Manual of R package "RAINLINK" version 1.1

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Aart Overeem

Motivation

Microwave links in commercial cellular communication networks hold a promise for areal rainfall monitoring and could complement rainfall estimates from ground-based weather radars, rain gauges, and satellites. A microwave link is defined as a connection from one telephone tower to another telephone tower. The basic principle of rainfall estimation using microwave links is as follows. Rainfall attenuates the electromagnetic signals transmitted from the directional antenna of one telephone tower to another. The received power at one end of a microwave link as a function of time is stored operationally by communication companies to monitor the quality of their networks. From the decrease in received signal level with respect to the reference signal level, being representative of dry weather, the rainfall-induced path-integrated attenuation can be calculated. This can be converted to average rainfall intensities over the path of a link. Rainfall estimates from networks of individual links could in turn potentially be employed to create near real-time rainfall maps. This is particularly interesting for those countries where few surface rainfall observations are available.

The R[1] package "RAINLINK" enables to obtain rainfall maps from microwave links in a cellular telecommunication network. The code is publicly available via GitHub[2] under the condition of version 3 of the GNU General Public License. It contains a working example to compute link-based rainfall maps for the entire surface area of The Netherlands from real microwave link data. This is a working example using two days of actual data from an extensive network of commercial microwave links. This will allow users to test their own algorithms and compare their results with ours. Note that link data are utilised in a stand-alone fashion to obtain rainfall maps, i.e., data from rain gauges, weather radars, or satellites are not combined with the link data.

The purpose of this package is to promote rainfall mapping utilizing microwave links from cellular communication networks as an alternative or complementary means for continental-scale rainfall monitoring. We invite researchers to contribute to RAINLINK to make the code more generally applicable to data from different networks and climates. Ideally the code should be tested on data sets containing all seasons for varying networks and regions. Such an endeavour worldwide is currently difficult to achieve. It would require an enormous effort and it would also require data sharing among researchers, which is still not that easy to accomplish due to confidentiality requirements by telecommunication companies.

The modular programming facilitates users to adapt the code to their specific network and climate conditions. We hope that RAINLINK will promote the application of rainfall monitoring using microwave links in poorly gauged regions around the world.

[1] http://www.r-project.org/
[2] https://github.com/overeem11/RAINLINK

Documentation

The following documentation is available for the RAINLINK package:

- A scientific paper: Overeem, A., Leijnse, H. and Uijlenhoet, R. (2016): Retrieval algorithm for rainfall mapping from microwave links in a cellular communication network, Atmospheric Measurement Techniques, under review. It contains a detailed description of the employed rainfall retrieval and interpolation algorithm, as well as the corresponding computer code. It shows examples of what the algorithm is capable of. Moreover, this paper extensively discusses the transferability of the code to other networks and climates, and it provides a sensitivity analyses of parameters of the rainfall retrieval algorithm.

- The file "RAINLINK.pdf", which comes with the RAINLINK package. It gives a description of the (sub)functions of the package, such as function arguments. This information is also available in the R help documentation of the package.

- This manual ("ManualRAINLINK.pdf"). It provides a motivation of the development of the RAINLINK package. Moreover, it gives information on the use of (sub)functions and the choice of parameter values. It is meant to facilitate running the RAINLINK package.

Overview of (sub)functions

Table 1 gives on overview of the (sub) functions in the RAINLINK package, which are needed for rainfall retrieval and mapping. It shows in which order they should be applied. If a function name contains "MinMaxRSL", the function is suited for a sampling strategy where minimum and maximum received signal powers are provided, and the transmitted power levels are constant. The other functions are generally applicable.

The script "Run.R", supplied with RAINLINK on GitHub, determines which (sub)functions are being applied. I.e. it shows how to run the functions from the RAINLINK package.

Overview of the variables, includer header names

Table 2 provides an overview of the variables, including header names for all (sub)functions in the rainfall retrieval algorithm.

Parameters in the rainfall retrieval algorithm

Table 3 shows the parameters used in the rainfall retrieval algorithm and their default values. All these parameters can be modified. Their values have to be supplied as function arguments. The configuration file "Config.R" can be utilised to load most of these parameter values. By running (parts of) "Run.R" the functions can be easily executed.

Table 1: Overview of functions needed for processing link data from received signal powers to rainfall maps. Italicised (sub)functions are optional. A choice has to be made between bold subfunctions. The script "Run.R" can be employed to determine which (sub)functions are being applied.

Step	Function	Subfunction	Description
1	PreprocessingMinMaxRSL	-	Preprocessing of linkdata
2	*WetDryNearbyLinkApMinMaxRSL*		Wet-dry classification with nearby link approach
3	RefLevelMinMaxRSL	-	Reference signal level determination
4	*OutlierFilterMinMaxRSL**	-	Remove outliers
5	CorrectMinMaxRSL		Correction of received signal powers
6	RainRetrievalMinMaxRSL		Compute mean path-averaged rainfall intensities
		MinMaxRSLToMeanR	Convert minimum and maximum to mean rainfall intensities
7	Interpolation		Interpolate path-averaged rainfall intensities
		IntpPathToPoint	Compute path-averaged rainfall intensities for unique link paths
			Assign path-averaged intensities to points at middle of link paths
		ClimVarParam	Compute values of sill, range, and nugget of spherical variogram model
		OrdinaryKriging	Interpolate link rainfall intensities by ordinary kriging using assigned values of sill, range, and nugget of spherical variogram model from ClimVarParam or by manually supplying them as function arguments
		IDW	Apply inverse distance weighted interpolation
8	RainMapsLinksTimeStep		Link rainfall maps for time interval of link data
	RainMapsRadarsTimeStep		Gauge-adjusted rainfall maps for time interval of link data
	RainMapsLinksDaily		Daily link rainfall maps from link data at given time interval
	RainMapsRadarsDaily		Daily gauge-adjusted rainfall map for specified radar file
		Polygons	Make data frame for polygons
		ToPolygonsRain	Values of rainfall grid are assigned to polygons
		*ReadRainLocation***	Extract (interpolated) rainfall depth for supplied latitude and longitude
9	PlotLinkLocations		Plot a map with the link locations

