500, resY = 100, resZ = 100, Verbose = TRUE)

Arguments

- **u**: measured wind speed at reference height. Will mostly be measured in meters per second.
- **refHeight**: reference height in meters. This is the height at which the incoming wind speed u is measured.
- **maxX**: the number of steps down the x axis for which to compute the model.
- **resY**: the number of steps along the y axis for which to compute the model. Note that as y may take negative values, the resolution space should be chosen not too small, here. If, e.g., resY = 100, this means that y may take values from -50 to 50, which may be too low a resolution in some cases.
- **resZ**: the number of steps up the z axis for which to compute the model.
- **Verbose**: selectes whether the function displays status reports during computation, as it may take some time, dependent on the resolution setting.

Details

Users may choose to compute a rather fine resolution run over night and then save the returned object so it can be loaded in future sessions. The Gaussian wake model is loosely based on the initial contribution by Bastankhah & Porte-Agel (2014).

Value

GenerateGauss returns the three-dimensional array containing wind speeds.

Note

Note that the model assumes that along the x axis, x = 0 is the turbine location. x expands along the wind direction downwind. y denoted whether a point is 'left' or 'right' the x axis. Thus, the x-z plane is the plane along the x axis and perpendicular to the ground. The z axis is height, starting at 0 = ground level.
Geo2Ari

Author(s)
Carsten Croonenbroeck

References

See Also
Use GaussWS for a convenience function to look-up the values from the returned array. See QuickGauss3D for the same algorithm, immediately returning the wind speed at one single point only.

Examples
```r
## Not run:
Gauss <- GenerateGauss(maxX = 500, resY = 1000, resZ = 1000)
## End(Not run)
```

Geo2Ari

Converts degrees between the arithmetic system and the azimuth system (and vice versa).

Description
Use this function to convert degrees from the arithmetic system (0° being east, ascending counter-clockwise) into the azimuth system (0° being north, ascending clockwise) and vice versa.

Usage
```
Geo2Ari(g)
```

Arguments
```
g contains a single value degree (usually between 0° and 360°, decimal fractions allowed).
```

Details
```
g may contain degrees from both systems, the function turns the data into the respective other system.
```

Value
```
Geo2Ari returns a single value of degrees.
```
GetAngle

Author(s)

Carsten Croonenbroeck

See Also

GetDirInfo for further degree information.

Examples

Geo2Ari(0)
## In an arithmetic system, 0° means 'east', while 'east' in
## azimuth notation is 90°. This call returns 90.
Geo2Ari(90)
## In an azimuth system, 90° means 'east', while 'east' in
## arithmetic notation is 0°. This call returns 0.
Geo2Ari(Geo2Ari(123))
## Returns 123.

GetAngle

Returns the angle between two turbines.

Description

As seen from a point in the wind farm, computes the angle to another point in that farm.

Usage

GetAngle(x1, y1, x2, y2)

Arguments

x1 must be a single value. Provide the x location of the first turbine.
y1 must be a single value. Provide the y location of the first turbine.
x2 must be a single value. Provide the x location of the second turbine.
y2 must be a single value. Provide the y location of the second turbine.

Details

From point 2's point of view, computes the angle to point 1.

Value

GetAngle returns a single number between 0 and 360. If both points are identical, the return value is 0.
**Note**

Note that this function returns an angle in arithmetic degrees notation. To convert to azimuth notation, use `Geo2Ari`.

**Author(s)**

Carsten Croonenbroeck

**See Also**

Use `JensenAngle` to compute the wake cone and with it, use `JensenTrapezoid` to see if another turbine B is in turbine A's wake.

**Examples**

```r
GetAngle(0.2, 0.2, 0.1, 0.1)
## Looking from point (0.1, 0.1) at point (0.2, 0.2), the angle is 45° (arithmetic).
```

---

**Description**

Given a point, an angle information (in arithmetic degrees), and a length information, computes start and end points of an arrow usable via the `arrows` function.

**Usage**

```r
GetArrow(BaseX, BaseY, Degrees, Frac = 25)
```

**Arguments**

- **BaseX** must be a single value containing the x value of a point which later will be the center of the arrow.
- **BaseY** must be a single value containing the y value of a point which later will be the center of the arrow.
- **Degrees** must be a single value containing the desired rotation degree of the arrow.
- **Frac** must be a single value containing the length of the arrow. Default is 25 and for convenience, this parameter should in most cases be identical to FarmVars$Width.

**Details**

This function will be used internally by `PlotResult`.

**Value**

`GetArrow` returns a vector of four values representing x and y for the start point and x and y for the end point of an arrow (in that order).
GetDirInfo

Author(s)

Carsten Croonenbroeck

See Also

Use PlotResult to visualize the optimization result. See FarmVars for the data object.

Examples

GetArrow(0.5, 0.5, 45)
#At c(0.5, 0.5), generates an arrow pointing in north-eastern direction.

\[
\text{GetDirInfo}(x, y, \text{Dirs}, \text{SDs})
\]

Arguments

\begin{itemize}
\item \textbf{x} must be a single value containing the 'x' location of a turbine in problem space.
\item \textbf{y} must be a single value containing the 'y' location of a turbine in problem space.
\item \textbf{Dirs} a matrix containing average yearly wind directions. Usually, the third element of the list object FarmData will be used as this matrix.
\item \textbf{SDs} a matrix containing average yearly wind direction standard deviations. Usually, the fourth element of the list object FarmData will be used as this matrix.
\end{itemize}

Value

GetDirInfo returns a vector of two elements, the first being the average wind direction in degrees and the second being the corresponding standard deviation. Note that degrees are meant in the arithmetic degrees system (0° being east, ascending counterclockwise). To transform into an azimuth system (0° being north, ascending clockwise), use function Geo2Ari. Also note that wind directions are meant to denote 'where the wind is going to' rather than 'where the wind is coming from'.

Author(s)

Carsten Croonenbroeck
See Also

Profit to see where to use GetDirInfo, Yield for a similar function for adjusted yield. See FarmVars for the data object.

Examples

```
Dirs <- FarmData[[3]][e$FarmVars$StartPoint:e$FarmVars$EndPoint, e$FarmVars$StartPoint:e$FarmVars$EndPoint]
SDs <- FarmData[[4]][e$FarmVars$StartPoint:e$FarmVars$EndPoint, e$FarmVars$StartPoint:e$FarmVars$EndPoint]
GetDirInfo(0.5, 0.7, Dirs, SDs)
## Returns wind direction and standard deviation for the given location
## and provided the matrices given.
```

GetFarmFromLonLat  
Accesses full FarmData set and returns a compatible list object for the requested location.

Description

This function accepts a pair longitude (decimal system, east) and latitude (decimal system, north) coordinates as well a a desired edge length in m and if valid, returns a list object similar to FarmData, but at the specified location and with the specified size.

Usage

GetFarmFromLonLat(Top, Left, EdgeLen, DoPlot = FALSE)

Arguments

- **Top**  
  longitude value (decimal system, east).
- **Left**  
  latitude value (decimal system, north).
- **EdgeLen**  
  edge length in meters. Note that the returned farm data object is always a square area and thus, contains square matrices.
- **DoPlot**  
  optionally plots the annual energy production (AEP) 'landscape' in the returned object using a terrain.colors coloring scheme, together with a color key.

