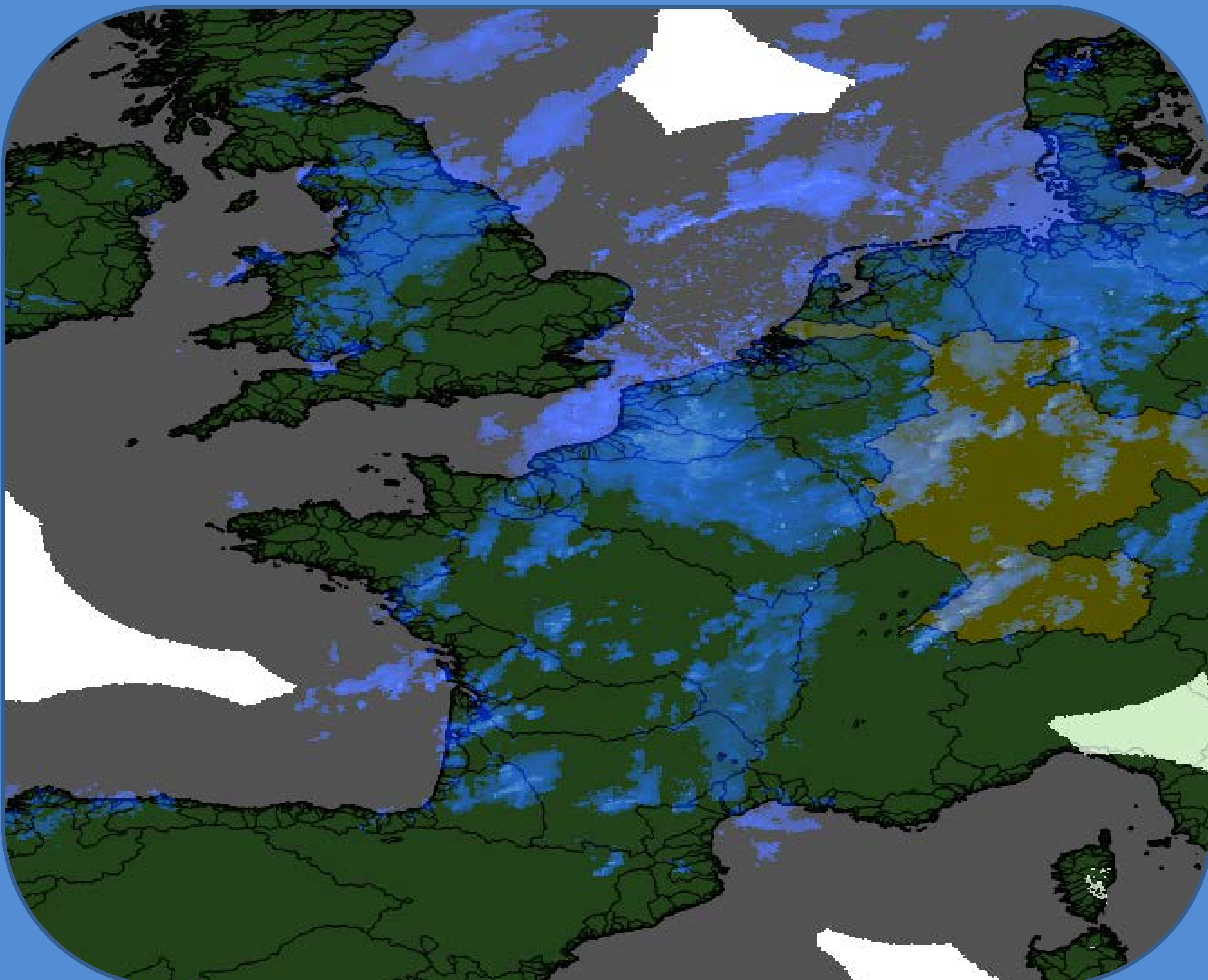
Radar to Catchment

User manual



Radar to Catchment - User manual

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Suggestions for changes to increase functionality or to overcome possible errors, are highly appreciated. Please contact:

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The image on the front page is constructed in QGIS with radar data of the OPERA program of EUMETNET and with data of the USGS Hydrosheds program [3, 11].

Contents

1 Aim of the tool

This project started because of current advances in the hydrology sector, which encompasses a shift from lumped hydrological models towards distributed models [6, 1]. The hydrology sector has made a call for precipitation data with a higher spatial and temporal resolution than usually provided by only rain gauges [8]. This call is not only there for distributed models, but also for lumped models, which need, for model improvement, better precipitation estimations than only measurements from local rain gauges.. At the same time, the meteorological sector is becoming able to provide radar, and even satellite, precipitation data on both high spatial and temporal resolution [9, 3]. The call seems to be answered, however, an easy to use and free software tool to extract data from such a large data set for the area of a catchment, is not there yet.