* *Outliers can only be removed when "WetDryNearbyLinkApMinMaxRSL" has been run.*

** *This subfunction can also be used as a function to extract (interpolated) rainfall depths from a data frame of (interpolated) rainfall values for supplied latitude and longitude.*

Processing large microwave link data sets

In case of large microwave link data sets, e.g. one year of data for a few thousands of links, the following strategies could be followed:

- Make use of the multiple processors in a computer. Each processor can then be employed to run a subset of the data set, for instance one day per processor. To process a large number of days in an automated fashion, a loop could be constructed which selects the data from e.g. one day per iteration, each processor having its own loop. This limits the memory usage and helps to speed up the processing. I.e. loading several days at once into memory may result in a large increase in computational time.

- Divide a region into sub-regions. This will particularly help to speed up the wet-dry classification.

- It can be useful to write output data from intermediate processing steps to disk. E.g. the wet-dry classification takes a lot of computer time. After this classification one

Table 2: Most important variables used in the (sub)functions of the rainfall retrieval algorithm.

Name in (sub)function	**Symbol in AMT paper**	**Unit**	**Description**
a	a	mm h^{-1} dB^{-b} km^{b}	Coefficient of R-k power law
Amax	A_{max}	dB	Maximum rain-induced attenuation
Amin	A_{min}	dB	Minimum rain-induced attenuation
b	b	-	Exponent of R-k power law
DateTime	N/A	UTC	Date and time
Dry	N/A	-	Should interval be considered dry for reference level determination? (0 = wet; 1 = dry)
F	F	dB km^{-1} h	Computed for filter to remove outliers
Frequency	f	GHz	Microwave frequency
ID	ID	-	Unique link identifier
PathLength	L	km	Path length
Rmean	$\langle R \rangle$	mm h^{-1}	Path-averaged rainfall intensity
Pmin	P_{min}	dB	Minimum received power
PminCor	P^{C}_{min}	dB	Corrected minimum received power
Pmax	P_{max}	dB	Maximum received power
PmaxCor	P^{C}_{max}	dB	Corrected maximum received power
Pref	P_{ref}	dB	Reference level
XStart	N/A	° (km)	Longitude (or easting) of start of microwave link
XEnd	N/A	° (km)	Longitude (or easting) of end of microwave link
YStart	N/A	° (km)	Latitude (or northing) of start of microwave link
YEnd	N/A	° (km)	Latitude (or northing) of end of microwave link

may decide whether an outlier filter is applied or not. Storing data avoids rerunning the wet-dry classification when different processing steps are to be tested. Storing and reading data does hardly cost additional time; I/O is not a limiting factor for the RAINLINK package.

Table 3: Values of the parameters used in the rainfall retrieval algorithm. All these parameter values can be modified. The configuration file "Config.R" can be utilised to load all parameter values.

Variable description	**Symbol and unit**	**Value**	**Depends on:**
Wet-dry classification			
Radius	r (km)	15	Spatial correlation of rainfall
Minimum number of available (surrounding) links		3	
Number of previous hours over which $\max(P_{\mathrm{min}})$ is to be computed	h	24	
Minimum number of hours needed to compute $\max(P_{\mathrm{min}})$	h	6	
Threshold	$\mathrm{median}(\Delta P_{\mathrm{L}})$ (dB km^{-1})	-0.7	Spatial correlation of rainfall
Threshold	$\mathrm{median}(\Delta P)$ (dB)	-1.4	Spatial correlation of rainfall
Threshold (step 8 in Appendix C in AMT paper)	dB	2	
Reference signal level			
Period over which reference level is to be determined	h	24	
Minimum number of hours that should be dry in preceding period	h	2.5	
Outlier filter			
Outlier filter threshold	F_{t} (dB km^{-1} h)	-32.5	Malfunctioning of links
Rainfall retrieval			
Wet antenna attenuation	A_{a} (dB)	2.3	Rainfall intensity, number of wet antennas, antenna cover*
Coefficient	α (–)	0.33	Time variability of rainfall**
Coefficient of R-k power law	a (mm h^{-1} dB^{-b} km^{b})	3.4–25.0	Drop size distribution, frequency***
Exponent of R-k power law	b (–)	0.81–1.06	Drop size distribution, frequency***

* *Here A_a is fixed.*

** *Here α is fixed.*

*** *And to some extent on polarization, temperature, drop shape, and canting angle distribution (this has not been taken into account). Here values have been computed from one data set of measured drop size distributions (p. 65 in Leijnse, H., 2007: Hydrometeorological application of microwave links - Measurement of evaporation and precipitation. PhD thesis, Wageningen University, Wageningen).*