Details

Requires that the full FarmData dataset is loaded. See AcquireData on how to obtain it.

Value

Returns a list object following the structure of FarmData, but only containing the farm area starting from the top-left point specified and as many 'tiles' required to meet the desired edge length at 200 m tiles resolution.
**GK2Index**

**Author(s)**
Carsten Croonenbroeck

**See Also**
See [Index2GK](#) to convert index coordinates to Gauss-Kruger coordinates, and [GK2LonLat](#) to convert Gauss-Kruger coordinates to longitude/latitude coordinates.

**Examples**

```r
# This will return a farm at the specified location, edge length 5,000 m (5 km).
# Requires full data set to be loaded.
## Not run:
MyFarm <- GetFarmFromLonLat(51.49594, 11.58818, 5000, DoPlot = FALSE)
## End(Not run)
```

**GK2Index**

Converts Gauss-Kruger coordinates to FarmData indices.

**Description**

This function accepts Gauss-Kruger (GK) coordinates that are within the FarmData space and converts them to a pair of indices that point to locations within the FarmData matrices.

**Usage**

```r
GK2Index(X, Y)
```

**Arguments**

- **X**: a numeric value for the 'right' value in the GK coordinate system.
- **Y**: a numeric value for the 'top' value in the GK coordinate system.

**Details**

Assumes that the GK zone is EPSG 31467. References to indices valid if the full data set is loaded, see [FarmData](#) and [AcquireData](#).

**Value**

Returns index values between 1 and 3,250 for X and between 1 and 4,400 for Y.

**Author(s)**
Carsten Croonenbroeck
GK2LonLat

See Also
Index2GK for the inverse.

Examples
GK2Index(3280000, 5230000) # Will return c(1, 4400), the lower left point.
GK2Index(3929800, 6109800) # Will return c(3250, 1), the top right point.

GK2LonLat

Converts Gauss-Kruger coordinates to longitude/latitude coordinates.

Description
This function accepts a pair of Gauss-Kruger (GK) coordinates and converts them to longitude (decimal system, east) and latitude (decimal system, north) coordinates by performing re-projection.

Usage
GK2LonLat(X, Y)

Arguments
X a numeric value for the 'right' value in the GK coordinate system.
Y a numeric value for the 'top' value in the GK coordinate system.

Details
Assumes that the GK zone is EPSG 31467.

Value
Returns a vector of two values where longitude is first, latitude second.

Author(s)
Carsten Croonenbroeck

See Also
LonLat2GK for the inverse.

Examples
LonLat <- GK2LonLat(3702793, 5998319) # Will return c(12.09750, 54.07547).
Height

Returns the elevation of a turbine’s location.

**Description**

For a turbine’s location represented by x and y, looks up the elevation from the matrix Elev. Internally transforms coordinates of x and y from problem space (usually unit square) to the matrix space of Elev.

**Usage**

```
Height(x, y, Elev)
```

**Arguments**

- **x**: must be a single value containing the ’x’ location of a turbine in problem space.
- **y**: must be a single value containing the ’y’ location of a turbine in problem space.
- **Elev**: a matrix containing heights. Usually, the fifth element of the list object `FarmData` will be used as this matrix.

**Details**

Height is a convenience function for looking up heights as required e.g. for a partial Jensen wake model, independent from the actual size of the area under investigation.

**Value**

Height returns a single value, the elevation in meters.

**Author(s)**

Carsten Croonenbroeck

**See Also**

`Profit` to see where to use Height. See `FarmData` for the data set.

**Examples**

```r
## Returns adjusted yield for the given location.
P <- c(0.5868695, 0.9722714)
Height(P[1], P[2], FarmData[[5]][e$FarmVars$StartPoint:e$FarmVars$EndPoint, 
e$FarmVars$StartPoint:e$FarmVars$EndPoint])
```
**ImposeVectorField**

**Simple helper function for PlotResult.**

**Description**

Draws a set of arrows over an existing plot. Will be used internally by **PlotResult** to visualize the vector field of wind directions over a plot of the wind farm.

**Usage**

```r
ImposeVectorField(xNum = 5, yNum = 5, ColMain = "black",
                    ColBand = "white", Frac = 25, DoSDs = TRUE)
```

**Arguments**

- **xNum** must be a single value containing the desired number of arrows horizontally.
- **yNum** must be a single value containing the desired number of arrows vertically.
- **ColMain** must be a single value containing the desired color for the main wind direction arrow.
- **ColBand** must be a single value containing the desired color for the secondary arrows representing the standard deviation arrows. Only used if **DoSDs = TRUE**.
- **Frac** must be a single value containing the desired length information for the arrows. Will be passed to **GetArrow** internally.
- **DoSDs** must be **TRUE** or **FALSE**. If **TRUE**, will not only draw one arrow for the main wind direction per point, but also two additional arrows (using color **ColBand**) representing the main wind direction plus/minus half the standard deviation.

**Details**

This function will be used internally by **PlotResult**. **ImposeVectorField** requires **FarmData** to be present and an existing plot to impose the vector field over.

**Value**

**ImposeVectorField** returns nothing.

**Author(s)**

Carsten Croonenbroeck

**See Also**

Use **PlotResult** to visualize the optimization result.
Index2GK

Converts FarmData indices to Gauss-Kruger coordinates.

Description

This function accepts indices that are within the FarmData space and converts them to a pair of Gauss-Kruger (GK) coordinates.

Usage

Index2GK(X, Y)

Arguments

X

a numeric value for the 'X' value in the FarmData space.

Y

a numeric value for the 'Y' value in the FarmData space.

Details

Assumes that the GK zone is EPSG 31467. References to indices are valid if the full data set is loaded, see FarmData and AcquireData.

Value

For index values between 1 and 3,250 for X and between 1 and 4,400 for Y, returns Gauss-Kruger coordinates valid in the EPSG 31467 coordinate system.

Author(s)

Carsten Croonenbroeck

See Also

GK2Index for the inverse.

Examples

Index2GK(1, 4400) # Will return c(3280000, 5230000), the lower left point.
Index2GK(3250, 1) # Will return c(3929800, 6109800), the top right point.
For a given distance $x$, computes the wake cone generated by a turbine.

Description

In Jensen’s wake model, a wake cone is generated by a turbine based on the turbine’s hub height $z$, its rotor radius $r_0$, the terrain’s roughness length $z_0$ and the distance $x$ between the turbine under investigation and a certain second point. $z$, $r_0$ and $z_0$ are taken from the FarmVars settings object, while $x$ is to be provided.

Usage

```
JensenAngle(x)
```

Arguments

- $x$ must be a single value. Provide distance in meters.

Details

If a second turbine (B) is in a first turbine (A)’s wake, turbine B’s power output must be penalized due to turbulence. This can be performed via Jensen’s wake model, but first, it should be checked whether B is actually in A’s wake. This function computes the angle of the wake cone generated by turbine A. This can be used together with function `JensenTrapezoid` `PointInPolygon` and to see if B is in the wake of A.

