Package 'RAINLINK'

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Type Package

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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.

Imports sf, s2, gstat, hexbin, sfheaders, abind, stars

RoxygenNote 7.3.1

Installation To install this R package run: install.packages("RAINLINK_1.31.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.

New as of RAINLINK version 1.31: When Rmean is not available, just use Rmean=NULL as argument. Then, the availability is also computed, but no selections with Rmean are performed. So no preprocessing is needed in that case.

Usage

```
DataAvailability(
  Data,
  cex.axis,
  cex.lab,
  FigNameBarplotAvailabilityLinks,
  FigNameBarplotAvailabilityLinkPaths,
  FigNameTimeseriesAvailability,
  ps,
  Rmean,
  TimeZone = "UTC",
  LocationLegendTimeseriesAvailability,
  MaxPercLinkPaths,
  MaxPercSubLinks,
  PlotTitleDataAvailability,
  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".
LocationLegendTimeseriesAvailability	Location of legend of figure with time series of number of sub-links and link paths. Choose from "bottomright", "bottomright", "bottom", "bottomleft", "left", "topleft", "top", "topright", "right" and "center"
MaxPercLinkPaths	Maximum percentage on scale for bar plot of link path availability.
MaxPercSubLinks	Maximum percentage on scale for bar plot of sub-link availability.
PlotTitleDataAvailability	Title of plots (e.g., which CML vendor or period).
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",
MaxPercLinkPaths=100,MaxPercSubLinks=100,PlotTitleDataAvailability="Timeseries of data availability",
LocationLegendTimeseriesAvailability="topright")
```

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 a Cartesian coordinate system.
Rainlink	Coordinates of links in a 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,
  idp = 2,
  InputCoorSystem,
  IntpMethod = "OK",
  LocalCartesianCoorSystem,
  nmax = 50,
  NUGGET,
  RANGE,
  RainGrid,
  Rmean,
  SILL,
  TimeZone = "UTC",
  Variogram = "ClimVar",
  OutputDir = NULL
)
```

Arguments

`Data`	Data frame with microwave link data.
`idp`	The inverse distance weighting power.
`InputCoorSystem`	Define EPSG code for input coordinate system (e.g., 4326L for WGS84 in degrees).
`IntpMethod`	Interpolation method: Ordinary kriging ("OK") or inverse distance weighted interpolation ("IDW").
`LocalCartesianCoorSystem`	Define EPSG code for (local) Cartesian coordinate system (meters).

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 link locations (InputCoorSystem).
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,idp=2.0,InputCoorSystem=4326L,
IntpMethod="OK",LocalCartesianCoorSystem=28992,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,
  LocalCartesianCoorSystem,
  Rmean,
  XEnd,
  XStart,
  YEnd,
  YStart
)
```

Arguments

ID	Link identifier.
LocalCartesianCoorSystem	Define EPSG code for (local) Cartesian coordinate system (meters).
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 (local) 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,LocalCartesianCoorSystem=28992,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 (°; decimal degrees; WGS84).
- YStart: Latitude of start of links (°; decimal degrees; WGS84).
- XEnd: Longitude of end of links (°; decimal degrees; WGS84).
- YEnd: Latitude of end of links (°; decimal degrees; 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 a Cartesian coordinate system.
`Rainlink`	Coordinates of links in a 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.

Usage

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

Arguments

InputCoorSystem	Define EPSG code for input coordinate system (e.g., 4326L for WGS84 in degrees).
XStart	List with longitude of start of microwave links.
XEnd	List with longitude of end of microwave links.
YStart	List with latitude of start of microwave links.
YEnd	List with latitude of end of microwave links.

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(InputCoorSystem=4326L,XStart=XStart,XEnd=XEnd,YStart=YStart,YEnd=YEnd)
```

`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)
```

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(
  dataf,
  FileGrid,
  InputCoorSystem,
  Lat,
  LocalCartesianCoorSystem,
  Lon
)
```

Arguments

dataf	Data frame of (interpolated) rainfall values.
FileGrid	File with interpolation grid in same coordinate system as InputCoorSystem.
InputCoorSystem	Define EPSG code for input coordinate system (e.g., 4326L for WGS84 in degrees).
Lat	Latitude of location for which (interpolated) rainfall value is to be extracted (in coordinate system InputCoorSystem).
Lot	Longitude of location for which (interpolated) rainfall value is to be extracted (in coordinate system InputCoorSystem).

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(dataf=dataf,FileGrid=FileGrid,InputCoorSystem=4326L,
Lat=Lat,LocalCartesianCoorSystem=28992,Lon=Lon)
```

`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,
  FigNameBarplotAngle,
  FigNameBarplotFrequency,
  FigNameBarplotPathLength,
  FigNameFrequencyVsPathLength,
  FigNameScatterdensityplotFrequencyVsPathLength,
  InputCoorSystem,
  LocalCartesianCoorSystem,
  Maxf,
  Minf,
  MaxL,
```

```
  MinL,
  Rmean = NULL,
  Stepf,
  StepL,
  MaxPercFrequency,
  MaxPercOrientation,
  MaxPercPathLength,
  PlotTitleTopology,
  verbose = TRUE
)
```

Arguments

Data	Data frame with microwave link data (use data(Linkdata) to load example data).
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".
InputCoorSystem	Define EPSG code for input coordinate system (e.g., 4326L for WGS84 in degrees).
LocalCartesianCoorSystem	Define EPSG code for (local) Cartesian coordinate system (meters).
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.
MaxPercFrequency	Maximum percentage on scale for bar plot of microwave frequency.
MaxPercOrientation	Maximum percentage on scale for bar plot of orientation.
MaxPercPathLength	Maximum percentage on scale for bar plot of path length.
PlotTitleTopology	Title of plots (e.g., which CML vendor or period).

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,FigNameBarplotAngle="Barplot_Orientation.pdf",
FigNameBarplotFrequency="Barplot_Frequency.pdf",FigNameBarplotPathLength="Barplot_PathLength.pdf",
FigNameFrequencyVsPathLength="Frequency_vs_PathLength.pdf",
FigNameScatterdensityplotFrequencyVsPathLength="ScatterdensityPlot_Frequency_vs_PathLength.pdf",
InputCoorSystem=4326L,LocalCartesianCoorSystem=28992,
Maxf=40,Minf=13,MaxL=21,MinL=1,Rmean=Rmean,Stepf=1.5,StepL=2,MaxPercFrequency=40,
MaxPercOrientation=7,MaxPercPathLength=30,PlotTitleTopology="Topology")
```

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,
  InputCoorSystem = InputCoorSystem,
  LocalCartesianCoorSystem = LocalCartesianCoorSystem,
  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.
`InputCoorSystem`	Define EPSG code for input coordinate system (e.g., 4326L for WGS84 in degrees).
`LocalCartesianCoorSystem`	Define EPSG code for (local) Cartesian coordinate system (meters).
`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,InputCoorSystem=4326L,
LocalCartesianCoorSystem=28992, MinHoursPmin=6,PeriodHoursPmin=24,Radius=15,
Step8=TRUE,ThresholdMedian=-1.4, ThresholdMedianL=-0.7,ThresholdNumberLinks=3,
ThresholdWetDry=2)
```

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