Package 'RAINLINK'

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Type Package

Title Retrieval algorithm for rainfall mapping from microwave links in a cellular communication network.

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Description The RAINLINK software enables to obtain rainfall maps from microwave links in a cellular telecommunication network.

Suggests backports, vctrs, curl, sp, gstat, crayon, withr, ggplot2, ggmap, maps, mapproj, labeling, rgdal, digest, farver, ncdf4, hexbin, geosphere

RoxygenNote 7.1.1

Installation To install this R package run: install.packages("RAINLINK_1.21.tar.gz", repos=NULL, type = "source"). To install it in a specified directory, add ", path", where path is the name of the folder where the package needs to be installed, e.g. "Rlibraries" (use quotation marks).

Available at https://github.com/overeem11/RAINLINK

Additional information see "ManualRAINLINK.pdf"

R topics documented:

`ClimVarParam` *Subfunction for obtaining climatological values of sill, range, and nugget of spherical variogram model for RAINLINK.*

Description

Subfunction for obtaining climatological values of sill, range, and nugget of spherical variogram model. This is based on a climatological variogram based on 30-year automatic rain gauge data sets from The Netherlands. Spherical variograms have been modelled as function of the day number and duration in Van de Beek et al. (2012). They use durations of 1 - 24 h. In this function the relationships can be extrapolated to, e.g. 15-min, data.

Usage

```
ClimVarParam(DateStr, TimeScaleHours, TimeZone)
```

Arguments

`DateStr`	The end date of the chosen daily period.
`TimeScaleHours`	Rainfall aggregation interval in hours.
`TimeZone`	Time zone of data (e.g. "UTC").

Value

Data frame with values of sill, range and nugget.

Author(s)

Aart Overeem & Hidde Leijnse

References

"ManualRAINLINK.pdf"

Overeem, A., Leijnse, H., and Uijlenhoet, R., 2016: Retrieval algorithm for rainfall mapping from microwave links in a cellular communication network, Atmospheric Measurement Techniques, 9, 2425-2444, https://doi.org/10.5194/amt-9-2425-2016.

Van de Beek, C. Z., Leijnse, H., Torfs, P. J. J. F., and Uijlenhoet, R., 2012: Seasonal semi-variance of Dutch rainfall at hourly to daily scales, Adv. Water Resour., 45, 76-85, doi:10.1016/j.advwatres.2012.03.023.

Examples

```
ClimVarParam(DateStr="20110911",TimeScaleHours=0.25,TimeZone="UTC")
```

`CorrectMinMaxRSL` *Function for correcting minimum and maximum received signal powers.*

Description

Function for correcting minimum (Pmin) and maximum (Pmax) received signal powers. For a rainy time interval the corrected minimum received signal power becomes equal to the minimum received signal power if this is below the reference signal level (Pref). Otherwise the corrected minimum received signal power becomes equal to the reference signal level. The corrected maximum received signal power becomes equal to the maximum received signal power if both the maximum received signal power and the corrected minimum received signal power are below the reference signal level.

Works for a sampling strategy where minimum and maximum received signal powers are provided, and the transmitted power levels are constant.

Also works for a sampling strategy where instantaneous transmitted and received signal levels are obtained. In case of instantaneous signal levels, it does not matter whether transmitted power levels vary or are constant. The only requirement is that the input data for RAINLINK needs some preprocessing. See "ManualRAINLINK.pdf" for instructions.

Also works for a sampling strategy where average transmitted and received signal levels are obtained. In case of average signal levels, it does not matter whether transmitted power levels vary or are constant. The only requirement is that the input data for RAINLINK needs some preprocessing. See "ManualRAINLINK.pdf" for instructions.

Usage

```
CorrectMinMaxRSL(Data = DataOutlierFiltered, Dry = NULL, Pref = Pref)
```

Arguments

`Data`	Data frame with microwave link data.
`Dry`	Data frame: Should interval be considered dry for reference level determination? (0 = wet; 1 = dry). Use Dry=NULL if no wet-dry classification has been performed.
`Pref`	Reference level (dB).

Value

Data frame with corrected minimum and maximum received powers (dB).

Author(s)

Aart Overeem & Hidde Leijnse

References

"ManualRAINLINK.pdf"

Overeem, A., Leijnse, H., and Uijlenhoet, R., 2016: Retrieval algorithm for rainfall mapping from microwave links in a cellular communication network, Atmospheric Measurement Techniques, 9, 2425-2444, https://doi.org/10.5194/amt-9-2425-2016.

Examples

```
CorrectMinMaxRSL(Data=DataOutlierFiltered,Dry=WetDry$Dry,Pref=Pref)
```

DataAvailability *Function for plotting data availability of commercial microwave link network.*

Description

Function for plotting data availability of commercial microwave link data. This function provides the following figures:

1. Bar plot with percentage of sub-links for bins of data availability (
2. Bar plot with percentage of link paths for bins of data availability (
3. Plot with average number of sub-links and link paths for each time interval of the sampling strategy.

In addition, the Average number of sub-links and link paths is printed to the screen.

Does not depend on sampling strategy.

The input microwave link data do not have to be sorted chronologically. Full-duplex links will give two data entries, these will both be used.

Data availability is computed over the number of time intervals in the dataset as obtained from DateTime. In case a time interval is missing, i.e. not present in DateTime, it is not included in the computations. Hence, the computed availability does only refer to the time intervals for which a DateTime entry is present in the dataset. In the computation of availabilities only links or paths are counted as available in case the link-derived rainfall intensities are equal to or larger than 0 (mm h^{-1}). I.e., NA values in Rmean are taken into account in the computation of data availability. So data availability is always computed over all time intervals in DateTime. Note that NA values do not exist in the DateTime object if function "PreprocessingMinMaxRSL" has been run and note that Data must be preprocessed, because Rmean is used.

Usage

```
DataAvailability(
  Data,
  cex.axis,
  cex.lab,
  FigNameBarplotAvailabilityLinks,
  FigNameBarplotAvailabilityLinkPaths,
```

```
  FigNameTimeseriesAvailability,
  ps,
  Rmean,
  TimeZone = "UTC",
  verbose = TRUE
)
```

Arguments

Data	Data frame with microwave link data (use data(Linkdata) to load example data).
cex.axis	The magnification to be used for axis annotation relative to the current setting of "cex" in file FigNameTimeseriesAvailability.
cex.lab	The magnification to be used for x and y labels relative to the current setting of "cex" in file FigNameTimeseriesAvailability.
FigNameBarplotAvailabilityLinks	Name of file with bar plot with percentage of links for bins of link orientation. The extension must be ".pdf".
FigNameBarplotAvailabilityLinkPaths	Name of file with bar plot with percentage of links for bins of link path length. The extension must be ".pdf".
FigNameTimeseriesAvailability	Name of file with bar plot with percentage of links for bins of microwave frequency. The extension must be ".pdf".
ps	integer; the point size of text (but not symbols) in file FigNameTimeseriesAvailability.
Rmean	Vector of link-derived rainfall intensities (mm h^{-1}) with length equal to Data.
TimeZone	Time zone of data (e.g. "UTC").

Value

Figures with data availability of commercial microwave link network.

Author(s)

Aart Overeem

References

"ManualRAINLINK.pdf"

Overeem, A., Leijnse, H., and Uijlenhoet, R., 2016: Retrieval algorithm for rainfall mapping from microwave links in a cellular communication network, Atmospheric Measurement Techniques, 9, 2425-2444, https://doi.org/10.5194/amt-9-2425-2016.

Examples

```
data(Linkdata)
DataAvailability(Data=Linkdata,cex.axis=0.9,cex.lab=1.15,
FigNameBarplotAvailabilityLinks="Barplot_Availability_Links.pdf",
FigNameBarplotAvailabilityLinkPaths="Barplot_Availability_LinkPaths.pdf",
FigNameTimeseriesAvailability="TimeseriesAvailability.pdf",ps=18,Rmean=Rmean,TimeZone="UTC")
```

IDW *Subfunction for inverse distance weighted interpolation on point data.*

Description

Subfunction for inverse distance weighted interpolation on point data.

Usage

```
IDW(idp, rain.grid, Rainlink)
```

Arguments

idp	The inverse distance weighting power.
rain.grid	Interpolation grid in Azimuthal Equidistant Cartesian coordinate system.
Rainlink	Coordinates of links in Azimuthal Equidistant Cartesian coordinate system. and rainfall intensity (latitude in km, longitude in km, intensity in mm h^{-1}).

Value

Interpolated field of rainfall intensities.

Author(s)

Aart Overeem & Hidde Leijnse

References

"ManualRAINLINK.pdf"

Overeem, A., Leijnse, H., and Uijlenhoet, R., 2016: Retrieval algorithm for rainfall mapping from microwave links in a cellular communication network, Atmospheric Measurement Techniques, 9, 2425-2444, https://doi.org/10.5194/amt-9-2425-2016.

Examples

```
IDW(idp=idp,rain.grid=rain.grid,Rainlink=Rainlink)
```

Interpolation *Interpolation of link-based path-averaged rainfall estimates.*

Description

Interpolation of link-based path-averaged rainfall estimates. The type of interpolation has to be specified. The following types are available: 1) Inverse distance weighted interpolation on data (subfunction IDW); 2) Ordinary kriging with spherical variogram model. Its parameter values nugget, sill, and range, can be defined by the user; 3) Ordinary kriging with spherical variogram model with climatological parameter values based on a 30-year rain gauge data set. These are computed for the day of year as obtained from the file name, thus taking into account seasonality in spatial rainfall correlation. The subfunction ClimVarParam computes these parameter values.

Ordinary kriging is performed by subfunction OrdinaryKriging. Note that this interpolation algorithm is developed for interpolation of link-based rainfall estimates, which are path averages. The subfunction IntpPathToPoint computes the path-averaged rainfall intensities for unique link paths. And it assigns path-averaged intensity to the point at the middle of the link path.

The time interval does not have to be an integer but should be equidistant. The minimum time interval length is automatically computed and is employed as the time interval length.

Usage

```
Interpolation(
  Data,
  CoorSystemInputData = NULL,
  idp = 2,
  IntpMethod = "OK",
  nmax = 50,
  NUGGET,
  RANGE,
  RainGrid,
  Rmean,
  SILL,
  TimeZone = "UTC",
  Variogram = "ClimVar",
  OutputDir = NULL
)
```

Arguments

Data	Data frame with microwave link data.
CoorSystemInputData	Define coordinate system of input data (in case of WGS84 provide NULL).
idp	The inverse distance weighting power.
IntpMethod	Interpolation method: Ordinary kriging ("OK") or inverse distance weighted interpolation ("IDW").
nmax	The number of nearest observations that should be used for a kriging prediction or simulation, where nearest is defined in terms of the space of the spatial locations.
NUGGET	Nugget of spherical variogram model (mm).
RANGE	Range of spherical variogram model (km).
RainGrid	Data frame containing information on the points in space where rainfall needs to be estimated, is assumed to be in the same coordinate system as the original link data.
Rmean	Vector of link-derived rainfall intensities (mm h^{-1}) with length equal to Data.

SILL	Sill of spherical variogram model (mm^2).
TimeZone	Time zone of data (e.g. "UTC").
Variogram	For OK: which variogram to use? Use "ClimVar" for climatological spherical variogram model. Use "Manual" for spherical variogram model with NUGGET, SILL, and RANGE values supplied as function arguments.
OutputDir	If supplied (not NULL), files with resulting interpolated rainfall fields will be written to this directory. If not supplied, the interpolated fields will be returned.

Value

Interpolated field of rainfall intensities (mm h^{-1}).

Author(s)

Aart Overeem & Hidde Leijnse

References

”ManualRAINLINK.pdf”

Overeem, A., Leijnse, H., and Uijlenhoet, R., 2016: Retrieval algorithm for rainfall mapping from microwave links in a cellular communication network, Atmospheric Measurement Techniques, 9, 2425-2444, https://doi.org/10.5194/amt-9-2425-2016.

Examples

```
Interpolation(Data=DataPreprocessed,CoorSystemInputData=NULL,idp=2.0,
IntpMethod="OK",nmax=50,NUGGET=0.37,RANGE=18.7,RainGrid=RainGrid,
Rmean=Rmean,SILL=3.7,TimeZone="UTC",Variogram="ClimVar",OutputDir="RainMapsLinks15min")
```

IntpPathToPoint *Subfunction for computing path-averaged rainfall intensities for unique link paths. A path-averaged rainfall intensity is assigned to a point at the middle of the link path.*

Description

Subfunction for computing path-averaged rainfall intensities for unique link paths. The link-based, e.g. a 15-minute path-averaged rainfall accumulation is converted to a path-averaged rainfall intensity, and subsequently assigned to a point at the middle of the link path. Path-averaged rainfall intensities are obtained, so data from full-duplex links are averaged.

Usage

```
IntpPathToPoint(ID, Rmean, XEnd, XStart, YEnd, YStart)
```

Arguments

ID	Link identifier.
Rmean	Data frame with mean path-averaged rainfall intensities (mm h^{-1}).
XEnd	Easting of end of links (km).
XStart	Easting of start of links (km).
YEnd	Northing of end of links (km).
YStart	Northing of start of links (km).

Value

Coordinates of middle of links in Azimuthal Equidistant Cartesian coordinate system (latitude, longitude) and rainfall intensity (mm h^{-1})).

Author(s)

Aart Overeem & Hidde Leijnse

References

"ManualRAINLINK.pdf"

Overeem, A., Leijnse, H., and Uijlenhoet, R., 2016: Retrieval algorithm for rainfall mapping from microwave links in a cellular communication network, Atmospheric Measurement Techniques, 9, 2425-2444, https://doi.org/10.5194/amt-9-2425-2016.

Examples

```
IntpPathToPoint(ID=ID,Rmean=Rmean,Xend=Xend,XStart=XStart,YEnd=YEnd,YStart=YStart)
```

Linkdata

Microwave link dataset from which path-averaged rainfall intensities can be computed. Received signal powers were obtained from Nokia microwave links in one of the national cellular communication networks in The Netherlands, operated by T-Mobile NL. The minimum and maximum received powers over 15-min intervals were provided, based on 10-Hz sampling. The transmitted power was almost constant. Here the data have a resolution of 1 dB, and the majority of these Nokia links used vertically polarised signals.