Value

`JensenAngle` returns the (onesided) angle of the wake cone generated by a turbine for distance $x$.

Author(s)

Carsten Croonenbroeck

References


See Also

- `JensenTrapezoid` to check whether there are wake effects present. `FarmVars` for the data object.

Examples

```
JensenAngle(500)
```

## For a distance of 500 m, the function returns a wake cone angle of 9.2233 degrees

## (given standard values for $z$, $z_0$ and $r_0$ in the FarmVars settings object).
JensenFactor

For a given distance $x$, computes the penalty factor for a turbine’s wake.

Description

In Jensen’s wake model, a wake cone is generated by a turbine based on the turbine’s hub height $z$, its rotor radius $r_0$, the terrain’s roughness length $z_0$ and the distance $x$ between the turbine under investigation and a certain second point. $z$, $r_0$ and $z_0$ are taken from the FarmVars settings object, while $x$ is to be provided.

Usage

JensenFactor($x$)

Arguments

$x$ must be a single value. Provide distance in meters.

Details

If a second turbine (B) is in a first turbine (A)’s wake, turbine B’s power output must be penalized due to turbulence. This function computes the penalty factor for that wake.

Value

JensenFactor returns the a single number between 0 and 1, which can immediately be used a a penalty factor.

Note

Note that for Jensen’s multiple wake model, wake penalties from several potentially influencing upwind turbines must be computed. As the factors are between 0 and 1, they can conveniently multiplied by each other afterward. If there are four turbines (A, B, C, D) inside a wind farm, you are investigating turbine D and it turns out that D is in the wake of B and C, but not A, then compute penalty for B (assume 0.7) and C (assume 0.8). Now, the penalty factors for A, B and C are 1, 0.7 and 0.8, so $1 \times 0.7 \times 0.8 = 0.56$ is the penalty for turbine D.

Author(s)

Carsten Croonenbroeck

References

JensenTrapezoid

See Also

Use JensenAngle to compute the wake cone and with it, use JensenTrapezoid to see if another turbine B is in turbine A's wake. Apply JensenFactor only if this is the case.

Examples

JensenFactor(500)
  ## Provided that turbine B is in turbine A's wake and that the two turbines are 500 meters apart,
  ## turbine B must be penalized by a factor of 0.7952.

JensenTrapezoid Computes the four corner points of a Jensen trapezoid (or cone).

Description

Provided a wind direction, a point and a downwind length, computes the corner points of a Jensen trapezoid (in the literature oftentimes called a 'cone').

Usage

JensenTrapezoid(WindDir, Point, x, Margin = TRUE)

Arguments

WindDir unique value, a wind direction in degrees.
Point a vector of two containing x and y coordinates of a point. Usually, both will be between 0 and 1.
x downwind distance of the cone in meters.
Margin specified whether to add a small margin to the distance parameter (i.e. internally, compute x * 1.1). Defaults to TRUE.

Value

JensenTrapezoid returns a matrix of four columns (the four corner points) and two rows (x and y coordinates).

Author(s)

Carsten Croonenbroeck

References

LonLat2GK

See Also

JensenAngle to compute ‘cone’ angle information, PointInPolygon for a test whether a point is inside a polygon.

Examples

MyTrapezoid <- JensenTrapezoid(45, c(0.5, 0.5), 500)

LonLat2GK

Converting longitude/latitude coordinates to Gauss-Kruger coordinates.

Description

This function accepts a pair longitude (decimal system, east) and latitude (decimal system, north) coordinates and converts them to Gauss-Kruger (GK) coordinates by performing re-projection.

Usage

LonLat2GK(Lon, Lat)

Arguments

Lon longitude value (decimal system, east).
Lat latitude value (decimal system, north).

Details

The resulting values are in GK zone EPSG 31467.

Value

Returns a vector of two values where X is first, Y second.

Author(s)

Carsten Croonenbroeck

See Also

GK2LonLat for the inverse.

Examples

LonLat2GK(12.09750, 54.07548) # Will return c(3702793, 5998320).
MosettiTurbineCost

Returns Mosetti's cost model for a number of turbines.

Description

This function returns the dimensionless cost based on Mosetti et al. (1994).

Usage

MosettiTurbineCost(N)

Arguments

N    number of turbines for which cost is to be computed.

Details

Wind farm cost does not increase linearly with the number of turbines. Economies of scale lead to disproportionate cost increases. This function returns the dimensionless cost based on Mosetti et al. (1994).

Value

MosettiTurbineCost returns a dimensionless cost factor.

Author(s)

Carsten Croonenbroeck

References


See Also

Cost for a plug-in cost function for profit.

Examples

MosettiTurbineCost(1)
MosettiTurbineCost(20)
PairPenalty  

*Returns the Jensen wake penalty factor for a pair of turbines.*

**Description**

As seen from a turbine in the wind farm, computes the wake penalty factor for another turbine in that farm.

**Usage**

```
PairPenalty(x1, y1, x2, y2, Dirs, SDs)
```

**Arguments**

- `x1` must be a single value. Provide the x location of the first turbine.
- `y1` must be a single value. Provide the y location of the first turbine.
- `x2` must be a single value. Provide the x location of the second turbine.
- `y2` must be a single value. Provide the y location of the second turbine.
- `Dirs` a matrix containing average yearly wind directions. Usually, the third element of the list object `FarmData` will be used as this matrix.
- `SDs` a matrix containing average yearly wind direction standard deviations. Usually, the fourth element of the list object `FarmData` will be used as this matrix.

**Details**

First, this function uses `GetAngle` to compute the angle between the two points provided, as seen from point 2’s point of view. It then obtains the wind direction at point 2 using `GetDirInfo`. After that, the distance between the two points is computed. With it, the wake cone is computed using `JensenAngle` to check whether point 2 is in point 1’s wake using `JensenTrapezoid`. If that is the case, `JensenFactor` is used to compute the penalty factor.

Note that the penalty is the deduction to wind speed. It applies to wind power by its third power, so the user is responsible to take it to its cube himself. `Profit` does that automatically internally.

**Value**

PairPenalty returns a single number between 0 and 1. If point 2 is not in the wake of point 1, the function returns 1.

**Author(s)**

Carsten Croonenbroeck

**See Also**

Use `JensenFactor` to see how this function operates. See `FarmVars` for the data object.
Examples

```r
dirs <- FarmData[[3]][e$FarmVars$StartPoint:e$FarmVars$EndPoint,
e$FarmVars$StartPoint:e$FarmVars$EndPoint]
sds <- FarmData[[4]][e$FarmVars$StartPoint:e$FarmVars$EndPoint,
e$FarmVars$StartPoint:e$FarmVars$EndPoint]
PairPenalty(0.9, 0.8, 0.6, 0.9, dirs, sds)
# Weak wake penalty
PairPenalty(0.1, 0.1, 0.6, 0.9, dirs, sds)
# No wake penalty
```

PartialJensen

*Computes the partial Jensen wake effect.*

Description

If a rotor disc of a first turbine is only partially covered by a wake cone of a second turbine, the penalty must be adjusted accordingly. This function returns partial penalties, if partial wake applies, or full penalty, if not.