This project, and the resulting *Radar to Catchment* tool, aims to provide the user with an easy way to extract radar and satellite data for the area within a shapefile. The main design reason is for river catchments, but this tool could also be used for other purposes than hydrology.

The *Radar to Catchment* tool gives the user the following options:

- Extract data from a radar or satellite data set for a given shapefile of an area. The resulting file is a GeoTiff or an ASCII file, with the following additional possibilities:
  - Choose the pixel resolution of the resulting file.
  - Choose the spatial reference system of the resulting file.
  - Change dBZ into millimeters of precipitation.
  - Let the tool calculate zonal statistics per time step, such as the minimum precipitation value, the maximum precipitation value and the mean value for the area.
- Obtain a .csv-file with, per time step, precipitation data for a certain pixel within the data set.

2 Supported datasets

2.1 NL-Radar NL25 rac mfbs

The 'RAD_NL25_RAC_MFBS_5min' data set consists of adjusted five minute precipitation accumulations from the two KNMI (Royal Netherlands Meteorological Institute) weather radars for the Netherlands. The radar data set has already been masked for the land area of the Netherlands and is also available on an hourly or a daily temporal resolution. For the adjustment of the data, the KNMI rain gauge network in the Netherlands was used and the data set has a monthly update [9, 10].

Specifications of this dataset:

- Time period: January 14, 2008 08:00 UTC - Ongoing.
- Temporal resolution: 5 minutes.
- Spatial resolution: 1 x 1 km^2.
- Spatial Reference System: WGS 84 Arctic Polar Stereographic.
- Area covered: The Netherlands.
- Data format: HDF5.
- Pixel values: Precipitation in mm.

2.2 NL-Radar NL21 rac mfbs

The 'RAD_NL21_RAC_MFBS_5min' data set consists of adjusted five minute precipitation accumulations from the two KNMI (Royal Netherlands Meteorological Institute) weather radars for the Netherlands. The radar data set has already been masked for the land area of the Netherlands. For the adjustment of the data, the KNMI rain gauge network in the Netherlands was used and the data set has a monthly update [9, 10].

Specifications of this dataset:

- Time period: January 1, 1998 00:00 UTC - Ongoing.
- Temporal resolution: 5 minutes.
- Spatial resolution: 2.4 x 2.4 km^2.
- Spatial Reference System: WGS 84 Arctic Polar Stereographic.
- Area covered: The Netherlands.
- Data format: HDF5.
- Pixel values: Precipitation in mm.

2.3 DE-Radar Radolan

The Radolan data set consists of adjusted hourly precipitation accumulations from the seventeen DWD (German Weather Service) weather radars for Germany. The dataset provides precipitation data for Germany, but also for (small) parts of: the Netherlands, Belgium, France, Switzerland, Austria, the Czech Republic, Poland and Denmark. The hourly accumulations are available for every 50^{th} minute of the hour [2].

Specifications of this dataset:

- Time period: June 1, 2005 00:50 UTC - December 31, 2016 23:50 UTC.
- Temporal resolution: 60 minutes.
- Spatial resolution: 1 x 1 km^2.
- Spatial Reference System: Polar Stereographic North Pole, with a datum specific for Radolan.
- Area covered: Germany and part of its surroundings (see also Figure 1).
- Data format: ASCII.
- Pixel values: Precipitation in mm/h.

2.4 NL-Radar KNMI Data Centre: Average Monthly Precipitation

This data set consists of a long term average of monthly precipitation for the period 1981-2010, based on an interpolation by kriging of precipitation data from the KNMI (Royal Netherlands Meteorological Institute) manual rain gauge network in the Netherlands [7]. The *Radar to Catchment* tool is tested on this data set, but also works on other KNMI Data Centre data sets provided as NETCDF-files. As long as these other data sets have the same Spatial Reference System and variable, the tool will accept them.

Specifications of this dataset:

- Time period: January, 1981 - December, 2010.
- Temporal resolution: Monthly.
- Spatial resolution: 1 x 1 km^2.
- Spatial Reference System: Amersfoort RD New.
- Area covered: The Netherlands.
- Data format: NETCDF.
- Pixel values: Precipitation in mm.