Description

Data were obtained from September 9, 0800 UTC - September 11, 0800 UTC (2011). The data set contains data from 2612 microwave links.

Usage

```
data(Linkdata)
```

Format

A data frame with link data from a commercial cellular communication network

Details

Several functions in the RAINLINK package read a data frame with microwave link data. Such a data frame always contains the variables as indicated below, i.e. the variables in the data set supplied to PreprocessingMinMaxRSL.

For each link and time interval the following variables are provided:

- Frequency: microwave frequency f (GHz).
- DateTime: date and end time of observation (YYYYMMDDhhmm, i.e. year (2011), month (09), day (11), hour (08), minutes (00): 201109110800).
- Pmin: minimum received power P_{min} (dBm).
- Pmax: maximum received power P_{max} (dBm).
- PathLength: length of microwave link path L (km).
- XStart: Longitude of start of links (°; WGS84).
- YStart: Latitude of start of links (°; WGS84).
- XEnd: Longitude of end of links (°; WGS84).
- YEnd: Latitude of end of links (°; WGS84).
- ID: Link identifier.

`MinMaxRSLToMeanR` *Subfunction for path-averaged rainfall estimation from minimum and maximum attenuations from microwave links.*

Description

Subfunction for path-averaged rainfall estimation using microwave links. Compute minimum (Amin) and maximum (Amax) attenuation over the link path. Convert these to minimum and maximum path-averaged rainfall intensities. Convert minimum and maximum path-averaged rainfall intensities to mean path-averaged rainfall intensities.

Works for a sampling strategy where minimum and maximum received signal powers are provided, and the transmitted power levels are constant.

Also works for a sampling strategy where instantaneous transmitted and received signal levels are obtained. In case of instantaneous signal levels, it does not matter whether transmitted power levels vary or are constant. The only requirement is that the input data for RAINLINK needs some preprocessing. See "ManualRAINLINK.pdf" for instructions.

Also works for a sampling strategy where average transmitted and received signal levels are obtained. In case of average signal levels, it does not matter whether transmitted power levels vary or are constant. The only requirement is that the input data for RAINLINK needs some preprocessing. See "ManualRAINLINK.pdf" for instructions.

Usage

```
MinMaxRSLToMeanR(a, Aa, alpha, b, PathLength, PmaxCor, PminCor, Pref)
```

Arguments

a	Coefficients in relationship between rainfall intensity and specific attenuation (mm h^{-1} dB^{-b} km^{b}).
Aa	Wet antenna attenuation correction A_a (dB).
alpha	Coefficient (α) determining contribution of minimum and maximum path-averaged rainfall intensity to mean path-averaged rainfall intensity (-).
b	Exponents in relationship between rainfall intensity and specific attenuation (-).
PathLength	Lengths of link paths (km).

Value

Data frame with mean path-averaged rainfall intensities (mm h^{-1}).

Author(s)

Aart Overeem & Hidde Leijnse

References

"ManualRAINLINK.pdf"

Overeem, A., Leijnse, H., and Uijlenhoet, R., 2016: Retrieval algorithm for rainfall mapping from microwave links in a cellular communication network, Atmospheric Measurement Techniques, 9, 2425-2444, https://doi.org/10.5194/amt-9-2425-2016.

Examples

```
MinMaxRSLToMeanR(a=a,Aa=Aa,alpha=alpha,b=b,PathLength=Data$PathLength,
PmaxCor=PmaxCor,PminCor=PminCor,Pref=Pref)
```

OrdinaryKriging *Subfunction for ordinary kriging interpolation of point values using spherical variogram model with predefined parameters sill, range, and nugget.*

Description

Subfunction for ordinary kriging interpolation of point values using spherical variogram model with predefined parameters sill, range, and nugget.

Usage

```
OrdinaryKriging(nmax, Nugget, rain.grid, Rainlink, Range, Sill)
```

Arguments

nmax	The number of nearest observations that should be used for a kriging prediction or simulation, where nearest is defined in terms of the space of the spatial locations.
Nugget	Nugget of spherical variogram model (mm).
rain.grid	Interpolation grid in Azimuthal Equidistant Cartesian coordinate system.
Rainlink	Coordinates of links in Azimuthal Equidistant Cartesian coordinate system and rainfall intensity (latitude in km, longitude in km, intensity in mm h^{-1}).
Range	Range of spherical variogram model (km).
Sill	Sill of spherical variogram model (mm^2).

Value

Interpolated field of rainfall intensities.

Author(s)

Aart Overeem & Hidde Leijnse

References

"ManualRAINLINK.pdf"

Overeem, A., Leijnse, H., and Uijlenhoet, R., 2016: Retrieval algorithm for rainfall mapping from microwave links in a cellular communication network, Atmospheric Measurement Techniques, 9, 2425-2444, https://doi.org/10.5194/amt-9-2425-2016.

Examples

```
OrdinaryKriging(nmax=50,Nugget=0.37,rain.grid=rain.grid,Rainlink=Rainlink,
Range=18.7,Sill=3.7)
```

OutlierFilterMinMaxRSL

Function to apply filter to remove outliers in path-averaged microwave link attenuations.

Description

Function to apply filter to remove outliers in link-based rainfall estimates. Malfunctioning link antennas can cause outliers in rainfall retrievals (especially for daily accumulations). These outliers can be removed by using a filter that is based on the assumption that rainfall is correlated in space. The filter discards a time interval of a link for which the cumulative difference between its specific attenuation and that of the surrounding links over the previous 24 h (including the present time interval), F, becomes lower than a threshold value in dB h km^{-1}.

Works for a sampling strategy where minimum and maximum received signal powers are provided, and the transmitted power levels are constant.

The outlier filter has been extensively tested on minimum received signal powers, i.e. for a sampling strategy where minimum and maximum received signal powers are provided, and the transmitted power levels are constant. This function can also be applied in case of other sampling strategies,

because it does not explicitly require minimum and maximum received signal powers. It just applies the selection on all rows in a data frame. Whether the outlier filter will give good results when applied to link data obtained from other sampling strategies would need to be tested. Hence, "MinMaxRSL" is kept in this function name to stress that it has been tested for a sampling strategy where minimum and maximum received powers are provided.

Also works for a sampling strategy where instantaneous transmitted and received signal levels are obtained. In case of instantaneous signal levels, it does not matter whether transmitted power levels vary or are constant. The only requirement is that the input data for RAINLINK needs some preprocessing. See "ManualRAINLINK.pdf" for instructions.

Also works for a sampling strategy where average transmitted and received signal levels are obtained. In case of average signal levels, it does not matter whether transmitted power levels vary or are constant. The only requirement is that the input data for RAINLINK needs some preprocessing. See "ManualRAINLINK.pdf" for instructions.

Can only be applied when function WetDryNearbyLinkApMinMaxRSL has been executed.

Usage

```
OutlierFilterMinMaxRSL(Data, F, FilterThreshold = -32.5)
```

Arguments

`Data`	Data frame with microwave link data.
`F`	Values for filter to remove outliers (dB km^{-1} h).
`FilterThreshold`	Outlier filter threshold (dB h km^{-1}).

Value

Data frame with microwave link data.

Author(s)

Aart Overeem & Hidde Leijnse

References

"ManualRAINLINK.pdf"

Overeem, A., Leijnse, H., and Uijlenhoet, R., 2016: Retrieval algorithm for rainfall mapping from microwave links in a cellular communication network, Atmospheric Measurement Techniques, 9, 2425-2444, https://doi.org/10.5194/amt-9-2425-2016.

Examples

```
OutlierFilterMinMaxRSL(Data=DataPreprocessed,F=WetDry$F,FilterThreshold=-32.5)
```

PathLength *Function to compute path length of microwave links from coordinates.*

Description

Function for computing path length of microwave links from coordinates.

Coordinates should be provided as longitudes and latitudes of start and end of a link. It uses the function "distVincentyEllipsoid" from the R package "geosphere", which computes the "Vincenty" (Ellipsoid) Great Circle Distance. The shortest distance between two points (i.e., the "great-circle-distance" or "as the crow flies"), according to the "Vincenty (ellipsoid)" method. The WGS84 ellipsoid is used.

Usage

```
PathLength(XStart, XEnd, YStart, YEnd)
```

Arguments

XStart	List with longitude of start of microwave links (decimal degrees)
XEnd	List with longitude of end of microwave links (decimal degrees)
YStart	List with latitude of start of microwave links (decimal degrees)
YEnd	List with latitude of end of microwave links (decimal degrees)

Value

Path length of microwave links (km).

Author(s)

Aart Overeem

References

"ManualRAINLINK.pdf"

Overeem, A., Leijnse, H., and Uijlenhoet, R., 2016: Retrieval algorithm for rainfall mapping from microwave links in a cellular communication network, Atmospheric Measurement Techniques, 9, 2425-2444, https://doi.org/10.5194/amt-9-2425-2016.

Examples

```
PathLength(XStart=XStart,XEnd=XEnd,YStart=YStart,YEnd=YEnd)
```

PlotLinkLocations *Function which visualises microwave link paths on a map.*

Description

Function which visualises microwave link paths on a map.

Usage

```
PlotLinkLocations(
  AlphaLinkLocations,
  BBoxOSMauto,
  OSMBottom,
  ColourLinks,
  ColourType,
  dataf,
  DateTime,
  ExtraTextLinkLocations,
  FigFileLinkLocations,
  FigHeight,
  FigWidth,
  FilePolygonsGrid,
  FolderFigures,
  FontFamily,
  GoogleLocDegSpecified,
  GoogleLocLat,
  GoogleLocLon,
  GoogleLocName,
  GoogleLocNameSpecified,
  GoogleMapType,
  GoogleZoomlevel,
  LabelAxisLat,
  LabelAxisLonGoogle,
  LabelAxisLonOSM,
  LabelAxisLonStamen,
  MapBackground,
  OSMLeft,
  OSMRight,
  OSMScale,
  OSMTop,
  OutputFileType,
  SizeLinks,
  SizePlotTitle,
  StamenMapType,
  StamenZoomlevel,
  TitleLinkLocations
)
```

Arguments

AlphaLinkLocations
: Transparency of link paths.

`BBoxOSMauto` Compute bounding box from input data or used bounding box defined above? (for OpenStreetMap and Stamen Map only). Use "yes" if bounding box is to be computed from interpolation grid.

`OSMBottom` Latitude in decimal degrees (WGS84) for bottom side of the area for which rainfall depths are to be plotted (for OpenStreetMap & Stamen Maps only).

`ColourLinks` Colour of plotted link paths.

`ColourType` Colour or black-and-white background map? Use "color" for colour and "bw" for black-and-white background map.

`dataf` data frame which contains (at least) locations of microwave links in degrees.

`DateTime` Date and time for which link locations are plotted. This is used in the title caption of the figure and in the file name.

`ExtraTextLinkLocations`
Second part of title of plot.

`FigFileLinkLocations`
Part of figure output file name.

`FigHeight` Figure height. 1280 times 1280 pixels seems maximum graphical resolution for downloaded Google Maps. Because also axes and legend are plotted, it is advised to use e.g. 1450 times 1450 pixels. Then the Google Map will remain approximately 1280 times 1280 pixels. Using higher values is not a problem (e.g. 2000). In this way it is tried to get the highest possible resolution. For OpenStreetMap the maps may reach resolutions of 1500 - 2000 pixels. Hence, using FigWidth and FigHeight of 2000 pixels or higher is advised. The OpenStreetMap itself is stored in file "ggmapTemp.png". From this file the resolution of the background map can be obtained. This can be useful for determining an appropriate FigWidth and FigHeight above.

`FigWidth` Figure width. 1280 times 1280 pixels seems maximum graphical resolution for downloaded Google Maps. Because also axes and legend are plotted, it is advised to use e.g. 1450 times 1450 pixels. Then the Google Map will remain approximately 1280 times 1280 pixels. Using higher values is not a problem (e.g. 2000). In this way it is tried to get the highest possible resolution. For OpenStreetMap the maps may reach resolutions of 1500 - 2000 pixels. Hence, using FigWidth and FigHeight of 2000 pixels or higher is advised. The OpenStreetMap itself is stored in file "ggmapTemp.png". From this file the resolution of the background map can be obtained. This can be useful for determining an appropriate FigWidth and FigHeight above.

`FilePolygonsGrid`
Name of file with polygons of interpolation grid.

`FolderFigures` Folder name of figures.

`FontFamily` Specify font family of text in figures. To select the default font use "". Using "Times" may give warnings when executing the visualisation. In that case the font is not installed on the computer. This can be solved by using the default font ("").

`GoogleLocDegSpecified`
If GoogleLocDegSpecified is "yes" then the specified location in decimal degrees is used as the centre of the Google Map. If both GoogleLocNameSpecified and GoogleLocDegSpecified are not equal to "yes", the bounding box of the map is determined from the provided grid and used as centre of the Google Map.

`GoogleLocLat` Latitude of middle of Google Map (decimal degrees).

`GoogleLocLon` Longitude of middle of Google Map (decimal degrees).

`GoogleLocName` Location of middle of Google Map, provided as text, e.g. name of city, street name, country.

`GoogleLocNameSpecified`
If GoogleLocNameSpecified is "yes" then the specified location name GoogleLocName is used as the centre of the Google Map. If both GoogleLocNameSpecified and GoogleLocDegSpecified are not equal to "yes", the bounding box of the map is determined from the provided grid and used as centre of the Google Map.

`GoogleMapType` In case of Google Maps: which map type should be used? Available map types: "terrain", "satellite", "roadmap", and "hybrid".

`GoogleZoomlevel`
Which zoom level to use for the Google Maps?

`LabelAxisLat` Label name of vertical axis.

`LabelAxisLonGoogle`
Label name of horizontal axis (for Google Maps only).

`LabelAxisLonOSM`
Label name of horizontal axis (for OpenStreetMap only).

`LabelAxisLonStamen`
Label name of horizontal axis (for Stamen Map only).