Usage

```r
PartialJensen(x2, y2, x1, y1, dirs, sds, elev, Z = NULL, drawtop = FALSE,
drawfront = FALSE, drawside = FALSE)
```

Arguments

- `x1` must be a single value. Provide the x location of the first turbine.
- `y1` must be a single value. Provide the y location of the first turbine.
- `x2` must be a single value. Provide the x location of the second turbine.
- `y2` must be a single value. Provide the y location of the second turbine.
- `dirs` a matrix containing average yearly wind directions. Usually, the third element of the list object `FarmData` will be used as this matrix.
- `sds` a matrix containing average yearly wind direction standard deviations. Usually, the fourth element of the list object `FarmData` will be used as this matrix.
- `elev` a matrix containing elevations. Usually, the fifth element of the list object `FarmData` will be used as this matrix.
- `Z` accepts a vector of two representing the heights of the turbines at the two points in meters. If NULL (the default), PartialJensen uses e$FarmVars$z as the heights information for both points. In all cases, the heights are added to the terrain topography information from `elev`.
- `drawtop` If TRUE, draws a top view of the partial wake situation. Defaults to FALSE. Should not be TRUE at the same time as `drawfront` or `drawside`.
- `drawfront` If TRUE, draws a front view of the partial wake situation. Defaults to FALSE. Should not be TRUE at the same time as `drawtop` or `drawside`.
- `drawside` If TRUE, draws a side view of the partial wake situation. Defaults to FALSE. Should not be TRUE at the same time as `drawtop` or `drawfront`.
Details

The function first checks whether there is partial coverage. If so, it adjusts the penalty internally
given by `PairPenalty` and if not, returns the full penalty. Therefore, the function is imposed over
an existing Jensen model and refines it.
Note that the penalty is the deduction to wind speed. It applies to wind power by its third power, so
the user is responsible to take it to its cube himself. `Profit` does that automatically internally.

Value

`PartialJensen` returns a penalty between 0 and 1.

Author(s)

Carsten Croonenbroeck

References

Journal of Wind Engineering and Industrial Aerodynamics, 39(1-3), pp. 251-265, https://doi.org/10.1016/0167-
6105(92)90551-K.

See Also

`JensenTrapezoid` to check whether there are wake effects present. `FarmVars` for the data object.
`PairPenalty` for the non-partial wake penalty.

Examples

```r
P1 <- c(0.5868695, 0.9722714)
P2 <- c(0.4827957, 0.9552658)
if (exists("FarmData", envir = e, inherits = FALSE))
{
 Dirs <- e$FarmData[[3]][e$FarmVars$StartPoint:e$FarmVars$EndPoint, 
e$FarmVars$StartPoint:e$FarmVars$EndPoint]
 SDs <- e$FarmData[[4]][e$FarmVars$StartPoint:e$FarmVars$EndPoint, 
e$FarmVars$StartPoint:e$FarmVars$EndPoint]
  Elev <- e$FarmData[[5]][e$FarmVars$StartPoint:e$FarmVars$EndPoint, 
e$FarmVars$StartPoint:e$FarmVars$EndPoint]
} else
{
  Dirs <- FarmData[[3]][e$FarmVars$StartPoint:e$FarmVars$EndPoint, 
e$FarmVars$StartPoint:e$FarmVars$EndPoint]
  SDs <- FarmData[[4]][e$FarmVars$StartPoint:e$FarmVars$EndPoint, 
e$FarmVars$StartPoint:e$FarmVars$EndPoint]
  Elev <- FarmData[[5]][e$FarmVars$StartPoint:e$FarmVars$EndPoint, 
e$FarmVars$StartPoint:e$FarmVars$EndPoint]
}
#
## First, compute the non-partial penalty:
Penal <- PairPenalty(P2[1], P2[2], P1[1], P1[2], Dirs, SDs)
```
## Then, correct it for partial coverage:
Penal2 <- PartialJensen(P2[1], P2[2], P1[1], P1[2], Dirs, SDs, Elev)

## Now draw a top view:
Penal2 <- PartialJensen(P2[1], P2[2], P1[1], P1[2], Dirs, SDs, Elev, DrawTop = TRUE)

## Now draw a front view:
Penal2 <- PartialJensen(P2[1], P2[2], P1[1], P1[2], Dirs, SDs, Elev, DrawFront = TRUE)
## Note that the downwind point is somewhat elevated, seems 'right'
## from the upwind point of view, and far away (rotor disc seems smaller).

## Now draw a side view:
Penal2 <- PartialJensen(P2[1], P2[2], P1[1], P1[2], Dirs, SDs, Elev, DrawSide = TRUE)

## For elevation, see
Height(P1[1], P1[2], Elev) # (upwind point)
## and
Height(P2[1], P2[2], Elev) # (downwind point)

## Instead, for the next example, the downwind point is closer
## to the upwind point (larger impression of rotor disc), 'left'
## of it and lower in terms of elevation:
x1 <- 0.5
y1 <- 0.5
x2 <- 0.45
y2 <- 0.478
Penal <- PairPenalty(x2, y2, x1, y1, Dirs, SDs)
Penal2 <- PartialJensen(x2, y2, x1, y1, Dirs, SDs, Elev, DrawTop = TRUE)
Penal2 <- PartialJensen(x2, y2, x1, y1, Dirs, SDs, Elev, DrawFront = TRUE)
## For elevation, see
Height(x1, y1, Elev) # (upwind point)
## and
Height(x2, y2, Elev) # (downwind point)

---

**PlotResult**

*Visualizes the wind farm layout optimization result.*

**Description**

This function draws the adjusted yields of the wind farm under investigation using **image**, superimposes a contour plot using **contour** and arrows for the wind directions using **ImposeVectorField** and then draws the points for the turbines’ locations (aligned to their respective raster grid centers).

**Usage**

```
PlotResult(Result, ImageData = NULL, DoLabels = FALSE, Labels = “IDs”)
```
Arguments

Result must be an optimization result as returned by an optimizer such as `optim`. Usually, this will be a list at least containing `'$par'`. Most optimizers comply with this R standard. If your optimizer does not, wrap its result into a list containing an object `'$par'` containing the optimization result (i.e., a vector of points).

ImageData a matrix containing the data for the background, processed via `image`. If not provided (or NULL), uses the data in `FarmData[[1]]` or, if present, `e$FarmData[[1]]`. Defaults to NULL.

DoLabels a boolean that indicates whether labels should be plotted next to the points. Defaults to FALSE.

Labels a vector of length \( n = N / 2 \), can be numeric values or strings. Defines the labels to be shown if DoLabels = TRUE. Defaults to "IDs", in which case the points are sequently numbered from 1:n. Labels is ignored if DoLabels = FALSE.

Details

For maximum convenience and compatibility with numeric optimizers of most kinds, this function expects nothing but the usual optimization result list. This, however, requires that the `FarmData` dataset as well as the `FarmVars` object is present defining additional settings.