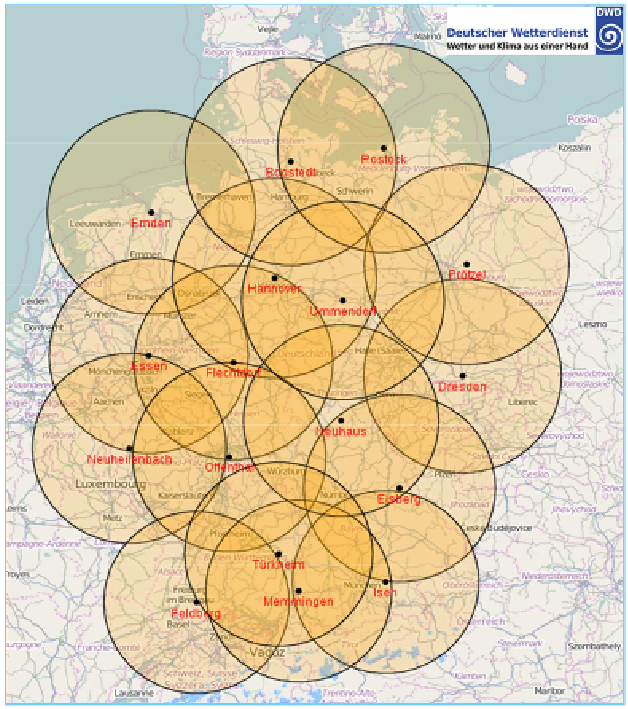

Figure 1: Area covered by the seventeen weather radars in Germany. The data of these radars is part of the Radolan data set. Source: DWD (German Weather Service), 2016.

2.5 EU-Radar EUMETNET OPERA

The OPERA (Operational Programme for the Exchange of Weather Radar Information) data set consists of fifteen minutes accumulations of weather radar data from most European countries (see also Figure 2). The project started in 2013 and lasts until 2018. It does not yet give gauge adjusted precipitation data, but the data coverage is good for a large part of Europe [3].

Specifications of this dataset:

- Time period: 2013 - present (every 15 minutes).
- Temporal resolution: 15 minutes.
- Spatial resolution: 4 x 4 km^2.
- Spatial Reference System: WGS 84 Arctic Polar Stereographic.
- Area covered: Europe (see also Figure 2).
- Data format: HDF5.
- Pixel values: Precipitation in mm or dBZ.

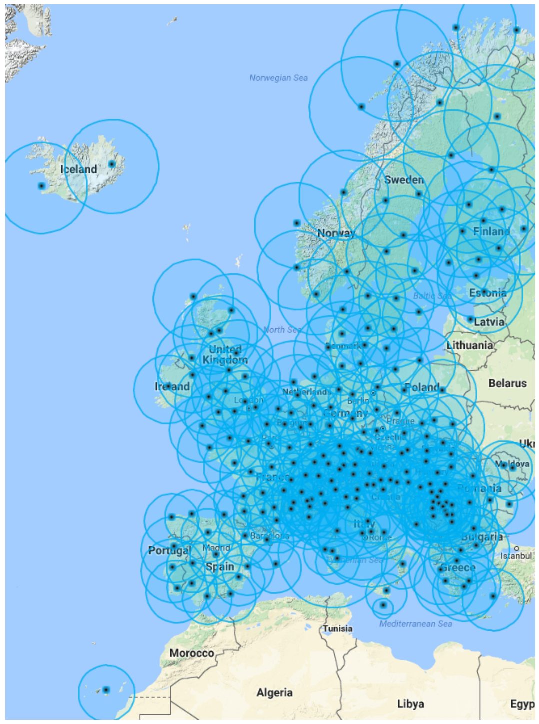

Figure 2: Area of Europe covered by the European weather radars that are part of the OPERA project. Source: EUMETNET & Google Maps, 2017.

2.6 NASA GPM IMERG HQ Precipitation

The HQ precipitation data set is a result of the NASA algorithm, used on observations of the GPM constellation of satellites, which is intended to intercalibrate, merge, and interpolate microwave precipitation estimates, together with microwave-calibrated infrared satellite estimates and precipitation gauge analyses. From the obtained satellite images, NASA provides a level 3 thirty minutes accumulation of estimated precipitation in mm/h [5].

Specifications of this dataset:

- Time period: March 12, 2014 00:00 UTC - February 28, 2017 00:00 UTC.
- Temporal resolution: 30 minutes.
- Spatial resolution: 0.1° x 0.1°.
- Spatial Reference System: WGS 84.
- Area covered: World.
- Data format: HDF5.
- Pixel values: Precipitation in mm/h.

3 Getting Started on Linux

The *Radar to Catchment* tool is written in Python and is fastest in a Linux environment. It is therefore recommended to use the tool in this environment. This section is a brief manual for the opening and the use of the tool within a Linux environment.

3.1 Starting the tool

Before running the Python script, make sure the following requirements are met:

- A main folder in a directory with the data of any of the supported data sets as described in section 2. This main folder should have:
  - The data, as separate files in the main folder or in sub-directories (e.g. in folders ordered per year, month or day).
  - A map *RasterIn* in the main folder.
  - A map *Results* in the main folder. Make sure this map is empty before running the script. After running the script, the results will be placed inside this folder.
- A shapefile of a catchment or certain area. It does not matter which Spatial Reference System this shapefile has, as long as the shapefile is a polygon. Note that having a shapefile is not necessary when only a list of values for one pixel has to be calculated by the tool.
- All required Python packages should be installed. The installation of packages is a matter of making use of the commander and type: *pip install 'name of package'*. The necessary packages can be found in the script; just open the script in Python and have a look at the starting list, clearly indicated by many lines starting with *Import [package]*, at the beginning of the script. Easier is to run the script in the commander (see below) and to install the scripts that are indicated as missing by an error.