`MapBackground` Google Maps, OpenStreetMap or Stamen Map as background? Use "Google" for Google Maps, "OSM" for OpenStreetMap and "Stamen" for Stamen Map (based on OpenStreetMap data). Note that Google Maps will only plot on a square figure. It seems that mapping with OpenStreetMap ("get openstreetmap") is no langer supported. This implies that mapping can only be done employing Google Maps (if Google API key is obtained) or via Stamen Map. This is not related to the RAINLINK version.

`OSMLeft` Longitude in decimal degrees (WGS84) for left side of the area for which rainfall depths are to be plotted (for OpenStreetMap & Stamen Maps only).

`OSMRight` Longitude in decimal degrees (WGS84) for right side of the area for which rainfall depths are to be plotted (for OpenStreetMap & Stamen Maps only).

`OSMScale` Give value of scale (for OpenStreetMap only). A proper choice of the scale parameter in get_openstreetmap is difficult. It cannot be computed automatically. Hence, a scale parameter value should be provided below. The scale parameter should be as small as possible to get the highest graphical resolution. However, a too low value may result in a map not being downloaded. Hence, the user should manually supply get_openstreetmap with a scale. It may require some iterations to find the appropriate value for scale. The file "ggmapTemp.png" is written to disk when an OpenStreetMap is loaded. The highest possible resolution for a square area is about 2000 x 2000 pixels.

`OSMTop` Latitude in decimal degrees (WGS84) for top side of the area for which rainfall depths are to be plotted (for OpenStreetMap & Stamen Maps only).

`OutputFileType` Choose output file type of image: jpeg, png or tiff.

`SizeLinks` Size of plotted link paths.

`SizePlotTitle` Size of plot title.

`StamenMapType` In case of Stamen Maps: which map type should be used? Available map types which seem most useful and work: "toner-hybrid" &, recommended: "toner-lite", "terrain" & "watercolor".

`StamenZoomlevel`
: Which zoom level to use for the Stamen Maps? This determines the level of detail. Large values take more time. It does not determine the domain of the area which is plotted.

`TitleLinkLocations`
: First part of title of plot.

Author(s)

Aart Overeem & Hidde Leijnse

References

"ManualRAINLINK.pdf"

Overeem, A., Leijnse, H., and Uijlenhoet, R., 2016: Retrieval algorithm for rainfall mapping from microwave links in a cellular communication network, Atmospheric Measurement Techniques, 9, 2425-2444, https://doi.org/10.5194/amt-9-2425-2016.

Examples

```
PlotLinkLocations(AlphaLinkLocations=AlphaLinkLocations,BBoxOSMauto=BBoxOSMauto,
OSMBottom=OSMBottom,ColourLinks=ColourLinks,ColourType=ColourType,dataf=dataf,
DateTime=DateTime,ExtraTextLinkLocations=ExtraTextLinkLocations,
FigFileLinkLocations=FigFileLinkLocations,FigHeight=FigHeight,
FigWidth=FigWidth,FilePolygonsGrid=FilePolygonsGrid,FolderFigures=FolderFigures,
FontFamily=FontFamily,GoogleLocDegSpecified=GoogleLocDegSpecified,
GoogleLocLat=GoogleLocLat,GoogleLocLon=GoogleLocLon,GoogleLocName=GoogleLocName,
GoogleLocNameSpecified=GoogleLocNameSpecified,GoogleMapType=GoogleMapType,
GoogleZoomlevel=GoogleZoomlevel,LabelAxisLat=LabelAxisLat,
LabelAxisLonGoogle=LabelAxisLonGoogle,LabelAxisLonOSM=LabelAxisLonOSM,
LabelAxisLonStamen=LabelAxisLonStamen,MapBackground=MapBackground,OSMLeft=OSMLeft,
OSMRight=OSMRight,OSMScale=OSMScale,OSMTop=OSMTop,OutputFileType=OutputFileType,
SizeLinks=SizeLinks,SizePlotTitle=SizePlotTitle,StamenMapType=StamenMapType,
StamenZoomlevel=StamenZoomlevel,TitleLinkLocations=TitleLinkLocations)
```

Polygons *Subfunction which makes dataframe for polygons with rainfall estimates in specific rainfall class.*

Description

Subfunction which makes dataframe for polygons with rainfall estimates in specific rainfall class.

Usage

```
Polygons(cond, Selected)
```

Arguments

`cond`	Row numbers of dataframe which fall in specific rainfall class.
`Selected`	Coordinates of polygons and their assigned rainfall values.

Value

Data frame

Author(s)

Aart Overeem & Hidde Leijnse

References

"ManualRAINLINK.pdf"

Overeem, A., Leijnse, H., and Uijlenhoet, R., 2016: Retrieval algorithm for rainfall mapping from microwave links in a cellular communication network, Atmospheric Measurement Techniques, 9, 2425-2444, https://doi.org/10.5194/amt-9-2425-2016.

Examples

```
RAINLINK::Polygons(cond=cond,Selected=Selected)
```

`PreprocessingMinMaxRSL` *Function for preprocessing of microwave link data.*

Description

Function for preprocessing of microwave link data. This function performs the following tasks:

1. Link data are selected for microwave frequencies within chosen range.
2. Data selection criteria are applied.

Works for a sampling strategy where minimum and maximum received signal powers are provided, and the transmitted power levels are constant.

Also works for a sampling strategy where instantaneous transmitted and received signal levels are obtained. In case of instantaneous signal levels, it does not matter whether transmitted power levels vary or are constant. The only requirement is that the input data for RAINLINK needs some preprocessing. See "ManualRAINLINK.pdf" for instructions.

Also works for a sampling strategy where average transmitted and received signal levels are obtained. In case of average signal levels, it does not matter whether transmitted power levels vary or are constant. The only requirement is that the input data for RAINLINK needs some preprocessing. See "ManualRAINLINK.pdf" for instructions.

The input microwave link data do not have to be sorted chronologically.

It is strongly advised to use the same unique link identifier (ID) for a link during the entire processed period(s). First of all, time series of sufficient length are needed in order to compute e.g. a reference signal level. Moreover, utilizing the same ID allows for plotting (continuous) time series from the same link.

Usage

```
PreprocessingMinMaxRSL(
  Data,
  MaxFrequency = Inf,
  MinFrequency = 0,
  verbose = TRUE
)
```

Arguments

Data	Data frame with microwave link data (use data(Linkdata) to load example data).
MaxFrequency	Maximum allowed microwave frequency of link in output (GHz; default infinite).
MinFrequency	Minimum allowed microwave frequency of link in output (GHz; default 0).

Value

Data frame with microwave link data.

Author(s)

Aart Overeem & Hidde Leijnse & Lotte de Vos

References

"ManualRAINLINK.pdf"

Overeem, A., Leijnse, H., and Uijlenhoet, R., 2016: Retrieval algorithm for rainfall mapping from microwave links in a cellular communication network, Atmospheric Measurement Techniques, 9, 2425-2444, https://doi.org/10.5194/amt-9-2425-2016.

Examples

```
data(Linkdata)
PreprocessingMinMaxRSL(Data=Linkdata,MaxFrequency=40.5,MinFrequency=12.5)
```

RainMapsLinksDaily *Function which visualises daily link-based rainfall depths.*

Description

Function which visualises daily link-based rainfall depths. Requires interpolation grid and file with polygons of pixels. Daily rainfall depths are computed irrespective of the number of available files. If, for instance, only one out of 96 files is available, the daily rainfall depth is still computed and visualised. The data availability is plotted as a percentage in the title caption of the graph. Function will also plot accumulations for other aggregation intervals. Note that the data availability, plotted in the figure caption is only correctly computed for daily intervals.

Usage

```
RainMapsLinksDaily(
  AlphaLinksDaily,
  AlphaPlotLocation,
  AlphaPolygon,
  AutDefineLegendTop,
  BBoxOSMauto,
  ColourLinks,
  ColoursNumber,
  ColourPlotLocation,
  ColourPlotLocationText,
  ColourScheme,
  ColourType,
  ColourHighestClass,
  ConversionDepthToIntensity,
  CoorSystemInputData,
  DateTimeEndRainMaps,
  DateTimeStartRainMaps,
  ExtraDeg,
  ExtraText,
  FigFileLinksDaily,
  FigHeight,
  FigWidth,
  FileGrid,
  FilePolygonsGrid,
  FolderFigures,
  FolderRainMaps,
  FolderRainEstimates,
  FontFamily,
  GoogleLocDegSpecified,
  GoogleLocLat,
  GoogleLocLon,
  GoogleLocName,
  GoogleLocNameSpecified,
  GoogleMapType,
  GoogleZoomlevel,
  LabelAxisLat,
  LabelAxisLonGoogle,
  LabelAxisLonOSM,
  LabelAxisLonStamen,
  LatLocation,
  LatText,
  LegendSize,
  LegendTitleLinksDaily,
  LonLocation,
  LonText,
  ManualScale,
  MapBackground,
  OSMBottom,
  OSMLeft,
  OSMRight,
  OSMScale,
```

```
  OSMTop,
  OutputFileType,
  PERIOD,
  PlotLocation,
  PixelBorderCol,
  PlotBelowScaleBottom,
  PlotLocLinks,
  ScaleBottomDaily,
  ScaleHigh,
  ScaleLow,
  ScaleTopDaily,
  SizeLinks,
  SizePixelBorder,
  SizePlotLocation,
  SizePlotTitle,
  StamenMapType,
  StamenZoomlevel,
  SymbolPlotLocation,
  TIMESTEP,
  TitleLinks,
  XMiddle,
  YMiddle
)
```

Arguments

AlphaLinksDaily	Transparency of link paths.
AlphaPlotLocation	Transparency of plotted symbol for specified location on map.
AlphaPolygon	Transparency of polygons.
AutDefineLegendTop	Let R automatically define highest value of legend in case of "yes". Then the highest class, i.e. the one plotted separately above the other classes, is not plotted anymore.
BBoxOSMauto	Compute bounding box from input data or used bounding box defined above? (for OpenStreetMap and Stamen Map only). Use "yes" if bounding box is to be computed from interpolation grid.
ColourLinks	Colour of plotted link paths.
ColoursNumber	Number of colour classes in legend.
ColourPlotLocation	Colour of plotted symbol for specified location on map.
ColourPlotLocationText	Colour of plotted rainfall depth for specified location on map.
ColourScheme	Hexadecimal codes or names for colours of legend.
ColourType	Colour or black-and-white background map? Use "color" for colour and "bw" for black-and-white background map.
ColourHighestClass	Colour of highest class.

`ConversionDepthToIntensity`
: Conversion factor from rainfall depth (mm) to intensity (mm/h).

`CoorSystemInputData`
: Define coordinate system of input data (e.g. "+init=epsg:4326" for WGS84 in decimal degrees).

`DateTimeEndRainMaps`
: Date and time at which rainfall mapping ends.

`DateTimeStartRainMaps`
: Date and time at which rainfall mapping starts.

`ExtraDeg`
: To reduce computational time, it is automatically determined which grid cells fall within the plotted region. To also plot grid cell values which partly fall outside the plotted region, a positive number for ExtraDeg should be specified (decimal degrees). This should typically be at least the size of one grid cell in decimal degrees.

`ExtraText`
: Second part of title of plot.

`FigFileLinksDaily`
: Part of figure output file name.

`FigHeight`
: Figure height. 1280 times 1280 pixels seems maximum graphical resolution for downloaded Google Maps. Because also axes and legend are plotted, it is advised to use e.g. 1450 times 1450 pixels. Then the Google Map will remain approximately 1280 times 1280 pixels. Using higher values is not a problem (e.g. 2000). In this way it is tried to get the highest possible resolution. For OpenStreetMap the maps may reach resolutions of 1500 - 2000 pixels. Hence, using FigWidth and FigHeight of 2000 pixels or higher is advised. The OpenStreetMap itself is stored in file "ggmapTemp.png". From this file the resolution of the background map can be obtained. This can be useful for determining an appropriate FigWidth and FigHeight above.

`FigWidth`
: Figure width. 1280 times 1280 pixels seems maximum graphical resolution for downloaded Google Maps. Because also axes and legend are plotted, it is advised to use e.g. 1450 times 1450 pixels. Then the Google Map will remain approximately 1280 times 1280 pixels. Using higher values is not a problem (e.g. 2000). In this way it is tried to get the highest possible resolution. For OpenStreetMap the maps may reach resolutions of 1500 - 2000 pixels. Hence, using FigWidth and FigHeight of 2000 pixels or higher is advised. The OpenStreetMap itself is stored in file "ggmapTemp.png". From this file the resolution of the background map can be obtained. This can be useful for determining an appropriate FigWidth and FigHeight above.

`FileGrid`
: File with interpolation grid in same coordinate system as CoorSystemInputData.

`FilePolygonsGrid`
: Name of file with polygons of interpolation grid.

`FolderFigures`
: Folder name of figures.

`FolderRainMaps`
: Folder name of interpolated link data (input).

`FolderRainEstimates`
: Folder name of input link path data.

`FontFamily`
: Specify font family of text in figures. To select the default font use "". Using "Times" may give warnings when executing the visualisation. In that case the font is not installed on the computer. This can be solved by using the default font ("").

`GoogleLocDegSpecified`
: If GoogleLocDegSpecified is "yes" then the specified location in decimal degrees is used as the centre of the Google Map. If both GoogleLocNameSpecified and GoogleLocDegSpecified are not equal to "yes", the bounding box of the map is determined from the provided grid and used as centre of the Google Map.

`GoogleLocLat`
: Latitude of middle of Google Map (decimal degrees).

`GoogleLocLon`
: Longitude of middle of Google Map (decimal degrees).

`GoogleLocName`
: Location of middle of Google Map, provided as text, e.g. name of city, street name, country.

`GoogleLocNameSpecified`
: If GoogleLocNameSpecified is "yes" then the specified location name GoogleLocName is used as the centre of the Google Map. If both GoogleLocNameSpecified and GoogleLocDegSpecified are not equal to "yes", the bounding box of the map is determined from the provided grid and used as centre of the Google Map.

`GoogleMapType`
: In case of Google Maps: which map type should be used? Available map types: "terrain", "satellite", "roadmap", and "hybrid".

`GoogleZoomlevel`
: Which zoom level to use for the Google Maps?