Value

PlotResult returns nothing.

Author(s)

Carsten Croonenbroeck

See Also

Use Profit to obtain an optimization result.

Examples

```r
#Will not provide a very good result
NumTurbines <- 4
set.seed(1357)
Result <- optim(par = runif(NumTurbines * 2), fn = Profit,
   method = "L-BFGS-B", lower = rep(0, NumTurbines * 2),
   upper = rep(1, NumTurbines * 2))
Result
PlotResult(Result)
```
PointInPolygon

Checks whether a point is inside a polygon.

Description

Uses the famous Jensen test to check whether a provided point is inside a polygon, the latter defined by a set of points.

Usage

PointInPolygon(PointMat, TestPoint)

Arguments

PointMat  a 2 x 4 matrix, four corner points of each x and y coordinates.
TestPoint  a vector of two containing x and y coordinates of a point to test.

Value

PointInPolygon returns TRUE if the point is inside the polygon, or FALSE, else.

Author(s)

Carsten Croonenbroeck

References


See Also

JensenTrapezoid to compute a Jensen trapezoid.

Examples

set.seed(1357)
Angle <- runif(n = 1, min = 0, max = 360)
Point <- runif(n = 2, min = 0, max = 1)
Dist <- rnorm(n = 1, mean = 200, sd = 200)
MyTrapezoid <- JensenTrapezoid(Angle, Point, Dist)

plot(x = MyTrapezoid[, ], y = MyTrapezoid[2, ], xlab = "", ylab = "")
lines(x = c(MyTrapezoid[1, 1], MyTrapezoid[1, 2]), y = c(MyTrapezoid[2, 1], MyTrapezoid[2, 2]))
lines(x = c(MyTrapezoid[1, 2], MyTrapezoid[1, 3]), y = c(MyTrapezoid[2, 2], MyTrapezoid[2, 3]))
lines(x = c(MyTrapezoid[1, 3], MyTrapezoid[1, 4]), y = c(MyTrapezoid[2, 3], MyTrapezoid[2, 4]))
lines(x = c(MyTrapezoid[1, 4], MyTrapezoid[1, 1]), y = c(MyTrapezoid[2, 4], MyTrapezoid[2, 1]))
NumTest <- 50

xTest <- runif(n = NumTest, min = min(MyTrapezoid[1, 1]), max = max(MyTrapezoid[1, 1]))
yTest <- runif(n = NumTest, min = min(MyTrapezoid[2, 1]), max = max(MyTrapezoid[2, 1]))

for (i in 1:NumTest)
{
  ThisPoint <- c(xTest[i], yTest[i])
  if (PointInPolygon(MyTrapezoid, ThisPoint))
  {
    points(ThisPoint[1], ThisPoint[2], pch = 16, col = "green")
  } else
  {
    points(ThisPoint[1], ThisPoint[2], pch = 16, col = "red")
  }
}

---

**Profit**

*Computes the economic profit for a given wind farm layout configuration*

---

**Description**

This is the bread-and-butter function to this package. It takes a set of points (turbine locations) and based on the adjusted yields in the field specified via the `FarmVars` settings object, checks whether the layout is valid, computes the Jensen penalties, generates the total marketable power production of this layout, takes cost and sale price into consideration and finally computes the farm’s economic profit. Note, however, that since most numeric optimizers by default operate as a minimizer, `Profit` returns the negative profit, i.e. a negative number for positive profit values and a positive number if cost is greater than revenue.

**Usage**

`Profit(X)`

**Arguments**

- `X` must be a numeric vector containing an even number of values, at least two. If the length of the vector is N, then n = N / 2 is the number of points. The first values 1,...,n are interpreted as x coordinates and the subsequent n + 1,...,N values are the y coordinates.

**Details**

For maximum convenience and compatibility with numeric optimizers of most kinds, this function expects nothing but the problem vector (the set of points) as a parameter. This, however, requires that the `FarmData` dataset as well as the `FarmVars` object is present defining additional settings. As `Profit` returns the negative profit for compatibility with minimizers, reverse the sign for actual profit values.
Profit

Profit requires the optimizer to accept box constraints, as Profit can not compute values outside the wind farm boundary (the function’s domain). If your optimizer does not accept box constraints, embed Profit into a wrapper function that returns the sum of costs if it least one point is outside the boundary.

Value

Profit returns a single number. The result is the negative profit for any valid setting of points and consequently, the sum of all costs for invalid settings.

Author(s)

Carsten Croonenbroeck

See Also

Calls Yield and Cost internally. Use PlotResult to visualize the optimization result.

Examples

```r
#Will not provide a very good result
NumTurbines <- 4
set.seed(1357)
Result <- optim(par = runif(NumTurbines * 2), fn = Profit,
               method = "L-BFGS-B", lower = rep(0, NumTurbines * 2),
               upper = rep(1, NumTurbines * 2))
Result
PlotResult(Result)

#Will provide a somewhat better result
#Necessary to install pso
## Not run:
NumTurbines <- 4
Result <- pso::psoptim(par = runif(NumTurbines * 2), fn = Profit,
                        lower = rep(0, NumTurbines * 2), upper = rep(1, NumTurbines * 2))
Result
PlotResult(Result)

## End(Not run)

#Simple wrapper function for optimizers not accepting box constraints
NumTurbines <- 4
lower <- rep(0, NumTurbines * 2)
upper <- rep(1, NumTurbines * 2)
Wrapper <- function(X)
{
xSel <- seq(from = 1, to = length(X) - 1, by = 2)
x <- X[xSel]
y <- X[xSel + 1]
if (any(x < lower) | any(x > upper) | any(y < lower) | any(y > upper))
{  
```
return(sum(rep(e$FarmVars$UnitCost, length(x))))
}

return(Profit(X))
}

## Not run:
set.seed(1357)
Result <- optim(par = runif(NumTurbines * 2), fn = Wrapper, method = "SANN")
Result
PlotResult(Result)
## End(Not run)

ProfitContributors

Computes profit contributions for all points in a setup solution.

Description

This function takes an optimizer result (or simple vector object) and computes the profit contribution for each point.

Usage

ProfitContributors(Result)

Arguments

Result must be an optimization result as returned by an optimizer such as optim or a vector. Usually, this will be a list at least containing '$par'.

Details

Neglecting a possibly invalid setup (caused by at least one point), computes the profit contributions. If the setup provided is valid, the sum of contributions is identical to the (absolute value of the) returned value of Profit.

Value

ProfitContributors returns a matrix of two columns and n rows, with n being the number of turbines. The first column is a sequence of 1:n, representing the turbine IDs, while the second column contains the actual profit contributions.