When these requirements are met, open the commander and start the tool by running the script in Python (see Figure 3 for an example in the commander).

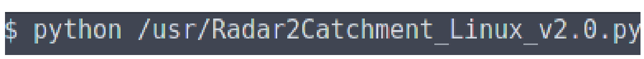

Figure 3: Example of how to run a Python script in a Linux commander. Make sure the command directs to the correct path.

The *Radar to Catchment* tool should open now and it will ask the following question:

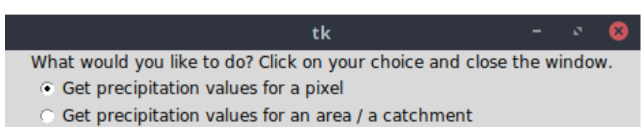

Figure 4: Opening question asked by the tool when the script is run.

Make a choice between *Get precipitation values for a pixel* and *Get precipitation values for an area / a catchment.* Click on the desired function and the tool will automatically proceed.

3.2 Get precipitation values for a pixel

In the event that *Get precipitation values for a pixel* is chosen, the tool will automatically ask which data set will be supplied (see Figure 5). Type in the window next to the six possibilities which data set will be supplied and press *Enter.* Other data sets could also be used; this could especially be the case for the KNMI Data Centre data sets, but also for other sources. When other data sets are provided, fill in the number of the data set that resembles most to the provided data set and make sure the data has equal specifications as the chosen data set number, concerning the spatial resolution, the Spatial Reference System, the data format and pixel value.

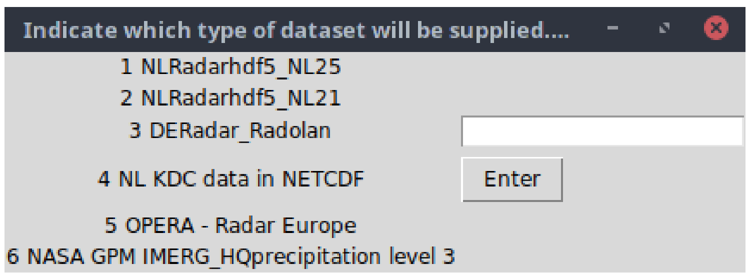

Figure 5: Indicate which data set will be supplied, or indicate to which data set the data resembles most, and press enter.

When the type of data set is given, the tool will ask to open the main folder with the data files and to press *OK.* Figure 6 gives an example of this process, for a case in which the first data set, *RAD_NL25_RAC_MFBS_5min*, was chosen. Search for the main directory of the data and open the main folder. Figure 6 displays what this main folder should look like. The folder contains the subfolders '1' and '2', indicating January and February, with inside these folders the data files. It is also possible to have the separate files directly inside the main folder or in sub-directories within a sub-directory. *Radar to Catchment* can handle all of these possibilities. Furthermore, the folder contains the subfolders *RasterIn* and *Results.* When all prerequisites are met, as they are in the example, press *OK.*

The next step will be to provide a column number and a row number of the desired cell (see Figure 7). These column and row numbers are equal to the column and row numbers in the provided data set. Hence, a 500 x 500 dataset can have no values larger than 500 for both the column and row number. After filling in both the column and row number, press *Enter.* The final step, before the tool will start its calculations, is to choose whether or not the data values have to be converted from dBZ to millimeters (see Figure 8). Answer with yes or no and press *Enter.* If no is answered, no conversion will take place. If yes is answered, another window will pop up (see Figure 9) that asks for the temporal resolution of the data in minutes. So, in the case the data has a temporal resolution of five minutes, fill in '5' and press *Enter.* Note that the user can change the parameters of the Z-R relationship in the script of the tool.

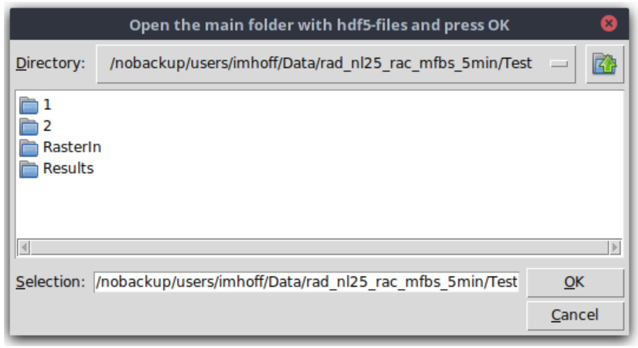

Figure 6: An example of a main folder called 'Test' which is opened. Give the path to this folder and when this folder meets the requirements, like in this example, press OK.