`LabelAxisLat`
: Label name of vertical axis.

`LabelAxisLonGoogle`
: Label name of horizontal axis (for Google Maps only).

`LabelAxisLonOSM`
: Label name of horizontal axis (for OpenStreetMap only).

`LabelAxisLonStamen`
: Label name of horizontal axis (for Stamen Map only).

`LatLocation`
: Latitude of location on map (decimal degrees).

`LatText`
: Latitude of text (rainfall depth) of location on map (decimal degrees).

`LegendSize`
: Size of legend (choose e.g. 75 for 6 classes and 50 for 10 classes).

`LegendTitleLinksDaily`
: Title of legend.

`LonLocation`
: Longitude of location on map (decimal degrees).

`LonText`
: Longitude of text (rainfall depth) of location on map (decimal degrees).

`ManualScale`
: Manually supply the legend breaks if ManuelScale is not equal to "no". Interval breaks are determined manually from ScaleLow and ScaleHigh. If ManualScale is "no" interval breaks are determined automatically.

`MapBackground`
: Google Maps, OpenStreetMap or Stamen Map as background? Use "Google" for Google Maps, "OSM" for OpenStreetMap and "Stamen" for Stamen Map (based on OpenStreetMap data). Note that Google Maps will only plot on a square figure. It seems that mapping with OpenStreetMap ("get openstreetmap") is no langer supported. This implies that mapping can only be done employing Google Maps (if Google API key is obtained) or via Stamen Map. This is not related to the RAINLINK version.

`OSMBottom`
: Latitude in decimal degrees (WGS84) for bottom side of the area for which rainfall depths are to be plotted (for OpenStreetMap & Stamen Maps only).

`OSMLeft`
: Longitude in decimal degrees (WGS84) for left side of the area for which rainfall depths are to be plotted (for OpenStreetMap & Stamen Maps only).

OSMRight	Longitude in decimal degrees (WGS84) for right side of the area for which rainfall depths are to be plotted (for OpenStreetMap & Stamen Maps only).
OSMScale	Give value of scale (for OpenStreetMap only). A proper choice of the scale parameter in get_openstreetmap is difficult. It cannot be computed automatically. Hence, a scale parameter value should be provided below. The scale parameter should be as small as possible to get the highest graphical resolution. However, a too low value may result in a map not being downloaded. Hence, the user should manually supply get_openstreetmap with a scale. It may require some iterations to find the appropriate value for scale. The file "ggmapTemp.png" is written to disk when an OpenStreetMap is loaded. The highest possible resolution for a square area is about 2000 x 2000 pixels.
OSMTop	Latitude in decimal degrees (WGS84) for top side of the area for which rainfall depths are to be plotted (for OpenStreetMap & Stamen Maps only).
OutputFileType	Choose output file type of image: jpeg, png or tiff.
PERIOD	Select daily time interval, i.e. "0800" implies 0800 UTC previous day - 0800 UTC present day (use 2400 for 0000 UTC).
PlotLocation	A location is plotted on map if PlotLocation is "yes".
PixelBorderCol	Choose colour of pixel borders. Use NA (without quotes) to not plot pixel borders. If the pixels are relatively small with respect to the plotted region, the graphical quality of the pixel borders deteriorates due to low number of pixels (low resolution).
PlotBelowScaleBottom	Plot grid lines for polygons below threshold ScaleBottomTimeStep or ScaleBottomDaily? If "yes" grid lines are plotted, otherwise they are not plotted.
PlotLocLinks	Plot locations of links in plot? If "yes" than locations of links are plotted in the plot. Note that full-duplex links are plotted twice.
ScaleBottomDaily	Lowest class starts at this threshold (minimum rainfall accumulation (mm) to be plotted). Using a value clearly above 0 mm can save a lot of computation time if the polygons belonging to values below the threshold are not plotted.
ScaleHigh	ScaleHigh Highest value per class interval, i.e. the highest legend breaks, if these are manually chosen. Please note that in case of x values in ColoursNumber, ScaleHigh should also contain x values.
ScaleLow	ScaleLow Lowest value per class interval, i.e. the lowest legend breaks, if these are manually chosen. Please note that in case of x values in ColoursNumber, ScaleLow should also contain x values.
ScaleTopDaily	Highest colour class ends here (maximum rainfall accumulation (mm) to be plotted). Sometimes the legend is not correctly plotted. In that case try other values for ScaleTopDaily and/or ScaleBottomDaily For instance, if the highest class (> x mm) is plotted below instead of above the other classes. Or if the number of classes does not match the number of chosen classes. Another way to prevent this is to manually give the legend breaks (ManualScale not equal to "no").
SizeLinks	Size of plotted link paths.
SizePixelBorder	Size of pixel borders.
SizePlotLocation	Size of symbol and and accompanied text for specified location on map.
SizePlotTitle	Size of plot title.

StamenMapType	In case of Stamen Maps: which map type should be used? Available map types which seem most useful and work: "toner-hybrid" &, recommended: "toner-lite", "terrain" & "watercolor".
StamenZoomlevel	Which zoom level to use for the Stamen Maps? This determines the level of detail. Large values take more time. It does not determine the domain of the area which is plotted.
SymbolPlotLocation	Symbol to be plotted for specified location on map.
TIMESTEP	Duration of time interval of sampling strategy (min).
TitleLinks	First part of title of plot.
XMiddle	The longitude of the centre of the Azimuthal Equidistant Cartesian coordinate system, given in the coordinate system of the input data.
YMiddle	The latitude of the centre of the Azimuthal Equidistant Cartesian coordinate system, given in the coordinate system of the input data.

Author(s)

Aart Overeem & Hidde Leijnse

References

”ManualRAINLINK.pdf”

Overeem, A., Leijnse, H., and Uijlenhoet, R., 2016: Retrieval algorithm for rainfall mapping from microwave links in a cellular communication network, Atmospheric Measurement Techniques, 9, 2425-2444, https://doi.org/10.5194/amt-9-2425-2016.

Examples

```
RainMapsLinksDaily(AlphaLinksDaily=AlphaLinksDaily,AlphaPlotLocation=AlphaPlotLocation,
AlphaPolygon=AlphaPolygon,AutDefineLegendTop=AutDefineLegendTop,BBoxOSMauto=BBoxOSMauto,
ColourLinks=ColourLinks,ColoursNumber=ColoursNumber,
ColourPlotLocation=ColourPlotLocation,ColourPlotLocationText=ColourPlotLocationText,
ColourScheme=ColourScheme,ColourType=ColourType,
ConversionDepthToIntensity=ConversionDepthToIntensity,
CoorSystemInputData=CoorSystemInputData,DateTimeEndRainMaps=DateTimeEndRainMaps,
DateTimeStartRainMaps=DateTimeStartRainMaps,ExtraDeg=ExtraDeg,ExtraText=ExtraText,
FigFileLinksDaily=FigFileLinksDaily,FigHeight=FigHeight,FigWidth=FigWidth,
FileGrid=FileGrid,FilePolygonsGrid=FilePolygonsGrid,FolderFigures=FolderFigures,
FolderRainMaps=FolderRainMaps,FolderRainEstimates=FolderRainEstimates,
FontFamily=FontFamily,GoogleLocDegSpecified=GoogleLocDegSpecified,
GoogleLocLat=GoogleLocLat,GoogleLocLon=GoogleLocLon,GoogleLocName=GoogleLocName,
GoogleLocNameSpecified=GoogleLocNameSpecified,GoogleMapType=GoogleMapType,
GoogleZoomlevel=GoogleZoomlevel,LabelAxisLat=LabelAxisLat,
LabelAxisLonGoogle=LabelAxisLonGoogle,LabelAxisLonOSM=LabelAxisLonOSM,
LabelAxisLonStamen=LabelAxisLonStamen,LatLocation=LatLocation,LatText=LatText,
LegendSize=LegendSize,LegendTitleLinksDaily=LegendTitleLinksDaily,
LonLocation=LonLocation,LonText=LonText,ManualScale=ManualScale,
MapBackground=MapBackground,OSMBottom=OSMBottom,OSMLeft=OSMLeft,
OSMRight=OSMRight,OSMScale=OSMScale,OSMTop=OSMTop,OutputFileType=OutputFileType,
PERIOD=PERIOD,PlotLocation=PlotLocation,PixelBorderCol=PixelBorderCol,
PlotBelowScaleBottom=PlotBelowScaleBottom,PlotLocLinks=PlotLocLinks,
ScaleBottomDaily=ScaleBottomDaily,ScaleHigh=ScaleHigh,ScaleLow=ScaleLow,
```

```
ScaleTopDaily=ScaleTopDaily,SizeLinks=SizeLinks,SizePixelBorder=SizePixelBorder,
SizePlotLocation=SizePlotLocation,SizePlotTitle=SizePlotTitle,
StamenMapType=StamenMapType,StamenZoomlevel=StamenZoomlevel,
SymbolPlotLocation=SymbolPlotLocation,TIMESTEP=TIMESTEP,TitleLinks=TitleLinks,
XMiddle=XMiddle,YMiddle=YMiddle)
```

`RainMapsLinksTimeStep` *Function which visualises link-based rainfall depths for each time interval in a supplied period.*

Description

Function which visualises link-based rainfall depths for each time interval in a supplied period. Requires interpolation grid and file with polygons of pixels, the polygons having four angular points. Note that the zoom level for Google Maps can be chosen. This zoom level will not always match with the area to be plotted. Downloading a GoogleMaps background map is very fast, but downloading an OpenStreetMap may require tenths of seconds. Note that such a map is downloaded only once, which saves time in case of multiple rainfall maps.

Usage

```
RainMapsLinksTimeStep(
  AlphaLinksTimeStep,
  AlphaPlotLocation,
  AlphaPolygon,
  AutDefineLegendTop,
  BBoxOSMauto,
  ColourLinks,
  ColoursNumber,
  ColourPlotLocation,
  ColourPlotLocationText,
  ColourScheme,
  ColourType,
  ColourHighestClass,
  ConversionDepthToIntensity,
  CoorSystemInputData,
  DateTimeEndRainMaps,
  DateTimeStartRainMaps,
  ExtraDeg,
  ExtraText,
  FigFileLinksTimeStep,
  FigHeight,
  FigWidth,
  FileGrid,
  FilePolygonsGrid,
  FolderFigures,
  FolderRainMaps,
  FolderRainEstimates,
  FontFamily,
  GoogleLocDegSpecified,
  GoogleLocLat,
```

```
  GoogleLocLon,
  GoogleLocName,
  GoogleLocNameSpecified,
  GoogleMapType,
  GoogleZoomlevel,
  LabelAxisLat,
  LabelAxisLonGoogle,
  LabelAxisLonOSM,
  LabelAxisLonStamen,
  LatLocation,
  LatText,
  LegendSize,
  LegendTitleLinksTimeStep,
  LonLocation,
  LonText,
  ManualScale,
  MapBackground,
  OSMBottom,
  OSMLeft,
  OSMRight,
  OSMScale,
  OSMTop,
  OutputFileType,
  PlotLocation,
  PixelBorderCol,
  PlotBelowScaleBottom,
  PlotLocLinks,
  ScaleBottomTimeStep,
  ScaleHigh,
  ScaleLow,
  ScaleTopTimeStep,
  SizeLinks,
  SizePixelBorder,
  SizePlotLocation,
  SizePlotTitle,
  StamenMapType,
  StamenZoomlevel,
  SymbolPlotLocation,
  TitleLinks,
  XMiddle,
  YMiddle
)
```

Arguments

AlphaLinksTimeStep	Transparency of link paths.
AlphaPlotLocation	Transparency of plotted symbol for specified location on map.
AlphaPolygon	Transparency of polygons.
AutDefineLegendTop	Let R automatically define highest value of legend in case of "yes". Then the

highest class, i.e. the one plotted separately above the other classes, is not plotted anymore.

`BBoxOSMauto` Compute bounding box from input data or used bounding box defined above? (for OpenStreetMap and Stamen Map only). Use "yes" if bounding box is to be computed from interpolation grid.

`ColourLinks` Colour of plotted link paths.

`ColoursNumber` Number of colour classes in legend.

`ColourPlotLocation`
Colour of plotted symbol for specified location on map.

`ColourPlotLocationText`
Colour of plotted rainfall depth for specified location on map.

`ColourScheme` Hexadecimal codes or names for colours of legend.

`ColourType` Colour or black-and-white background map? Use "color" for colour and "bw" for black-and-white background map.

`ColourHighestClass`
Colour of highest class.

`ConversionDepthToIntensity`
Conversion factor from rainfall depth (mm) to intensity (mm/h).

`CoorSystemInputData`
Define coordinate system of input data (e.g. "+init=epsg:4326" for WGS84 in decimal degrees).

`DateTimeEndRainMaps`
Date and time at which rainfall mapping ends.

`DateTimeStartRainMaps`
Date and time at which rainfall mapping starts.

`ExtraDeg` To reduce computational time, it is automatically determined which grid cells fall within the plotted region. To also plot grid cell values which partly fall outside the plotted region, a positive number for ExtraDeg should be specified (decimal degrees). This should typically be at least the size of one grid cell in decimal degrees.

`ExtraText` Second part of title of plot.

`FigFileLinksTimeStep`
Part of figure output file name.

`FigHeight` Figure height. 1280 times 1280 pixels seems maximum graphical resolution for downloaded Google Maps. Because also axes and legend are plotted, it is advised to use e.g. 1450 times 1450 pixels. Then the Google Map will remain approximately 1280 times 1280 pixels. Using higher values is not a problem (e.g. 2000). In this way it is tried to get the highest possible resolution. For OpenStreetMap the maps may reach resolutions of 1500 - 2000 pixels. Hence, using FigWidth and FigHeight of 2000 pixels or higher is advised. The OpenStreetMap itself is stored in file "ggmapTemp.png". From this file the resolution of the background map can be obtained. This can be useful for determining an appropriate FigWidth and FigHeight above.