Author(s)

Carsten Croonenbroeck

See Also

See ValidSetup to see how a setup is categorized as valid or not. Use PlotResult to visualize the optimization result.
Examples

# Prints a result and uses the profit contributions as labels.
NumTurbines <- 4
set.seed(1235)
Result <- optim(par = runif(NumTurbines * 2), fn = Profit,
    method = "L-BFGS-B", lower = rep(0, NumTurbines * 2),
    upper = rep(1, NumTurbines * 2))
MyLabels <- ProfitContributors(Result)
MyLabels
# PlotResult(Result, DoLabels = TRUE, Labels = MyLabels[, 2])

# Given a valid setup, this should be TRUE.
# identical(abs(Profit(Result$par)), sum(MyLabels[, 2]))

QuickGauss3D

For an incoming wind speed at reference height, this function computes a 3D Gaussian model based wind speed.

Description

This function computes Gaussian wind speeds.

Usage

QuickGauss3D(x, y, z, u = 8, refHeight = 10)

Arguments

x
must be a single value. Provide distance in meters.
y
must be a single value. Provide distance in meters.
z
must be a single value. Provide distance in meters.
u
must be a single value. Provide wind speed in meters per second.
refHeight
must be a single value. Provide reference height (the height at which wind speed u was measured) in meters.

Details

The Gaussian wake model is loosely based on the initial contribution by Bastankhah & Porte-Agel (2014).

Value

QuickGauss3D returns a single number which can be considered a wind speed in the wake of a turbine at location x, y, and z.
**ShowWakePenalizers**

**Note**

Note that the model assumes that along the x axis, \( x = 0 \) is the turbine location. \( x \) expands along the wind direction downwind. \( y \) denoted whether a point is 'left' or 'right' the x axis. Thus, the x-z plane is the plane along the x axis and perpendicular to the ground. The z axis is height, starting at 0 = ground level.

**Author(s)**

Carsten Croonenbroeck

**References**


**See Also**

Use `GenerateGauss` to compute the three-dimensional tensor array object containing the wind speed data. Use `GaussWS` for a convenience function to look-up the values from the returned array.

**Examples**

- `QuickGauss3D(100, 1, 100)`
- `QuickGauss3D(200, -40, 120)`
- `QuickGauss3D(50, 40, 70)`

---

**ShowWakePenalizers**

Visualizes the points causing/'suffering' from wake effects.

**Description**

After optimization, this function draws a reduced 'field' and shows which points cause wake penalties on which points. 'Causers' are displayed in grey, 'sufferers', i.e. points that are in (possibly multiple) wakes of (several) causers are displayed in gold.

**Usage**

`ShowWakePenalizers(Result, Cones = TRUE, All = FALSE, VectorField = TRUE, ImposeMST = FALSE, NS = FALSE, NSOnly = FALSE, Exaggerate = TRUE, DoubleLine = TRUE, Frames = 100, Alpha = 0.5, MaxContrast = TRUE, Soften = TRUE)`
Arguments

Result must be an optimization result as returned by an optimizer such as \texttt{optim}. Usually, this will be a list at least containing $'\text{par}'$. Most optimizers comply with this R standard. If your optimizer does not, wrap its result into a list containing an object $'\text{par}'$ containing the optimization result (i.e., a vector of points).

Cones triggers whether the Jensen cones are to be displayed as well. Defaults to \texttt{TRUE}.

All triggers whether all Jensen cones are to be displayed, instead of just causers and sufferers. Defaults to \texttt{FALSE}, as \texttt{TRUE} results in a mess most of the times.

VectorField controls whether or not to impose the wind directions vector field (arrows). Defaults to \texttt{TRUE}.

ImposeMST if \texttt{TRUE}, computes and imposes a minimum spanning tree for the vertices, useful for cable installation purposes. Defaults to \texttt{FALSE}.

NS if \texttt{TRUE}, imposes a computationally intensive Navier-Stokes based wake simulation image over the plot. Defaults to \texttt{FALSE}.

NSOnly if \texttt{TRUE}, imposes just the Navier-Stokes wake simulation (no Jensen wakes). Defaults to \texttt{FALSE}.

Exaggerate if \texttt{TRUE}, displays turbines as squares in the Navier-Stokes visualization. The turbine is then still to scale, but in reality the rotor is a disc instead of a cube, of course. This overly emphasizes wakes, which may be desired in most cases. Thus, defaults to \texttt{TRUE}. Set to \texttt{FALSE} for a more realistic look of the rotor discs, but this will make the wakes appear less severe.

DoubleLine applies only if \texttt{Exaggerate == TRUE}. The rotor disc is then a disc instead of a cube (or line instead of square), but the line will be two instead of one pixel wide. This option is a trade-off between \texttt{Exaggerate == TRUE} and \texttt{Exaggerate == FALSE}. Set to \texttt{TRUE} (the default) if \texttt{Exaggerate == FALSE} to apply. Note that only if \texttt{Exaggerate == FALSE} and \texttt{DoubleLine == FALSE}, the rotor disc is a one pixel wide line, the most realistic setting which however shows only weak wakes.

Frames number of frames to pre-compute for the Navier-Stokes simulation. 100 is a good value. Less makes the computation faster, but more inaccurate. More than 100 in only necessary for very low wind speeds. Thus, defaults to 100.

Alpha The Navier-Stokes wake simulation is imposed semi-transparent over the usual image. This controls the transparency. \texttt{Alpha = 0} means transparent, \texttt{Alpha = 1} means opaque. Defaults to 0.5.

MaxContrast increases the contrast to maximum (this is equivalent to histogram stretching). Defaults to \texttt{TRUE}.

Soften applies a Gaussian soften filter to the Navier-Stokes image to have a more homogeneous visualization. Defaults to \texttt{TRUE}.

Details

Enables the researcher to inspect the optimization result in an a-posteriori analysis of Jensen’s wake model. Parts of the Navier-Stokes code are inspired by Stam (2003).
ShowWakePenalizers invisibly returns a square matrix (dimension: 'number of turbines') of wake penalty pairs: Columns are sufferers, rows are causers. For each row/column pair unequal to one, the turbine in row i sheds wake on the turbine in column j. The actual numbers are those returned by JensenFactor.

Author(s)

Carsten Croonenbroeck

References


See Also

Use PlotResult to visualize the optimization result.

Examples

## Not run:
# Will show that turbine 1 sheds wake on turbine 5.
NumTurbines <- 8
set.seed(1357)
Result <- optim(par = runif(NumTurbines * 2), fn = Profit,
               method = "L-BFGS-B", lower = rep(0, NumTurbines * 2),
               upper = rep(1, NumTurbines * 2))
ShowWakePenalizers(Result)

# This may take some time. A progress bar is displayed.
Result = list(par = e$FarmVars$BenchmarkSolution)
ShowWakePenalizers(Result, All = TRUE, NS = TRUE, VectorField = FALSE, Alpha = 0.7)

# Generates a few frames of an animation.
Result <- list(par = e$FarmVars$BenchmarkSolution)
MakeFrames <- function(Frames)
{
  for (i in 100:(100 + Frames - 1))
  {
    bmp(file = paste(i, ".bmp", sep = ""))
    ShowWakePenalizers(Result, All = TRUE, NS = TRUE, Frames = i)
    dev.off()
  }
}
system.time(MakeFrames(30)) # May take an hour.
Description

This function helps with analyzing an already computed turbine setup. As Profit (together with an optimizer) finds an optimal setup given actual wind speeds in that area, the question arises whether that setup is 'robust' against changing wind directions. If for a given setup, there is no or only little wake dependence (analyze e.g. with ShowWakePenalizers), this may change if wind direction changes. Given a different wind direction, a situation may come up at which there is an upwind turbine and a local set of, say, two, three, or even more downwind turbines. As these downwind turbines are in the wake of the upwind turbines ('receiving' only reduced wind speeds), it may be beneficial to shut down the upwind turbine in order to have the downwind turbine receive full wind, thus possibly generating greater profit.