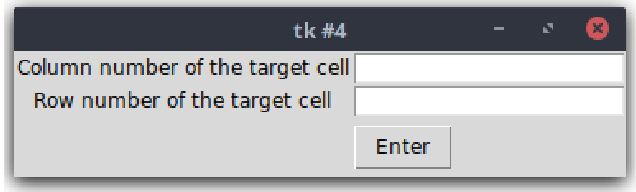

Figure 7: Give the column number and row number of the desired cell and press Enter.

It is time for the tool to do the work now: the tool will obtain the pixel values for every data file. The resulting file is a time-series with the pixel values, called *PixelPrec.csv*, and can be found in the Results of the main folder. Inside this file, two columns are present: the first column indicates the name of the file and the second column indicates the pixel value for the given column and row number. The header line states that this value is in millimeters, but this could be any unit that was present in the data.

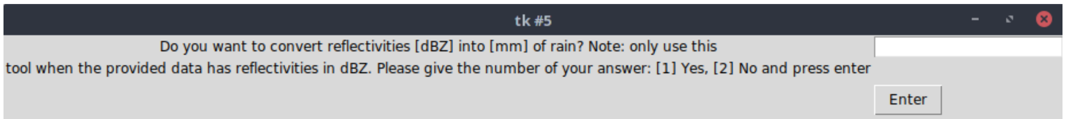

Figure 8: Final question of the tool. If the data is in dBZ and a conversion to mm is desired, answer 'yes', otherwise, answer 'no' and press enter.

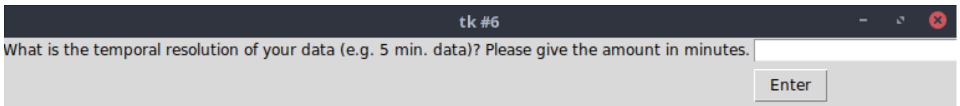

Figure 9: If the answer in Figure 9 is 'yes', this will be the follow-up question. Please provide the temporal resolution of the data set in minutes and press enter.

3.3 Get precipitation values for an area / a catchment

If the main functionality of this tool, *Get precipitation values for an area / a catchment*, is chosen, the tool will start and it will ask to choose a shapefile of the study area (see Figure 10). Locate the shapefile of the study area and press *Open*. Make sure that the following files are present in the folder, where the .shp file is located, to be able to properly open the shapefile:

- A *.dbf* file.
- A *.prj* file.
- A *.qpj* file.
- A *.shx* file.

Normally, these files, which carry the same name as the .shp file, are present for shapefiles, but it is important to have them in the same folder as the .shp file. Note that it does not matter for *Radar to Catchment* which Spatial Reference System the shapefile has.

When the shapefile is opened, the tool will proceed to ask which type of data set will be supplied (see Figure 5 in subsection 3.2). Type in the window next to the six possibilities which data set will be supplied and press *Enter*. Other data sets could also be used; this could especially be the case for the KNMI Data Centre data sets, but also for other sources. When other data sets are provided, fill in the number of the data set that resembles most to the provided data set and make sure the data has equal specifications as the chosen data set number, concerning the spatial resolution, the Spatial Reference System, the data format and pixel value.

Important to note is that *Radar to Catchment* will use the Spatial Reference System of the supplied dataset (see section 2 for the Spatial Reference Systems of the supported data sets) as main projection for the resulting files. Next, *Radar to Catchment* asks for the desired pixel resolution of the output files (see Figure 11). This is in km or in degrees depending

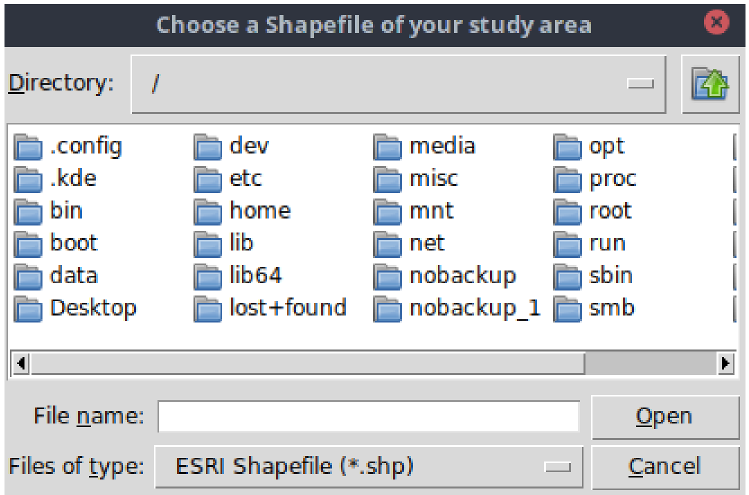

Figure 10: Locate the shapefile of the study area (e.g. a catchment) and click on Open.