`FigWidth` Figure width. 1280 times 1280 pixels seems maximum graphical resolution for downloaded Google Maps. Because also axes and legend are plotted, it is advised to use e.g. 1450 times 1450 pixels. Then the Google Map will remain approximately 1280 times 1280 pixels. Using higher values is not a problem (e.g. 2000). In this way it is tried to get the highest possible resolution. For

OpenStreetMap the maps may reach resolutions of 1500 - 2000 pixels. Hence, using FigWidth and FigHeight of 2000 pixels or higher is advised. The OpenStreetMap itself is stored in file "ggmapTemp.png". From this file the resolution of the background map can be obtained. This can be useful for determining an appropriate FigWidth and FigHeight above.

`FileGrid` File with interpolation grid in same coordinate system as CoorSystemInputData.

`FilePolygonsGrid`
Name of file with polygons of interpolation grid.

`FolderFigures` Folder name of figures.

`FolderRainMaps` Folder name of interpolated link data (input).

`FolderRainEstimates`
Folder name of input link path data.

`FontFamily` Specify font family of text in figures. To select the default font use "". Using "Times" may give warnings when executing the visualisation. In that case the font is not installed on the computer. This can be solved by using the default font ("").

`GoogleLocDegSpecified`
If GoogleLocDegSpecified is "yes" then the specified location in decimal degrees is used is used as the centre of the Google Map. If both GoogleLocNameSpecified and GoogleLocDegSpecified are not equal to "yes", the bounding box of the map is determined from the provided grid and used as centre of the Google Map.

`GoogleLocLat` Latitude of middle of Google Map (decimal degrees).

`GoogleLocLon` Longitude of middle of Google Map (decimal degrees).

`GoogleLocName` Location of middle of Google Map, provided as text, e.g. name of city, street name, country

`GoogleLocNameSpecified`
If GoogleLocNameSpecified is "yes" then the specified location name GoogleLocName is used as the centre of the Google Map. If both GoogleLocNameSpecified and GoogleLocDegSpecified are not equal to "yes", the bounding box of the map is determined from the provided grid and used as centre of the Google Map.

`GoogleMapType` In case of Google Maps: which map type should be used? Available map types: "terrain", "satellite", "roadmap", and "hybrid".

`GoogleZoomlevel`
Which zoom level to use for the Google Maps?

`LabelAxisLat` Label name of vertical axis.

`LabelAxisLonGoogle`
Label name of horizontal axis (for Google Maps only).

`LabelAxisLonOSM`
Label name of horizontal axis (for OpenStreetMap only).

`LabelAxisLonStamen`
Label name of horizontal axis (for Stamen Map only).

`LatLocation` Latitude of location on map (decimal degrees).

`LatText` Latitude of text (rainfall depth) of location on map (decimal degrees).

`LegendSize` Size of legend (choose e.g. 75 for 6 classes and 50 for 10 classes).

`LegendTitleLinksTimeStep`
Title of legend.

`LonLocation` Longitude of location on map (decimal degrees).

`LonText` Longitude of text (rainfall depth) of location on map (decimal degrees).

`ManualScale` Manually supply the legend breaks if ManuelScale is not equal to "no". Interval breaks are determined manually from ScaleLow and ScaleHigh. If ManualScale is "no" interval breaks are determined automatically.

`MapBackground` Google Maps, OpenStreetMap or Stamen Map as background? Use "Google" for Google Maps, "OSM" for OpenStreetMap and "Stamen" for Stamen Map (based on OpenStreetMap data). Note that Google Maps will only plot on a square figure. It seems that mapping with OpenStreetMap ("get openstreetmap") is no langer supported. This implies that mapping can only be done employing Google Maps (if Google API key is obtained) or via Stamen Map. This is not related to the RAINLINK version.

`OSMBottom` Latitude in decimal degrees (WGS84) for bottom side of the area for which rainfall depths are to be plotted (for OpenStreetMap & Stamen Maps only).

`OSMLeft` Longitude in decimal degrees (WGS84) for left side of the area for which rainfall depths are to be plotted (for OpenStreetMap & Stamen Maps only).

`OSMRight` Longitude in decimal degrees (WGS84) for right side of the area for which rainfall depths are to be plotted (for OpenStreetMap & Stamen Maps only).

`OSMScale` Give value of scale (for OpenStreetMap only). A proper choice of the scale parameter in get_openstreetmap is difficult. It cannot be computed automatically. Hence, a scale parameter value should be provided below. The scale parameter should be as small as possible to get the highest graphical resolution. However, a too low value may result in a map not being downloaded. Hence, the user should manually supply get_openstreetmap with a scale. It may require some iterations to find the appropriate value for scale. The file "ggmapTemp.png" is written to disk when an OpenStreetMap is loaded. The highest possible resolution for a square area is about 2000 x 2000 pixels.

`OSMTop` Latitude in decimal degrees (WGS84) for top side of the area for which rainfall depths are to be plotted (for OpenStreetMap & Stamen Maps only).

`OutputFileType` Choose output file type of image: jpeg, png or tiff.

`PlotLocation` A location is plotted on map if PlotLocation is "yes".

`PixelBorderCol` Choose colour of pixel borders. Use NA (without quotes) to not plot pixel borders. If the pixels are relatively small with respect to the plotted region, the graphical quality of the pixel borders deteriorates due to low number of pixels (low resolution).

`PlotBelowScaleBottom`
Plot grid lines for polygons below threshold ScaleBottomTimeStep or ScaleBottomDaily? If "yes" grid lines are plotted, otherwise they are not plotted.

`PlotLocLinks` Plot locations of links in plot? If "yes" than locations of links are plotted in the plot. Note that full-duplex links are plotted twice.

`ScaleBottomTimeStep`
ScaleBottomDaily Lowest class starts at this threshold (minimum rainfall accumulation (mm) to be plotted). Using a value clearly above 0 mm can save a lot of computation time if the polygons belonging to values below the threshold are not plotted.

`ScaleHigh` ScaleHigh Highest value per class interval, i.e. the highest legend breaks, if these are manually chosen. Please note that in case of x values in ColoursNumber, ScaleHigh should also contain x values.

`ScaleLow` ScaleLow Lowest value per class interval, i.e. the lowest legend breaks, if these are manually chosen. Please note that in case of x values in ColoursNumber, ScaleLow should also contain x values.

`ScaleTopTimeStep` Highest colour class ends here (maximum rainfall accumulation (mm) to be plotted). Sometimes the legend is not correctly plotted. In that case try other values for ScaleTopTimeStep and/or ScaleBottomTimeStep For instance, if the highest class (> x mm) is plotted below instead of above the other classes. Or if the number of classes does not match the number of chosen classes. Another way to prevent this is to manually give the legend breaks (ManualScale not equal to "no").

`SizeLinks` Size of plotted link paths.

`SizePixelBorder` Size of pixel borders.

`SizePlotLocation` Size of symbol and accompanied text for specified location on map.

`SizePlotTitle` Size of plot title.

`StamenMapType` In case of Stamen Maps: which map type should be used? Available map types which seem most useful and work: "toner-hybrid" &, recommended: "toner-lite", "terrain" & "watercolor".

`StamenZoomlevel` Which zoom level to use for the Stamen Maps? This determines the level of detail. Large values take more time. It does not determine the domain of the area which is plotted.

`SymbolPlotLocation` Symbol to be plotted for specified location on map.

`TitleLinks` First part of title of plot.

`XMiddle` The longitude of the centre of the Azimuthal Equidistant Cartesian coordinate system, given in the coordinate system of the input data.

`YMiddle` The latitude of the centre of the Azimuthal Equidistant Cartesian coordinate system, given in the coordinate system of the input data.

Author(s)

Aart Overeem & Hidde Leijnse

References

”ManualRAINLINK.pdf”

Overeem, A., Leijnse, H., and Uijlenhoet, R., 2016: Retrieval algorithm for rainfall mapping from microwave links in a cellular communication network, Atmospheric Measurement Techniques, 9, 2425-2444, https://doi.org/10.5194/amt-9-2425-2016.

Examples

```
RainMapsLinksTimeStep(AlphaLinksTimeStep=AlphaLinksTimeStep,
AlphaPlotLocation=AlphaPlotLocation,AlphaPolygon=AlphaPolygon,
AutDefineLegendTop=AutDefineLegendTop,BBoxOSMauto=BBoxOSMauto,ColourLinks=ColourLinks,
ColoursNumber=ColoursNumber,ColourPlotLocation=ColourPlotLocation,
ColourPlotLocationText=ColourPlotLocationText,ColourScheme=ColourScheme,
ColourType=ColourType,ConversionDepthToIntensity=ConversionDepthToIntensity,
```

```
CoorSystemInputData=CoorSystemInputData,DateTimeEndRainMaps=DateTimeEndRainMaps,
DateTimeStartRainMaps=DateTimeStartRainMaps,ExtraDeg=ExtraDeg,ExtraText=ExtraText,
FigFileLinksTimeStep=FigFileLinksTimeStep,FigHeight=FigHeight,FigWidth=FigWidth,
FileGrid=FileGrid,FilePolygonsGrid=FilePolygonsGrid,FolderFigures=FolderFigures,
FolderRainMaps=FolderRainMaps,FolderRainEstimates=FolderRainEstimates,
FontFamily=FontFamily,GoogleLocDegSpecified=GoogleLocDegSpecified,
GoogleLocLat=GoogleLocLat,GoogleLocLon=GoogleLocLon,GoogleLocName=GoogleLocName,
GoogleLocNameSpecified=GoogleLocNameSpecified,GoogleMapType=GoogleMapType,
GoogleZoomlevel=GoogleZoomlevel,LabelAxisLat=LabelAxisLat,
LabelAxisLonGoogle=LabelAxisLonGoogle,LabelAxisLonOSM=LabelAxisLonOSM,
LabelAxisLonStamen=LabelAxisLonStamen,LatLocation=LatLocation,LatText=LatText,
LegendSize=LegendSize,LegendTitleLinksTimeStep=LegendTitleLinksTimeStep,
LonLocation=LonLocation,LonText=LonText,ManualScale=ManualScale,
MapBackground=MapBackground,OSMBottom=OSMBottom,OSMLeft=OSMLeft,
OSMRight=OSMRight,OSMScale=OSMScale,OSMTop=OSMTop,OutputFileType=OutputFileType,
PlotLocation=PlotLocation,PixelBorderCol=PixelBorderCol,
PlotBelowScaleBottom=PlotBelowScaleBottom,PlotLocLinks=PlotLocLinks,
ScaleBottomTimeStep=ScaleBottomTimeStep,ScaleHigh=ScaleHigh,ScaleLow=ScaleLow,
ScaleTopTimeStep=ScaleTopTimeStep,SizeLinks=SizeLinks,SizePixelBorder=SizePixelBorder,
SizePlotLocation=SizePlotLocation,SizePlotTitle=SizePlotTitle,
StamenMapType=StamenMapType,StamenZoomlevel=StamenZoomlevel,
SymbolPlotLocation=SymbolPlotLocation,TitleLinks=TitleLinks,XMiddle=XMiddle,
YMiddle=YMiddle)
```

`RainMapsRadarsDaily` *Function which visualises daily radar rainfall depths.*

Description

Function which visualises daily radar rainfall depths. Requires interpolation grid and file with polygons of pixels. The radar data have been obtained from http://climate4impact.eu (catalog "Radar precipitation climatology") and are freely available.

Usage

```
RainMapsRadarsDaily(
  AlphaPlotLocation,
  AlphaPolygon,
  AutDefineLegendTop,
  BBoxOSMauto,
  ColoursNumber,
  ColourPlotLocation,
  ColourPlotLocationText,
  ColourScheme,
  ColourType,
  ColourHighestClass,
  CoorSystemInputData,
  DateMap,
  ExtraDeg,
  ExtraText,
  FigFileRadarsDaily,
  FigHeight,
  FigWidth,
```

```
  FileGrid,
  FileNameRadarDaily,
  FilePolygonsGrid,
  FolderFigures,
  FolderRadarRainMapsDaily,
  FontFamily,
  GoogleLocDegSpecified,
  GoogleLocLat,
  GoogleLocLon,
  GoogleLocName,
  GoogleLocNameSpecified,
  GoogleMapType,
  GoogleZoomlevel,
  LabelAxisLat,
  LabelAxisLonGoogle,
  LabelAxisLonOSM,
  LabelAxisLonStamen,
  LatLocation,
  LatText,
  LegendSize,
  LegendTitleRadarsDaily,
  LonLocation,
  LonText,
  ManualScale,
  MapBackground,
  OSMBottom,
  OSMLeft,
  OSMRight,
  OSMScale,
  OSMTop,
  OutputFileType,
  PathRadarRainfallDepth,
  PERIOD,
  PlotLocation,
  PixelBorderCol,
  PlotBelowScaleBottom,
  ScaleBottomDaily,
  ScaleHigh,
  ScaleLow,
  ScaleTopDaily,
  SizePixelBorder,
  SizePlotLocation,
  SizePlotTitle,
  StamenMapType,
  StamenZoomlevel,
  SymbolPlotLocation,
  TIMESTEP,
  TimeZone,
  TitleRadars,
  XMiddle,
  YMiddle
)
```

Arguments

AlphaPlotLocation	Transparency of plotted symbol for specified location on map.
AlphaPolygon	Transparency of polygons.
AutDefineLegendTop	Let R automatically define highest value of legend in case of "yes". Then the highest class, i.e. the one plotted separately above the other classes, is not plotted anymore.
BBoxOSMauto	Compute bounding box from input data or used bounding box defined above? (for OpenStreetMap and Stamen Map only). Use "yes" if bounding box is to be computed from interpolation grid.
ColoursNumber	Number of colour classes in legend.
ColourPlotLocation	Colour of plotted symbol for specified location on map.
ColourPlotLocationText	Colour of plotted rainfall depth for specified location on map.
ColourScheme	Hexadecimal codes or names for colours of legend.
ColourType	Colour or black-and-white background map? Use "color" for colour and "bw" for black-and-white background map.
ColourHighestClass	Colour of highest class
CoorSystemInputData	Define coordinate system of input data (e.g. "+init=epsg:4326" for WGS84 in decimal degrees).
DateMap	End date of daily period for which rainfall map should be plotted.
ExtraDeg	To reduce computational time, it is automatically determined which grid cells fall within the plotted region. To also plot grid cell values which partly fall outside the plotted region, a positive number for ExtraDeg should be specified (decimal degrees). This should typically be at least the size of one grid cell in decimal degrees.
ExtraText	Second part of title of plot.
FigFileRadarsDaily	Part of figure output file name.
FigHeight	Figure height. 1280 times 1280 pixels seems maximum graphical resolution for downloaded Google Maps. Because also axes and legend are plotted, it is advised to use e.g. 1450 times 1450 pixels. Then the Google Map will remain approximately 1280 times 1280 pixels. Using higher values is not a problem (e.g. 2000). In this way it is tried to get the highest possible resolution. For OpenStreetMap the maps may reach resolutions of 1500 - 2000 pixels. Hence, using FigWidth and FigHeight of 2000 pixels or higher is advised. The OpenStreetMap itself is stored in file "ggmapTemp.png". From this file the resolution of the background map can be obtained. This can be useful for determining an appropriate FigWidth and FigHeight above.
FigWidth	Figure width. 1280 times 1280 pixels seems maximum graphical resolution for downloaded Google Maps. Because also axes and legend are plotted, it is advised to use e.g. 1450 times 1450 pixels. Then the Google Map will remain approximately 1280 times 1280 pixels. Using higher values is not a problem (e.g. 2000). In this way it is tried to get the highest possible resolution. For

OpenStreetMap the maps may reach resolutions of 1500 - 2000 pixels. Hence, using FigWidth and FigHeight of 2000 pixels or higher is advised. The OpenStreetMap itself is stored in file "ggmapTemp.png". From this file the resolution of the background map can be obtained. This can be useful for determining an appropriate FigWidth and FigHeight above.