SwitchProfile expects a 'bit' pattern of turbines (so-called 'profiles') at which '1' means that a turbine is to be used, while '0' means, the turbine is to be shut down. For a total of four turbines in a setup, profile c(1, 1, 1, 1) means that all turbines are used, while profile c(1, 0, 0, 1) means that turbines 1 and 4 are used, turbines 2 and 3 are to be shut down. If a wind farm is 'robust' against wind direction changes, it should return profiles of all ones for all wind directions.

In the examples we show a short code sample that uses SwitchProfile to loop through 360 integer wind direction degrees and optimizes actual profiles. It is up to the researcher to use alternative optimizers in order to find (possibly) better profiles.

Usage

SwitchProfile(On, Result)

Arguments

On must be a numeric vector of length n, where n is the number of turbines in a setup.

Result the actual setup as an optimizer result. Must be a list that contains the turbine locations is a slot "$par". For example, use Result = list(par = e$FarmVars$BenchmarkSolution), see FarmVars for details.

Details

For compatibility with non-integer solution optimizers, SwitchProfile expects not only values equal to 0 or 1, but will assume that values below 0.5 are meant to be 0, and values >= 0.5 are coerced to 1.
SwitchProfile returns a single number. The result is the negative profit for the profile given. The result can be optimized in order to find the maximum profit profile, which should be identical to a profile of all ones if the setup is robust against wind direction changes.

Author(s)

Carsten Croonenbroeck

See Also

Use `Profit` for the target function used internally.

Examples

```r
Result <- list(par = e$FarmVars$BenchmarkSolution)
Profile1 <- rep(1, times = 20)
# Will be identical to Profit(Result$par):
SwitchProfile(Profile1, Result)

Profile2 <- Profile1
Profile2[8] <- 0 # Disable turbine 8.
# Returns farm profit if turbine 8 is off:
SwitchProfile(Profile2, Result)
```

# Warning, this will overwrite e$FarmData. If not dispensable,
# backup before use.
# Computation may be slow.

```r
## Not run:
Result <- list(par = e$FarmVars$BenchmarkSolution)
e$FarmData <- FarmData
n <- length(e$FarmVars$BenchmarkSolution) / 2
Profiles <- matrix(ncol = n, nrow = 360)
Dom <- cbind(rep(0, n), rep(1, n))
for (j in 1:360)
{
e$FarmData$WindDirection <- matrix(data = j, ncol = e$FarmVars$Width,
nrow = e$FarmVars$Width)
message(paste("Processing wind direction: ", j, " degrees.", sep = ""))
flush.console()
}
Result <- rgenoud::genoud(fn = SwitchProfile, nvars = n, starting.values = runif(n),
   Domains = Dom, boundary.enforcement = 2, MemoryMatrix = FALSE, print.level = 0,
   print.out = FALSE)
```

SwitchProfile
Result = Result)
On <- Result$par
On[On < 0.5] <- 0
On[On >= 0.5] <- 1
Profiles[, ] <- On
}

#Now 'Profiles' is a matrix of 360 rows (degrees) and n columns.
#If the setup is robust against wind direction changes, all values
#in the columns should be ones. If there are zeros left, double
#check these profiles (compare to full turbines setup) manually,
#e.g. using

for (i in 1:nrow(Profiles))
{
  if (any(Profiles[i, ] == 0))
  {
    e$FarmData$WindDirection <- matrix(data = i,
           ncol = e$FarmVars$Width, nrow = e$FarmVars$Width)

    print(paste("Is unrestricted profit (",
      abs(Profit(e$FarmVars$BenchmarkSolution)), ") still
      greater than 'profile profit' (",
      abs(SwitchProfile(Profiles[i, ], Result)), ")? ",
      abs(Profit(e$FarmVars$BenchmarkSolution)) >=
      abs(SwitchProfile(Profiles[i, ], Result)), ".", sep = ""))
  }
}

#Is absolute profile profit actually greater than the absolute value
#function Profit() returns? If yes, then it is beneficial to turn off
#turbines (use profiles) if wind comes from the given angle.

## End(Not run)

#########################################################################

#As an alternative to using an optimizer to find the optimal profile,
#all possible profiles can be 'looped through' deterministically using
#the following few lines of code.

#Warning, this will overwrite e$FarmData. If not dispensable,
#backup before use.

#Be advised, computation may be very slow, even if run on modern
#machines and even though using parallelization.

## Not run:
Result <- list(par = e$FarmVars$BenchmarkSolution)
e$FarmData <- FarmData

ComputeProfile <- function(i)
{
SwitchProfile

```
e$FarmData$WindDirection <- matrix(data = i, ncol = e$FarmVars$Width, nrow = e$FarmVars$Width)

BestProfit <- n * e$FarmVars$UnitCost
BestProfile <- rep(0, n)
for (j in 0:MaxNum)
{
  ThisProfile <- as.numeric(rev(intToBits(j)))[(32 - (n - 1)):32]
  if (length(which(ThisProfile == 1)) > 1)
    ThisProfit <- SwitchProfile(ThisProfile, Result)
  else
    ThisProfit <- n * e$FarmVars$UnitCost
  
  if (ThisProfit < BestProfit)
    {
      BestProfit <- ThisProfit
      BestProfile <- ThisProfile
    }
  }
return(BestProfile)
}

n <- length(e$FarmVars$BenchmarkSolution) / 2
MaxNum <- (2 ^ n) - 1
NumCores <- parallel::detectCores() - 1
cl <- snow::makeCluster(NumCores)
ParallelProfile <- new.env()
ParallelProfile$FarmVars <- e$FarmVars
ParallelProfile$FarmData <- e$FarmData
snow::clusterExport(cl, list = ls())
snow::clusterExport(cl, list = ls(envir = as.environment("package:wflo")))
doSNOW::registerDoSNOW(cl)

iterations <- 360
pb <- txtProgressBar(max = iterations, style = 3)
progress <- function(n) setTxtProgressBar(pb, n)
opts <- list(progress = progress)
`%dopar%` <- foreach::`%dopar%`
AllProfiles <- foreach::foreach(i = 1:iterations, .options.snow = opts) %dopar% ComputeProfile(i)

close(pb)
snow::stopCluster(cl)
```

## End(Not run)
ValidSetup

#Afterward, check the resulting list of profiles for remaining zeros as above.

#Thinking the thought of wind direction dependent layouts further,
#Profit() can be used to optimize a farm setup that takes all wind
direction wake patterns into account during the optimization
#stage already.