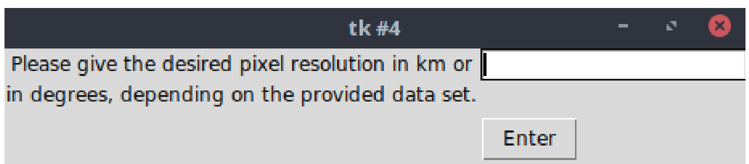

Figure 11: Fill in the desired pixel resolution of the output files and press Enter.

on the used unit, meters or degrees, in the Spatial Reference System of the chosen data set. Hence, the value that is given here, will be the pixel resolution of the output files after the clipping has taken place. If no particular spatial resolution is desired, it is recommended to use the spatial resolution of the data set. Fill in a pixel resolution and press *Enter*.

Radar to Catchment will convert the chosen shapefile into a raster with the indicated pixel size now. In this way, so by using a raster, the clipping of the data sets will always result in the same area and pixel locations for the resulting files. The tool will now ask to open the main folder with the data files and to press *OK*. Figure 6 in subsection 3.2 gives an example of this process, for a case in which the first data set, *RAD_NL25_RAC_MFBS_5min* was chosen. Search for the main directory of the data and open the main folder. Figure 6 in subsection 3.2 displays what this main folder should look like. The folder contains the subfolders '1' and '2', indicating January and February, with inside these folders the data files. It is also possible to have the separate files directly inside the main folder or in sub-directories within a sub-directory. Furthermore, the folder contains the subfolders *RasterIn* and *Results*. When all prerequisites are met, as they are in the example, press *OK*.

Both the shapefile and data set are known to the tool now. Before starting the 'clipping' process, the tool will ask one last question regarding a possible conversion from dBZ to millimeters (see Figure 8 in subsection 3.2). In the event the data is in dBZ and a conversion to millimeters is desired, answer with yes (please give the number of your answer). Otherwise, answer with no. If no is answered, no conversion will take place. If yes is answered, another window will pop up (see Figure 9 in subsection 3.2) that asks for the temporal resolution of the data in minutes. So, in the case the data has a temporal resolution of five minutes, fill in '5' and press *Enter*.

Rader to Catchment will run and after all data files are clipped, a window will pop-up telling that 'the clipping was successful'. Next, the tool gives the possibility to calculate statistics (minimum, maximum and mean) per time-step for the resulting raster files (see Figure 12). Indicate whether or not *Radar to Catchment* should calculate statistics for the resulting files and press *Enter*. If no is answered, nothing will happen and the tool will proceed. If yes is answered, the tool will ask to locate the folder with results. Open the folder *Results* in the main directory of the data set and press *Enter* (see Figure 13). *Radar to Catchment* will then calculate the above stated statistics for the given area on every time step. The result is a .csv file, called *stats.csv*, which is placed in the folder *Results*.

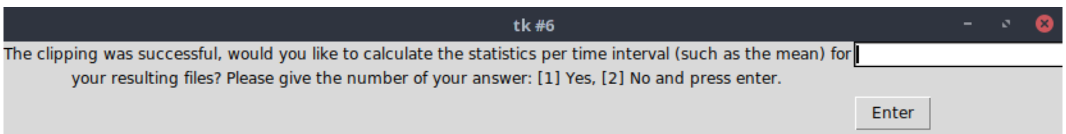

Figure 12: Indicate whether or not Radar to Catchment should calculate statistics for the resulting files. Fill in '1' for yes and '2' for no, and press Enter.

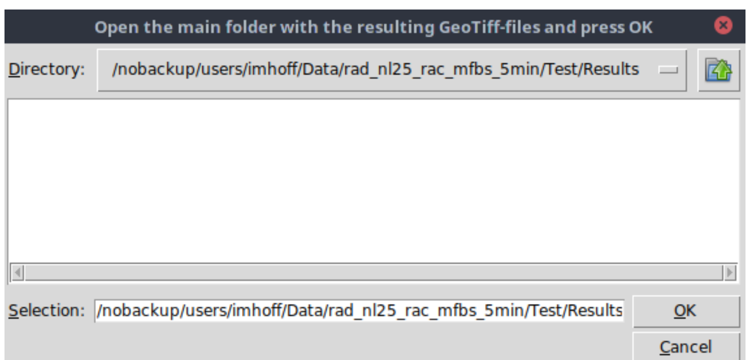

Figure 13: Open the folder with results, as displayed in this figure, and press enter.

The resulting data files have the same Spatial Reference System as the (chosen) input data set. It is, however, possible to change this Spatial Reference System and the tool will ask for that (see Figure 14). Answer with '1' for yes or '2' for no and press *Enter*. Note that this function is time consuming and it will delete the previous raster files with the old projection. If no is chosen, nothing will happen. If yes is chosen, the tool will ask to give the desired spatial projection of the resulting files (see Figure 15).