`FileGrid` File with interpolation grid in same coordinate system as CoorSystemInputData.

`FileNameRadarDaily`
Filename of radar file of rainfall depths to be visualised (NetCDF4 format).

`FilePolygonsGrid`
Name of file with polygons of interpolation grid.

`FolderFigures` Folder name of figures.

`FolderRadarRainMapsDaily`
Name of folder which contains daily radar rainfall files (input data)

`FontFamily` Specify font family of text in figures. To select the default font use "". Using "Times" may give warnings when executing the visualisation. In that case the font is not installed on the computer. This can be solved by using the default font ("").

`GoogleLocDegSpecified`
If GoogleLocDegSpecified is "yes" then the specified location in decimal degrees is used as the centre of the Google Map. If both GoogleLocNameSpecified and GoogleLocDegSpecified are not equal to "yes", the bounding box of the map is determined from the provided grid and used as centre of the Google Map.

`GoogleLocLat` Latitude of middle of Google Map (decimal degrees).

`GoogleLocLon` Longitude of middle of Google Map (decimal degrees).

`GoogleLocName` Location of middle of Google Map, provided as text, e.g. name of city, street name, country.

`GoogleLocNameSpecified`
If GoogleLocNameSpecified is "yes" then the specified location name GoogleLocName is used as the centre of the Google Map. If both GoogleLocNameSpecified and GoogleLocDegSpecified are not equal to "yes", the bounding box of the map is determined from the provided grid and used as centre of the Google Map.

`GoogleMapType` In case of Google Maps: which map type should be used? Available map types: "terrain", "satellite", "roadmap", and "hybrid".

`GoogleZoomlevel`
Which zoom level to use for the Google Maps?

`LabelAxisLat` Label name of vertical axis.

`LabelAxisLonGoogle`
Label name of horizontal axis (for Google Maps only).

`LabelAxisLonOSM`
Label name of horizontal axis (for OpenStreetMap only).

`LabelAxisLonStamen`
Label name of horizontal axis (for Stamen Map only).

`LatLocation` Latitude of location on map (decimal degrees).

`LatText` Latitude of text (rainfall depth) of location on map (decimal degrees).

`LegendSize` Size of legend (choose e.g. 75 for 6 classes and 50 for 10 classes).

`LegendTitleRadarsDaily`
: Title of legend.

`LonLocation`
: Longitude of location on map (decimal degrees).

`LonText`
: Longitude of text (rainfall depth) of location on map (decimal degrees).

`ManualScale`
: Manually supply the legend breaks if ManuelScale is not equal to "no". Interval breaks are determined manually from ScaleLow and ScaleHigh. If ManualScale is "no" interval breaks are determined automatically.

`MapBackground`
: Google Maps, OpenStreetMap or Stamen Map as background? Use "Google" for Google Maps, "OSM" for OpenStreetMap and "Stamen" for Stamen Map (based on OpenStreetMap data). Note that Google Maps will only plot on a square figure. It seems that mapping with OpenStreetMap ("get openstreetmap") is no langer supported. This implies that mapping can only be done employing Google Maps (if Google API key is obtained) or via Stamen Map. This is not related to the RAINLINK version.

`OSMBottom`
: Latitude in decimal degrees (WGS84) for bottom side of the area for which rainfall depths are to be plotted (for OpenStreetMap & Stamen Maps only).

`OSMLeft`
: Longitude in decimal degrees (WGS84) for left side of the area for which rainfall depths are to be plotted (for OpenStreetMap & Stamen Maps only).

`OSMRight`
: Longitude in decimal degrees (WGS84) for right side of the area for which rainfall depths are to be plotted (for OpenStreetMap & Stamen Maps only).

`OSMScale`
: Give value of scale (for OpenStreetMap only). A proper choice of the scale parameter in get_openstreetmap is difficult. It cannot be computed automatically. Hence, a scale parameter value should be provided below. The scale parameter should be as small as possible to get the highest graphical resolution. However, a too low value may result in a map not being downloaded. Hence, the user should manually supply get_openstreetmap with a scale. It may require some iterations to find the appropriate value for scale. The file "ggmapTemp.png" is written to disk when an OpenStreetMap is loaded. The highest possible resolution for a square area is about 2000 x 2000 pixels.

`OSMTop`
: Latitude in decimal degrees (WGS84) for top side of the area for which rainfall depths are to be plotted (for OpenStreetMap & Stamen Maps only).

`OutputFileType`
: Choose output file type of image: jpeg, png or tiff.

`PathRadarRainfallDepth`
: Path in NetCDF4 file with radar data.

`PERIOD`
: Select daily time interval, i.e. "0800" implies 0800 UTC previous day - 0800 UTC present day (use 2400 for 0000 UTC).

`PlotLocation`
: A location is plotted on map if PlotLocation is "yes".

`PixelBorderCol`
: Choose colour of pixel borders. Use NA (without quotes) to not plot pixel borders. If the pixels are relatively small with respect to the plotted region, the graphical quality of the pixel borders deteriorates due to low number of pixels (low resolution).

`PlotBelowScaleBottom`
: Plot grid lines for polygons below threshold ScaleBottomTimeStep or ScaleBottomDaily? If "yes" grid lines are plotted, otherwise they are not plotted.

`ScaleBottomDaily`
: ScaleBottomDaily Lowest class starts at this threshold (minimum rainfall accumulation (mm) to be plotted). Using a value clearly above 0 mm can save a lot of computation time if the polygons belonging to values below the threshold are not plotted.

ScaleHigh	ScaleHigh Highest value per class interval, i.e. the highest legend breaks, if these are manually chosen. Please note that in case of x values in ColoursNumber, ScaleHigh should also contain x values.
ScaleLow	ScaleLow Lowest value per class interval, i.e. the lowest legend breaks, if these are manually chosen. Please note that in case of x values in ColoursNumber, ScaleLow should also contain x values.
ScaleTopDaily	Highest colour class ends here (maximum rainfall accumulation (mm) to be plotted). Sometimes the legend is not correctly plotted. In that case try other values for ScaleTopDaily and/or ScaleBottomDaily For instance, if the highest class (> x mm) is plotted below instead of above the other classes. Or if the number of classes does not match the number of chosen classes. Another way to prevent this is to manually give the legend breaks (ManualScale not equal to "no").
SizePixelBorder	Size of pixel borders.
SizePlotLocation	Size of symbol and and accompanied text for specified location on map.
SizePlotTitle	Size of plot title.
StamenMapType	In case of Stamen Maps: which map type should be used? Available map types which seem most useful and work: "toner-hybrid" &, recommended: "toner-lite", "terrain" & "watercolor".
StamenZoomlevel	Which zoom level to use for the Stamen Maps? This determines the level of detail. Large values take more time. It does not determine the domain of the area which is plotted.
SymbolPlotLocation	Symbol to be plotted for specified location on map.
TimeZone	Time zone of data (e.g. "UTC").
TitleRadars	First part of title of plot.
XMiddle	The longitude of the centre of the Azimuthal Equidistant Cartesian coordinate system, given in the coordinate system of the input data.
YMiddle	The latitude of the centre of the Azimuthal Equidistant Cartesian coordinate system, given in the coordinate system of the input data.

Author(s)

Aart Overeem & Hidde Leijnse

References

”ManualRAINLINK.pdf”

Overeem, A., Leijnse, H., and Uijlenhoet, R., 2016: Retrieval algorithm for rainfall mapping from microwave links in a cellular communication network, Atmospheric Measurement Techniques, 9, 2425-2444, https://doi.org/10.5194/amt-9-2425-2016.

Examples

```
RainMapsRadarsDaily(AlphaPlotLocation=AlphaPlotLocation,AlphaPolygon=AlphaPolygon,
AutDefineLegendTop=AutDefineLegendTop,BBoxOSMauto=BBoxOSMauto,
ColoursNumber=ColoursNumber,ColourPlotLocation=ColourPlotLocation,
ColourPlotLocationText=ColourPlotLocationText,ColourScheme=ColourScheme,
```

```
ColourType=ColourType,CoorSystemInputData=CoorSystemInputData,DateMap=DateMap,
ExtraDeg=ExtraDeg,ExtraText=ExtraText,FigFileRadarsDaily=FigFileRadarsDaily,
FigHeight=FigHeight,FigWidth=FigWidth,FileGrid=FileGrid,
FileNameRadarDaily=FileNameRadarDaily,FilePolygonsGrid=FilePolygonsGrid,
FolderFigures=FolderFigures,FolderRadarRainMapsDaily=FolderRadarRainMapsDaily,
FontFamily=FontFamily,GoogleLocDegSpecified=GoogleLocDegSpecified,
GoogleLocLat=GoogleLocLat,GoogleLocLon=GoogleLocLon,GoogleLocName=GoogleLocName,
GoogleLocNameSpecified=GoogleLocNameSpecified,GoogleMapType=GoogleMapType,
GoogleZoomlevel=GoogleZoomlevel,LabelAxisLat=LabelAxisLat,
LabelAxisLonGoogle=LabelAxisLonGoogle,LabelAxisLonOSM=LabelAxisLonOSM,
LabelAxisLonStamen=LabelAxisLonStamen,LatLocation=LatLocation,LatText=LatText,
LegendSize=LegendSize,LegendTitleRadarsDaily=LegendTitleRadarsDaily,
LonLocation=LonLocation,LonText=LonText,ManualScale=ManualScale,
MapBackground=MapBackground,OSMBottom=OSMBottom,OSMLeft=OSMLeft,
OSMRight=OSMRight,OSMScale=OSMScale,OSMTop=OSMTop,OutputFileType=OutputFileType,
PathRadarRainfallDepth=PathRadarRainfallDepth,PERIOD=PERIOD,
PlotLocation=PlotLocation,PixelBorderCol=PixelBorderCol,
PlotBelowScaleBottom=PlotBelowScaleBottom,ScaleBottomDaily=ScaleBottomDaily,
ScaleHigh=ScaleHigh,ScaleLow=ScaleLow,ScaleTopDaily=ScaleTopDaily,
SizePixelBorder=SizePixelBorder,SizePlotLocation=SizePlotLocation,
SizePlotTitle=SizePlotTitle,StamenMapType=StamenMapType,
StamenZoomlevel=StamenZoomlevel,SymbolPlotLocation=SymbolPlotLocation,
TimeZone=TimeZone,TitleRadars=TitleRadars,XMiddle=XMiddle,YMiddle=YMiddle)
```

`RainMapsRadarsTimeStep` *Function which visualises radar rainfall depths for chosen TIMESTEP in configuration file.*

Description

Function which visualises radar rainfall depths for chosen TIMESTEP. Requires interpolation grid and file with polygons of pixels.