#Warning, this will overwrite code(e$FarmData). If not dispensable,
#backup before use.
#Computation may be slow.

## Not run:
e$FarmData <- FarmData

SumProfit <- function(X)
{
  MySum <- as.numeric()
  for (i in 1:360)
  {
    e$FarmData$WindDirection <- matrix(data = i, ncol = e$FarmVars$Width,
                                        nrow = e$FarmVars$Width)
    MySum[i] <- Profit(X)
  }
  MySum <- sum(MySum)
  return(MySum)
}

n <- 20
Dom <- cbind(rep(0, 2 * n), rep(1, 2 * n))
Result <- rgenoud::genoud(fn = SumProfit, nvars = 2 * n, starting.values = runif(2 * n),
                          Domains = Dom, boundary.enforcement = 2, MemoryMatrix = FALSE, print.level = 1)

## End(Not run)

---

ValidSetup Checks whether all turbine locations provided satisfy the minimum distance criterion.

### Description

For a set of turbine locations represented by x and y, checks whether all possible pairs satisfy the minimum distance criterion.

### Usage

ValidSetup(x, y)
**Arguments**

\( x \) must be a numeric vector of at least two values, contains the 'x' location(s) of turbines.

\( y \) must be a numeric vector of at least two values, contains the 'y' location(s) of turbines.

**Value**

\texttt{ValidSetup} returns \texttt{TRUE} if all pairs of turbines are at least as far away from each other as 'MinDist' from the \texttt{FarmVars} settings object requests, or \texttt{FALSE}, else.

**Author(s)**

Carsten Croonenbroeck

**Examples**

\texttt{ValidSetup(c(0.5, 0.7), c(0.7, 0.9))}

## Returns TRUE if FarmVars$MinDist is at its standard value (0.1).

---

**wflo**  

\textit{Data set and functions for wind farm layout optimization.}

**Description**

This package makes two contributions to the Wind Farm Layout Optimization (WFLO) research branch: First, it provides a convenient and realistic data set of high resolution and accuracy encompassing wind speeds, wind directions, standard deviations of wind directions, and (adjusted) yields for the entire area of Germany. Second, it supplies a set of helper functions and a benchmark function for economically (profit) driven wind farm layout optimization. This enables researchers in the field of the np-hard problem of wflo to focus on their optimization methodology contribution and also provides a realistic benchmark setting for comparability among contributions.

**Author(s)**

Carsten Croonenbroeck  
David Hennecke
WindspeedHellmann  

Scales wind speeds to certain heights.

Description
For a wind speed at given height, returns a scaled wind speed at some different height. Often used to obtain wind speed at hub height.

Usage
WindspeedHellmann(v0, HH = 100, refHeight = 10, alpha = 1 / 7)

Arguments
- v0: wind speed (in meters per second) at reference height.
- HH: the height (in meters) at which wind speed is desired.
- refHeight: reference height (in meters). The height at which the actual wind speed (v0) was measured.
- alpha: power law parameter. Usually set to 1/7 for onshore sites.

Details
This function simply implements

\[ v = v_0 \left( \frac{HH}{refHeight} \right)^\alpha \]

Value
WindspeedHellmann returns a wind speed (in meters per second) at the desired height.

Author(s)
Carsten Croonenbroeck

See Also
WindspeedLog for a different way to scale wind speeds to heights.

Examples
WindspeedLog(v0 = 6, HH = 80, z0 = 0.1, refHeight = 20)
WindspeedHellmann(v0 = 6, HH = 80, refHeight = 20)
WindspeedLog

Scales wind speeds to certain heights.

Description

For a wind speed at given height, returns a scaled wind speed at some different height. Often used to obtain wind speed at hub height.

Usage

\[
\text{WindspeedLog}(v_0, HH = 100, z_0 = 0.1, \text{refHeight} = 10)
\]

Arguments

\begin{itemize}
  \item \texttt{v0} \hspace{1em} \text{wind speed (in meters per second) at reference height.}
  \item \texttt{HH} \hspace{1em} \text{the height (in meters) at which wind speed is desired.}
  \item \texttt{z0} \hspace{1em} \text{roughness length (in meters). Usually set to 0.1 m for onshore sites.}
  \item \texttt{refHeight} \hspace{1em} \text{reference height (in meters). The height at which the actual wind speed (v0) was measured.}
\end{itemize}

Details

This function simply implements

\[
v = v_0 \left( \log \frac{HH}{z_0} \right) \left( \log \frac{\text{refHeight}}{z_0} \right)
\]

Note that this way to scale wind speeds to certain heights is frequently considered deprecated in the literature. Use \texttt{WindspeedHellmann} instead.

Value

\text{WindspeedLog} \text{ returns a wind speed (in meters per second) at the desired height.}

Author(s)

Carsten Croonenbroeck

See Also

\texttt{WindspeedHellmann} for a different way to scale wind speeds to heights.

Examples

\[
\text{WindspeedLog}(v0 = 6, HH = 80, z0 = 0.1, \text{refHeight} = 20)
\]
\[
\text{WindspeedHellmann}(v0 = 6, HH = 80, \text{refHeight} = 20)
\]
Yield

Returns yearly yield for a turbine’s location.

Description

For a turbine’s location represented by x and y, looks up the (adjusted) yield from the matrix Adj. Internally transforms coordinates of x and y from problem space (usually unit square) to the matrix space of Adj.

Usage

Yield(x, y, Adj)

Arguments

x must be a single value containing the ’x’ location of a turbine in problem space.
y must be a single value containing the ’y’ location of a turbine in problem space.
Adj a matrix containing adjusted yields. Usually, the first element of the list object FarmData will be used as this matrix.

Details

Adjusted yields are the projected yearly average yields dependent on wind speed, hub height and other settings at each point in the raster data. Annual Energy Production (AEP) at a specific location, weighted by a location quality correction factor, produces adjusted yields. This adjustment returns a better guess on the marketable yield at a specific point. For details on the data, see the data set description to this package. Note that Profit internally multiplies the outcome of Yield by e$FarmVars$Price to obtain revenue. Users who replace the function by e$Yield need to provide that manually, if revenue is desired.

Value

Yield returns a single value.

Author(s)

Carsten Croonenbroeck

See Also

Profit to see where to use Yield, Cost for a similar function for yearly cost. FarmData for the data set.
Examples

## Returns adjusted yield for the given location.
Adj <- FarmData[[1]][e$FarmVars$StartPoint:e$FarmVars$EndPoint, 
                      e$FarmVars$StartPoint:e$FarmVars$EndPoint]
Yield(0.5, 0.7, Adj)

## Replace the function by another function
## also called 'Yield', embedded in environment e.
## Also, see the vignette.
## Not run:
e$Yield <- function(x, y, AEP) #x, y \in R
  { return(x + y) }
set.seed(1357)
NumTurbines <- 4 # For example.
Result <- pso::psoptim(par = runif(NumTurbines * 2), fn = Profit,
                        lower = rep(0, NumTurbines * 2), upper = rep(1, NumTurbines * 2))
Result
rm(Yield, envir = e)

## End(Not run)
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