The possibilities are:

- WGS 84
- Amersfoort RD New
- ETRS 89 Europe
- ETRS 89/LCC Germany (N-E)
- OSR-OGR: 6971 UK National Grid
- EPSG:2062 Madrid 1870 Spain
- WGS 84 Arctic Polar Stereographic

These are, however, only a couple of the many possible Spatial Reference Systems. It is possible to add other Spatial Reference Systems by opening the script and adding another Spatial Reference System (preferably in PROJ4 code) in the list. Fill in the number of the desired Spatial Reference System and press *Enter*. Again, *Radar to Catchment* will ask for the folder with the results, which is the same folder as displayed in Figure 13. Open this folder and press *Enter*. The files will be re-projected and placed in the folder *Results* with *_Reprojected* at the end of the name. Be aware of the fact that the results with the old projection will be deleted in this process.

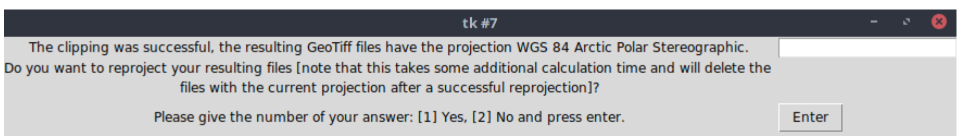

Figure 14: Choose whether or not the resulting raster files should be re-projected and press enter.

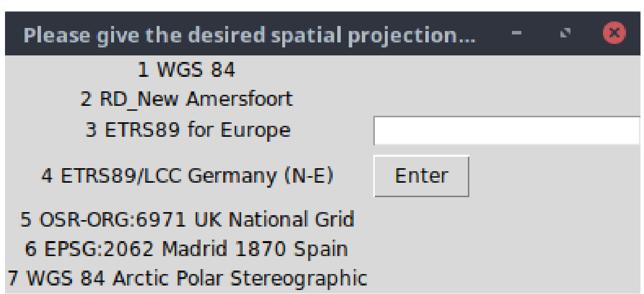

Figure 15: Pop-up window with possible Spatial Reference Systems. Choose one projection, fill in the number and press Enter.

The resulting files are GeoTiff files, but *Radar to Catchment* gives the user the possibility to change this into ASCII files (see Figure 16). Fill in the number of the choice and in the event a change to ASCII files is chosen, *Radar to Catchment* will ask for the folder with the results. This folder is still the same as displayed in Figure 13. Open this folder and press *Enter*. Now, the ASCII files will be produced and the GeoTiff files will be removed.

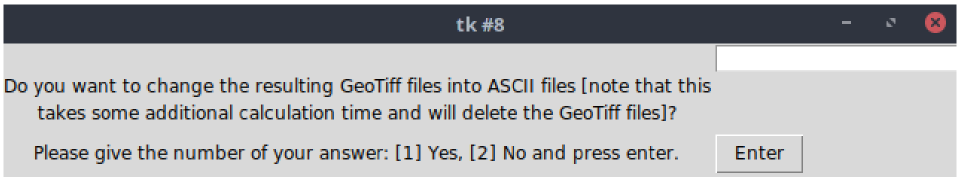

Figure 16: Indicate whether or not Radar to Catchment should convert the GeoTiff files into ASCII files. Fill in '1' or '2' and press Enter.

As a last question, *Radar to Catchment* gives the possibility to plot one or many of the resulting files on a map for visual inspection (see Figure 17). If the user chooses for a visualisation, a window will open that asks for a resulting file. Go to the *Results* folder and select one of the resulting files and click on *Open*. *Radar to Catchment* will plot and save the raster (in a PNG format in the *Results* folder) and, subsequently, the tool will ask the same question (Figure 17) again. This gives the possibility to make more visualisations or to end the script. Eventually, after answering with 'no', the script will end.

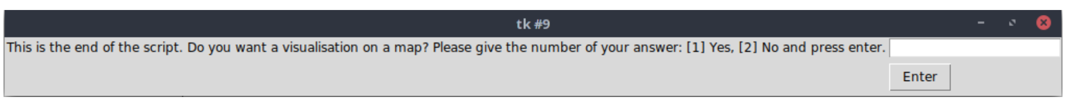

Figure 17: Indicate whether or not a visualisation on a map is desired. Fill in '1' or '2' and press Enter.

4 Getting Started on Windows

The *Radar to Catchment* tool is somewhat slower and also somewhat harder to get started in Windows than in a Linux environment, but it will nevertheless work properly on a Windows device. This section is a brief manual for the opening of and the use of the tool within a Windows environment. It is recommended, for a more pleasant use in Windows, to install Python(x,y) in order to have a user interface for running the script. This section will also be based on running the script with Python(x,y).