Usage

```
RainMapsRadarsTimeStep(
  AlphaPlotLocation,
  AlphaPolygon,
  AutDefineLegendTop,
  BBoxOSMauto,
  ColoursNumber,
  ColourPlotLocation,
  ColourPlotLocationText,
  ColourScheme,
  ColourType,
  ColourHighestClass,
  CoorSystemInputData,
  ExtraDeg,
  ExtraText,
  FigFileRadarsTimeStep,
  FigHeight,
  FigWidth,
```

```
  FileGrid,
  FilePolygonsGrid,
  FolderFigures,
  FolderRadarRainMapsTimeStep,
  FontFamily,
  GoogleLocDegSpecified,
  GoogleLocLat,
  GoogleLocLon,
  GoogleLocName,
  GoogleLocNameSpecified,
  GoogleMapType,
  GoogleZoomlevel,
  LabelAxisLat,
  LabelAxisLonGoogle,
  LabelAxisLonOSM,
  LabelAxisLonStamen,
  LatLocation,
  LatText,
  LegendSize,
  LegendTitleRadarsTimeStep,
  LonLocation,
  LonText,
  ManualScale,
  MapBackground,
  OSMBottom,
  OSMLeft,
  OSMRight,
  OSMScale,
  OSMTop,
  OutputFileType,
  PathRadarRainfallDepth,
  PERIOD,
  PlotLocation,
  PixelBorderCol,
  PlotBelowScaleBottom,
  ScaleBottomTimeStep,
  ScaleHigh,
  ScaleLow,
  ScaleTopTimeStep,
  SizePixelBorder,
  SizePlotLocation,
  SizePlotTitle,
  StamenMapType,
  StamenZoomlevel,
  SymbolPlotLocation,
  TIMESTEP,
  TimeZone,
  TitleRadars,
  XMiddle,
  YMiddle
)
```

Arguments

AlphaPlotLocation	Transparency of plotted symbol for specified location on map.
AlphaPolygon	Transparency of polygons.
AutDefineLegendTop	Let R automatically define highest value of legend in case of "yes". Then the highest class, i.e. the one plotted separately above the other classes, is not plotted anymore.
BBoxOSMauto	Compute bounding box from input data or used bounding box defined above? (for OpenStreetMap and Stamen Map only). Use "yes" if bounding box is to be computed from interpolation grid.
ColoursNumber	Number of colour classes in legend.
ColourPlotLocation	Colour of plotted symbol for specified location on map.
ColourPlotLocationText	Colour of plotted rainfall depth for specified location on map.
ColourScheme	Hexadecimal codes or names for colours of legend.
ColourType	Colour or black-and-white background map? Use "color" for colour and "bw" for black-and-white background map.
ColourHighestClass	Colour of highest class.
CoorSystemInputData	Define coordinate system of input data (e.g. "+init=epsg:4326" for WGS84 in decimal degrees).
ExtraDeg	To reduce computational time, it is automatically determined which grid cells fall within the plotted region. To also plot grid cell values which partly fall outside the plotted region, a positive number for ExtraDeg should be specified (decimal degrees). This should typically be at least the size of one grid cell in decimal degrees.
ExtraText	Second part of title of plot.
FigFileRadarsTimeStep	Part of figure output file name.
FigHeight	Figure height. 1280 times 1280 pixels seems maximum graphical resolution for downloaded Google Maps. Because also axes and legend are plotted, it is advised to use e.g. 1450 times 1450 pixels. Then the Google Map will remain approximately 1280 times 1280 pixels. Using higher values is not a problem (e.g. 2000). In this way it is tried to get the highest possible resolution. For OpenStreetMap the maps may reach resolutions of 1500 - 2000 pixels. Hence, using FigWidth and FigHeight of 2000 pixels or higher is advised. The OpenStreetMap itself is stored in file "ggmapTemp.png". From this file the resolution of the background map can be obtained. This can be useful for determining an appropriate FigWidth and FigHeight above.
FigWidth	Figure width. 1280 times 1280 pixels seems maximum graphical resolution for downloaded Google Maps. Because also axes and legend are plotted, it is advised to use e.g. 1450 times 1450 pixels. Then the Google Map will remain approximately 1280 times 1280 pixels. Using higher values is not a problem (e.g. 2000). In this way it is tried to get the highest possible resolution. For OpenStreetMap the maps may reach resolutions of 1500 - 2000 pixels. Hence,

using FigWidth and FigHeight of 2000 pixels or higher is advised. The OpenStreetMap itself is stored in file "ggmapTemp.png". From this file the resolution of the background map can be obtained. This can be useful for determining an appropriate FigWidth and FigHeight above.

`FileGrid` File with interpolation grid in same coordinate system as CoorSystemInputData.

`FilePolygonsGrid`
Name of file with polygons of interpolation grid.

`FolderFigures` Folder name of figures.

`FolderRadarRainMapsTimeStep`
Name of folder which contains 5-min radar rainfall files (input data).

`FontFamily` Specify font family of text in figures. To select the default font use "". Using "Times" may give warnings when executing the visualisation. In that case the font is not installed on the computer. This can be solved by using the default font ("").

`GoogleLocDegSpecified`
If GoogleLocDegSpecified is "yes" then the specified location in decimal degrees is used as the centre of the Google Map. If both GoogleLocNameSpecified and GoogleLocDegSpecified are not equal to "yes", the bounding box of the map is determined from the provided grid and used as centre of the Google Map.

`GoogleLocLat` Latitude of middle of Google Map (decimal degrees).

`GoogleLocLon` Longitude of middle of Google Map (decimal degrees).

`GoogleLocName` Location of middle of Google Map, provided as text, e.g. name of city, street name, country.

`GoogleLocNameSpecified`
If GoogleLocNameSpecified is "yes" then the specified location name GoogleLocName is used as the centre of the Google Map. If both GoogleLocNameSpecified and GoogleLocDegSpecified are not equal to "yes", the bounding box of the map is determined from the provided grid and used as centre of the Google Map.

`GoogleMapType` In case of Google Maps: which map type should be used? Available map types: "terrain", "satellite", "roadmap", and "hybrid".

`GoogleZoomlevel`
Which zoom level to use for the Google Maps?

`LabelAxisLat` Label name of vertical axis.

`LabelAxisLonGoogle`
Label name of horizontal axis (for Google Maps only).

`LabelAxisLonOSM`
Label name of horizontal axis (for OpenStreetMap only).

`LabelAxisLonStamen`
Label name of horizontal axis (for Stamen Map only).

`LatLocation` Latitude of location on map (decimal degrees).

`LatText` Latitude of text (rainfall depth) of location on map (decimal degrees).

`LegendSize` Size of legend (choose e.g. 75 for 6 classes and 50 for 10 classes).

`LegendTitleRadarsTimeStep`
Title of legend.

`LonLocation` Longitude of location on map (decimal degrees).

`LonText` Longitude of text (rainfall depth) of location on map (decimal degrees).

`ManualScale` Manually supply the legend breaks if ManuelScale is not equal to "no". Interval breaks are determined manually from ScaleLow and ScaleHigh. If ManualScale is "no" interval breaks are determined automatically.

`MapBackground` Google Maps, OpenStreetMap or Stamen Map as background? Use "Google" for Google Maps, "OSM" for OpenStreetMap and "Stamen" for Stamen Map (based on OpenStreetMap data). Note that Google Maps will only plot on a square figure. It seems that mapping with OpenStreetMap ("get openstreetmap") is no langer supported. This implies that mapping can only be done employing Google Maps (if Google API key is obtained) or via Stamen Map. This is not related to the RAINLINK version.

`OSMBottom` Latitude in decimal degrees (WGS84) for bottom side of the area for which rainfall depths are to be plotted (for OpenStreetMap & Stamen Maps only).

`OSMLeft` Longitude in decimal degrees (WGS84) for left side of the area for which rainfall depths are to be plotted (for OpenStreetMap & Stamen Maps only).

`OSMRight` Longitude in decimal degrees (WGS84) for right side of the area for which rainfall depths are to be plotted (for OpenStreetMap & Stamen Maps only).

`OSMScale` Give value of scale (for OpenStreetMap only). A proper choice of the scale parameter in get_openstreetmap is difficult. It cannot be computed automatically. Hence, a scale parameter value should be provided below. The scale parameter should be as small as possible to get the highest graphical resolution. However, a too low value may result in a map not being downloaded. Hence, the user should manually supply get_openstreetmap with a scale. It may require some iterations to find the appropriate value for scale. The file "ggmapTemp.png" is written to disk when an OpenStreetMap is loaded. The highest possible resolution for a square area is about 2000 x 2000 pixels.

`OSMTop` Latitude in decimal degrees (WGS84) for top side of the area for which rainfall depths are to be plotted (for OpenStreetMap & Stamen Maps only).

`OutputFileType` Choose output file type of image: jpeg, png or tiff.

`PathRadarRainfallDepth`
Path in NetCDF4 file with radar data.

`PERIOD` Select daily time interval, i.e. "0800" implies 0800 UTC previous day - 0800 UTC present day (use 2400 for 0000 UTC).

`PlotLocation` A location is plotted on map if PlotLocation is "yes".

`PixelBorderCol` Choose colour of pixel borders. Use NA (without quotes) to not plot pixel borders. If the pixels are relatively small with respect to the plotted region, the graphical quality of the pixel borders deteriorates due to low number of pixels (low resolution).

`PlotBelowScaleBottom`
Plot grid lines for polygons below threshold ScaleBottomTimeStep or ScaleBottomDaily? If "yes" grid lines are plotted, otherwise they are not plotted.

`ScaleBottomTimeStep`
ScaleBottomDaily Lowest class starts at this threshold (minimum rainfall accumulation (mm) to be plotted). Using a value clearly above 0 mm can save a lot of computation time if the polygons belonging to values below the threshold are not plotted.

`ScaleHigh` ScaleHigh Highest value per class interval, i.e. the highest legend breaks, if these are manually chosen. Please note that in case of x values in ColoursNumber, ScaleHigh should also contain x values.

`ScaleLow` ScaleLow Lowest value per class interval, i.e. the lowest legend breaks, if these are manually chosen. Please note that in case of x values in ColoursNumber, ScaleLow should also contain x values.

`ScaleTopTimeStep`
Highest colour class ends here (maximum rainfall accumulation (mm) to be plotted). Sometimes the legend is not correctly plotted. In that case try other values for ScaleTopTimeStep and/or ScaleBottomTimeStep For instance, if the highest class (> x mm) is plotted below instead of above the other classes. Or if the number of classes does not match the number of chosen classes. Another way to prevent this is to manually give the legend breaks (ManualScale not equal to "no").

`SizePixelBorder`
Size of pixel borders.

`SizePlotLocation`
Size of symbol and and accompanied text for specified location on map.

`SizePlotTitle` Size of plot title.

`StamenMapType` In case of Stamen Maps: which map type should be used? Available map types which seem most useful and work: "toner-hybrid" &, recommended: "toner-lite", "terrain" & "watercolor".

`StamenZoomlevel`
Which zoom level to use for the Stamen Maps? This determines the level of detail. Large values take more time. It does not determine the domain of the area which is plotted.

`SymbolPlotLocation`
Symbol to be plotted for specified location on map.

`TIMESTEP` Duration of time interval of sampling strategy (min).

`TimeZone` Time zone of data (e.g. "UTC").

`TitleRadars` First part of title of plot.

`XMiddle` The longitude of the centre of the Azimuthal Equidistant Cartesian coordinate system, given in the coordinate system of the input data.

`YMiddle` The latitude of the centre of the Azimuthal Equidistant Cartesian coordinate system, given in the coordinate system of the input data.

Author(s)

Aart Overeem & Hidde Leijnse

References

”ManualRAINLINK.pdf”

Overeem, A., Leijnse, H., and Uijlenhoet, R., 2016: Retrieval algorithm for rainfall mapping from microwave links in a cellular communication network, Atmospheric Measurement Techniques, 9, 2425-2444, https://doi.org/10.5194/amt-9-2425-2016.

Examples

```
RainMapsRadarsTimeStep(AlphaPlotLocation=AlphaPlotLocation,AlphaPolygon=AlphaPolygon,
AutDefineLegendTop=AutDefineLegendTop,BBoxOSMauto=BBoxOSMauto,
ColoursNumber=ColoursNumber,ColourPlotLocation=ColourPlotLocation,
ColourPlotLocationText=ColourPlotLocationText,ColourScheme=ColourScheme,
```

```
ColourType=ColourType,CoorSystemInputData=CoorSystemInputData,ExtraDeg=ExtraDeg,
ExtraText=ExtraText,FigFileRadarsTimeStep=FigFileRadarsTimeStep,FigHeight=FigHeight,
FigWidth=FigWidth,FileGrid=FileGrid,FilePolygonsGrid=FilePolygonsGrid,
FolderFigures=FolderFigures,FolderRadarRainMapsTimeStep=FolderRadarRainMapsTimeStep,
FontFamily=FontFamily,GoogleLocDegSpecified=GoogleLocDegSpecified,
GoogleLocLat=GoogleLocLat,GoogleLocLon=GoogleLocLon,GoogleLocName=GoogleLocName,
GoogleLocNameSpecified=GoogleLocNameSpecified,GoogleMapType=GoogleMapType,
GoogleZoomlevel=GoogleZoomlevel,LabelAxisLat=LabelAxisLat,
LabelAxisLonGoogle=LabelAxisLonGoogle,LabelAxisLonOSM=LabelAxisLonOSM,
LabelAxisLonStamen=LabelAxisLonStamen,LatLocation=LatLocation,LatText=LatText,
LegendSize=LegendSize,LegendTitleRadarsTimeStep=LegendTitleRadarsTimeStep,
LonLocation=LonLocation,LonText=LonText,ManualScale=ManualScale,
MapBackground=MapBackground,OSMBottom=OSMBottom,OSMLeft=OSMLeft,
OSMRight=OSMRight,OSMScale=OSMScale,OSMTop=OSMTop,OutputFileType=OutputFileType,
PathRadarRainfallDepth=PathRadarRainfallDepth,PERIOD=PERIOD,PlotLocation=PlotLocation,
PixelBorderCol=PixelBorderCol,PlotBelowScaleBottom=PlotBelowScaleBottom,
ScaleBottomTimeStep=ScaleBottomTimeStep,ScaleHigh=ScaleHigh,ScaleLow=ScaleLow,
ScaleTopTimeStep=ScaleTopTimeStep,SizePixelBorder=SizePixelBorder,
SizePlotLocation=SizePlotLocation,SizePlotTitle=SizePlotTitle,
StamenMapType=StamenMapType,StamenZoomlevel=StamenZoomlevel,
SymbolPlotLocation=SymbolPlotLocation,TIMESTEP=TIMESTEP,TimeZone=TimeZone,
TitleRadars=TitleRadars,XMiddle=XMiddle,YMiddle=YMiddle)
```

`RainRetrievalMinMaxRSL` *Function for path-averaged rainfall estimation using microwave links.*

Description

Function for path-averaged rainfall estimation using microwave links. Maximum and minimum path-averaged rainfall intensites are computed in subfunction "MinMaxRSLToMeanR", where a fixed correction factor is applied to remove wet antenna attenuation.

Works for a sampling strategy where minimum and maximum received signal powers are provided, and the transmitted power levels are constant.

Also works for a sampling strategy where instantaneous transmitted and received signal levels are obtained. In case of instantaneous signal levels, it does not matter whether transmitted power levels vary or are constant. The only requirement is that the input data for RAINLINK needs some preprocessing. See "ManualRAINLINK.pdf" for instructions.

Also works for a sampling strategy where average transmitted and received signal levels are obtained. In case of average signal levels, it does not matter whether transmitted power levels vary or are constant. The only requirement is that the input data for RAINLINK needs some preprocessing. See "ManualRAINLINK.pdf" for instructions.

Usage

```
RainRetrievalMinMaxRSL(
  Aa = 2.3,
  alpha = 0.33,
  Data,
  kRPowerLawDataH,
  kRPowerLawDataV,
  PmaxCor,
```

```
  PminCor,
  Pref
)
```

Arguments

Aa	Wet antenna attenuation correction A_a (dB).
alpha	Coefficient (α) determining contribution of minimum and maximum path-averaged rainfall intensity to mean path-averaged rainfall intensity (-).
Data	Data frame with microwave link data.
kRPowerLawDataH	Values of coefficients a and b employed to convert specific attenuation to path-averaged rainfall intensity for a range of microwave frequencies. For horizontally polarized radiation.
kRPowerLawDataV	Values of coefficients a and b employed to convert specific attenuation to path-averaged rainfall intensity for a range of microwave frequencies. For vertically polarized radiation.
PmaxCor	Data frame with corrected maximum received powers (dB).
PminCor	Data frame with corrected minimum received powers (dB).
Pref	Reference level (dB).

Value

Mean path-averaged rainfall intensity (mm h^{-1}).

Author(s)

Aart Overeem & Hidde Leijnse & Lotte de Vos

References

"ManualRAINLINK.pdf"

Overeem, A., Leijnse, H., and Uijlenhoet, R., 2016: Retrieval algorithm for rainfall mapping from microwave links in a cellular communication network, Atmospheric Measurement Techniques, 9, 2425-2444, https://doi.org/10.5194/amt-9-2425-2016.

Examples

```
RainRetrievalMinMaxRSL(Aa=2.3,alpha=0.33,Data=DataOutlierFiltered,
kRPowerLawDataH=kRPowerLawDataH,kRPowerLawDataV=kRPowerLawDataV,PmaxCor=Pcor$PmaxCor,
PminCor=Pcor$PminCor,Pref=Pref)
```

`ReadRainLocation` *Function for finding (interpolated) rainfall value for a given latitude and longitude.*

Description

Function for finding (interpolated) rainfall value for a given latitude and longitude. I.e. find the grid cell which belongs to the location for which latitude and longitude are provided.

Usage

```
ReadRainLocation(
  CoorSystemInputData,
  dataf,
  FileGrid,
  Lat,
  Lon,
  XMiddle,
  YMiddle
)
```

Arguments

`CoorSystemInputData`	Coordinate system of the input data (e.g. "+init=epsg:4326" for WGS84 in degrees).
`dataf`	Data frame of (interpolated) rainfall values.
`FileGrid`	File with interpolation grid in same coordinate system as CoorSystemInputData.
`Lat`	Latitude of location for which (interpolated) rainfall value is to be extracted (in coordinate system CoorSystemInputData).
`XMiddle`	The longitude of the centre of the Azimuthal Equidistant Cartesian coordinate system, given in the coordinate system of the input data.
`YMiddle`	The latitude of the centre of the Azimuthal Equidistant Cartesian coordinate system, given in the coordinate system of the input data.
`Lot`	Longitude of location for which (interpolated) rainfall value is to be extracted (in coordinate system CoorSystemInputData).

Value

Rainfall value for selected location (in unit of provided input rainfall data).

Author(s)

Aart Overeem & Hidde Leijnse

References

”ManualRAINLINK.pdf”

Overeem, A., Leijnse, H., and Uijlenhoet, R., 2016: Retrieval algorithm for rainfall mapping from microwave links in a cellular communication network, Atmospheric Measurement Techniques, 9, 2425-2444, https://doi.org/10.5194/amt-9-2425-2016.

Examples

```
ReadRainLocation(CoorSystemInputData=CoorSystemInputData,dataf=dataf,FileGrid=FileGrid,
Lat=Lat,Lon=Lon,XMiddle=XMiddle,YMiddle=YMiddle)
```

`RefLevelMinMaxRSL` *Function for determination of reference signal level (Pref), which is representative of dry weather.*

Description

Function for determination of reference signal level, which is representative of dry weather.

Works for a sampling strategy where minimum and maximum received signal powers are provided, and the transmitted power levels are constant.

Also works for a sampling strategy where instantaneous transmitted and received signal levels are obtained. In case of instantaneous signal levels, it does not matter whether transmitted power levels vary or are constant. The only requirement is that the input data for RAINLINK needs some preprocessing. See "ManualRAINLINK.pdf" for instructions.

Also works for a sampling strategy where average transmitted and received signal levels are obtained. In case of average signal levels, it does not matter whether transmitted power levels vary or are constant. The only requirement is that the input data for RAINLINK needs some preprocessing. See "ManualRAINLINK.pdf" for instructions.

The time interval does not have to be an integer but should be equidistant. The minimum time interval length in the time series is automatically computed and is employed as the time interval length.

Usage

```
RefLevelMinMaxRSL(
  Data,
  Dry = NULL,
  HoursRefLevel = 2.5,
  PeriodHoursRefLevel = 24
)
```

Arguments

`Data`	Data frame with microwave link data.
`Dry`	Data frame: Should interval be considered dry for reference level determination? (0 = wet; 1 = dry). Use Dry=NULL if no wet-dry classification has been performed. Then every time interval is considered dry and hence used for the reference level determination.
`HoursRefLevel`	Minimum number of hours that should be dry in preceding PeriodHoursRefLevel hours for computing reference level (h).
`PeriodHoursRefLevel`	Period over which reference level is to be determined (h).

Value

Reference level (dB).

Author(s)

Aart Overeem & Hidde Leijnse & Manuel F. Rios Gaona

References

"ManualRAINLINK.pdf"

Overeem, A., Leijnse, H., and Uijlenhoet, R., 2016: Retrieval algorithm for rainfall mapping from microwave links in a cellular communication network, Atmospheric Measurement Techniques, 9, 2425-2444, https://doi.org/10.5194/amt-9-2425-2016.

Examples

```
RefLevelMinMaxRSL(Data=DataPreprocessed,Dry=WetDry$Dry,HoursRefLevel=2.5,
PeriodHoursRefLevel=24)
```

Topology — *Function for plotting characteristics of topology of commercial microwave link network.*

Description

Function for plotting characteristics of topology of commercial microwave link data. This function provides the following figures:

1. Bar plot with percentage of links for bins of link path length (km).
2. Bar plot with percentage of links for bins of microwave frequency (GHz).
3. Bar plot with percentage of links for bins of orientation (degrees).
4. Scatter plot of microwave frequency (GHz) versus link path length (km).
5. Scatter density plot of microwave frequency (GHz) versus link path length (km).

Does not depend on sampling strategy.

The input microwave link data do not have to be sorted chronologically. Full-duplex links will give two data entries, these will both be used.

The computed percentages in the bar plots are only based on the range of classes presented in the bar plots, i.e. data outside these classes are not used in the computations.

When Rmean is provided, all figures are only based on data where the link-derived rainfall intensities are equal to or larger than 0 mm h^{-1}. Note that Data object must be preprocessed by function "PreprocessingMinMaxRSL" if Rmean is provided.

Usage

```
Topology(
  Data,
  CoorSystemInputData = NULL,
  FigNameBarplotAngle,
  FigNameBarplotFrequency,
  FigNameBarplotPathLength,
  FigNameFrequencyVsPathLength,
  FigNameScatterdensityplotFrequencyVsPathLength,
```

```
  Maxf,
  Minf,
  MaxL,
  MinL,
  Rmean = NULL,
  Stepf,
  StepL,
  verbose = TRUE
)
```

Arguments

Data	Data frame with microwave link data (use data(Linkdata) to load example data).
CoorSystemInputData	Define coordinate system of input data (in case of WGS84 provide NULL).
FigNameBarplotAngle	Name of file with bar plot with percentage of links for bins of link orientation. The extension must be ".pdf".
FigNameBarplotFrequency	Name of file with bar plot with percentage of links for bins of link path length. The extension must be ".pdf".
FigNameBarplotPathLength	Name of file with bar plot with percentage of links for bins of microwave frequency. The extension must be ".pdf".
FigNameFrequencyVsPathLength	Name of file with scatter plot of microwave frequency versus link path length. The extension must be ".pdf".
FigNameScatterdensityplotFrequencyVsPathLength	Name of file with scatter density plot of microwave frequency versus link path length. The extension must be ".pdf".
Maxf	Maximum microwave frequency to be plotted in bar plot (GHz). This is the value where the last bin class ends.
Minf	Minimum microwave frequency to be plotted in bar plot (GHz). This is the value where the first bin class ends.
MaxL	Maximum link path length to be plotted in bar plot (km). This is the value where the last bin class ends.
MinL	Minimum link path length to be plotted in bar plot (km). This is the value where the first bin class ends.
Rmean	Vector of link-derived rainfall intensities (mm h^{-1}) with length equal to Data.
Stepf	Bin size of microwave frequency classes for bar plot in GHz.
StepL	Bin size of link path length classes for bar plot in km.

Value

Figures with characteristics of topology of commercial microwave link network.

Author(s)

Aart Overeem

References

”ManualRAINLINK.pdf”

Overeem, A., Leijnse, H., and Uijlenhoet, R., 2016: Retrieval algorithm for rainfall mapping from microwave links in a cellular communication network, Atmospheric Measurement Techniques, 9, 2425-2444, https://doi.org/10.5194/amt-9-2425-2016.

Examples

```
data(Linkdata)
Topology(Data=Linkdata,CoorSystemInputData=NULL,FigNameBarplotAngle="Barplot_Orientation.pdf",
FigNameBarplotFrequency="Barplot_Frequency.pdf",FigNameBarplotPathLength="Barplot_PathLength.pdf",
FigNameFrequencyVsPathLength="Frequency_vs_PathLength.pdf",
FigNameScatterdensityplotFrequencyVsPathLength="ScatterdensityPlot_Frequency_vs_PathLength.pdf",
Maxf=40,Minf=13,MaxL=21,MinL=1,Rmean=Rmean,Stepf=1.5,StepL=2)
```

ToPolygonsRain *Subfunction which assignes values of rainfall grid to polygons.*

Description

Subfunction which assignes values of rainfall grid to polygons.

Usage

```
ToPolygonsRain(Data)
```

Arguments

Data	Field of rainfall depths at the chosen grid.

Value

Field of rainfall depths for the polygons at the chosen grid.

Author(s)

Aart Overeem & Hidde Leijnse

References

”ManualRAINLINK.pdf”

Overeem, A., Leijnse, H., and Uijlenhoet, R., 2016: Retrieval algorithm for rainfall mapping from microwave links in a cellular communication network, Atmospheric Measurement Techniques, 9, 2425-2444, https://doi.org/10.5194/amt-9-2425-2016.

Examples

```
ToPolygonsRain(Data=Data)
```

`WetDryNearbyLinkApMinMaxRSL` *Function for classifying wet and dry periods according to the nearby link approach. Function also prepares link data for determination of reference signal level and for computing corrected received powers.*

Description

The received signal powers often decrease during non-rainy periods, resulting in non-zero rainfall estimates, e.g. caused by reflection of the beam or dew formation on the antennas. To prevent this rainfall overestimation a reliable classification of wet and dry periods is needed. This is also beneficial for determining an appropriate reference signal level, representative for dry weather. In order to define wet and dry periods, we assume that rain is correlated in space, and hence that several links in a given area should experience a decrease in minimum received signal level in the case of rain. A time interval is labeled as wet if at least half of the links in the vicinity (for chosen radius) of the selected link experience such a decrease. This so called nearby link approach is applied in this function. The function also prepares link data for determination of reference signal level and for computing corrected received powers.

Works for a sampling strategy where minimum and maximum received signal powers are provided, and the transmitted power levels are constant.

Also works for a sampling strategy where instantaneous transmitted and received signal levels are obtained. In case of instantaneous signal levels, it does not matter whether transmitted power levels vary or are constant. The only requirement is that the input data for RAINLINK needs some preprocessing. See "ManualRAINLINK.pdf" for instructions.

Also works for a sampling strategy where average transmitted and received signal levels are obtained. In case of average signal levels, it does not matter whether transmitted power levels vary or are constant. The only requirement is that the input data for RAINLINK needs some preprocessing. See "ManualRAINLINK.pdf" for instructions.

The time interval does not have to be an integer but should be equidistant. The minimum time interval length in the time series is automatically computed and is employed as the time interval length.

Usage

```
WetDryNearbyLinkApMinMaxRSL(
  Data,
  CoorSystemInputData = NULL,
  MinHoursPmin = 6,
  PeriodHoursPmin = 24,
  Radius = 15,
  Step8 = TRUE,
  ThresholdMedian = -1.4,
  ThresholdMedianL = -0.7,
  ThresholdNumberLinks = 3,
  ThresholdWetDry = 2
)
```

Arguments

`Data`	Data frame with microwave link data.

`CoorSystemInputData`
: Define coordinate system of input data (in case of WGS84 provide NULL).

`MinHoursPmin`
: Minimum number of hours in the previous PeriodHoursPmin hours needed for computing max(P_{min}) (h).

`PeriodHoursPmin`
: Number of hours that is considered for computation of max(P_{min}) (h).

`Radius`
: Radius in wet-dry classification (km).

`Step8`
: If TRUE step 8 in the wet-dry classification is performed, else it is not executed.

`ThresholdMedian`
: Threshold value (dB).

`ThresholdMedianL`
: Threshold value (dB km^{-1}).

`ThresholdNumberLinks`
: Only use data if number of available (surrounding) links is at least larger than this threshold for the time interval under consideration. The selected link is also counted.

Value

Data frame: Should interval be considered dry for reference level. determination? (0 = wet; 1 = dry)

Values F for filter to remove outliers (dB km^{-1} h)

Author(s)

Aart Overeem & Hidde Leijnse

References

"ManualRAINLINK.pdf"

Overeem, A., Leijnse, H., and Uijlenhoet, R., 2016: Retrieval algorithm for rainfall mapping from microwave links in a cellular communication network, Atmospheric Measurement Techniques, 9, 2425-2444, https://doi.org/10.5194/amt-9-2425-2016.

Examples

```
WetDryNearbyLinkApMinMaxRSL(Data=DataPreprocessed,CoorSystemInputData=NULL,
MinHoursPmin=6,PeriodHoursPmin=24,Radius=15,Step8=TRUE,ThresholdMedian=-1.4,
ThresholdMedianL=-0.7,ThresholdNumberLinks=3,ThresholdWetDry=2)
```

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