4.1 Starting the tool

Before running the Python script, make sure the following requirements are met:

- Python, version 2.7 or higher, installed on the used Windows device.
- A main folder in a directory with the data of any of the supported data sets as described in section 2. This main folder should have:
  - The data, as separate files in the main folder or in sub-directories (e.g. in folders ordered per year, month or day).
  - A map *RasterIn* in the main folder and make sure this folder is empty.
  - A map *Results* in the main folder. Make sure this map is empty before running the script. After running the script, the results will be placed inside this folder.
- A shapefile of a catchment or certain area. It does not matter which Spatial Reference System this shapefile has, as long as the shapefile is a polygon. Note that having a shapefile is not necessary when only a list of values for one pixel has to be calculated by the tool.
- All required Python packages should be installed. The installation of packages is not fairly easy in Windows. Go to the windows commander (Start > type cmd > Commander) and locate the directory of the Python scripts. Quite often, this is located in the C-drive of the device. Locate the directory by typing: *cd C:\Python27\Scripts*, for which '27' or any other number indicates the version of Python that is installed on the device. The next step is to install the package. Type: *pip install −−upgrade pip*, to get the latest installation package and then type: *pip install 'package'* with instead of 'package' the name of the package (see also Figure 18). The necessary packages can be found in the script; just open the script in Python(x,y) and have a look at the starting list, clearly indicated by many lines starting with *Import [package]*, at the beginning of the script. Easier is to run the script in the Python Shell of Python(x,y) and to install the scripts that are indicated as missing by an error (see also below for an example on how to run the script).

When these requirements are met, open Python(x,y) and open IDLE in *Applications*. The Python Shell opens and now it is possible to open the Python script of *Radar to Catchment*. Go to File > Open > and open the script. Figure 19 displays an example of how to open *Radar to Catchment* in a Python Shell.

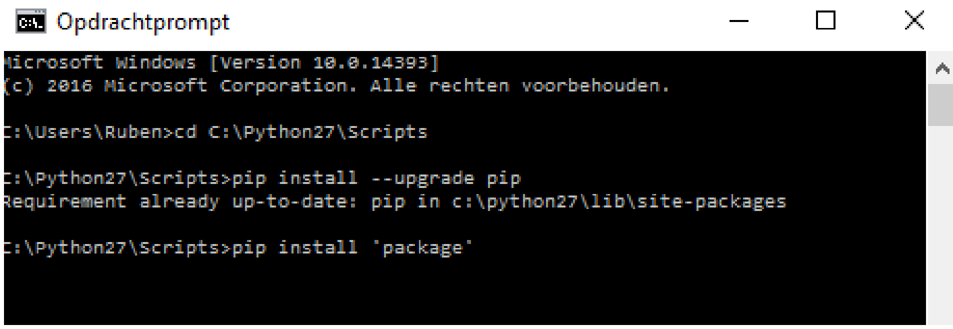

Figure 18: The installation of packages in Windows is possible with the commander. This figure displays a way to install packages in the commander.

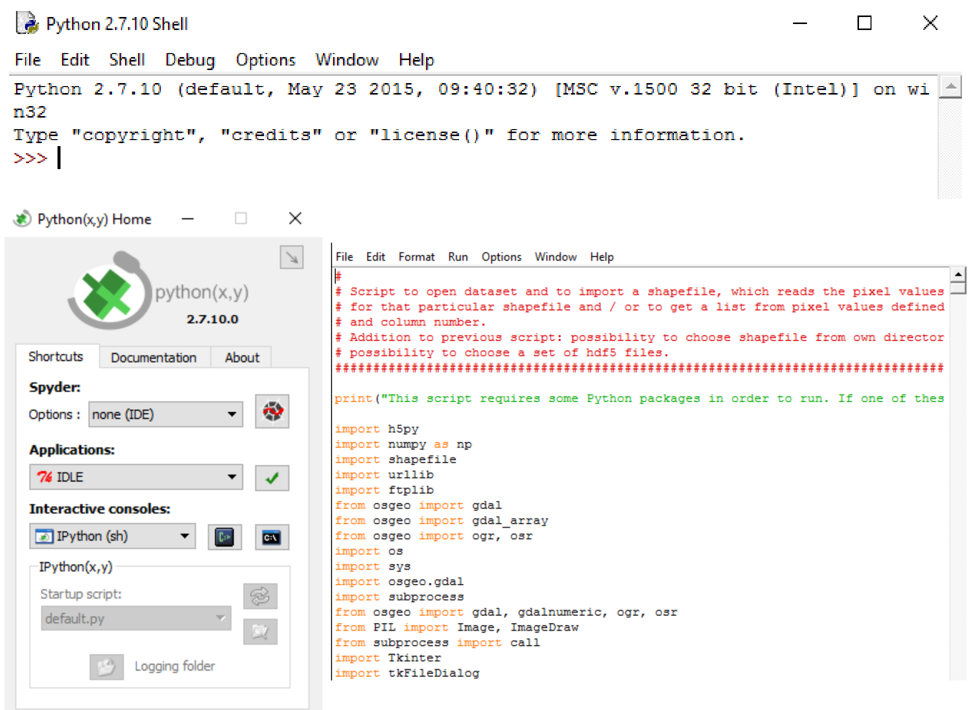

Figure 19: The opening of a script in the Python Shell of Python(x,y) using IDLE. Top of figure: Python Shell of Python (x,y). Lower left: Main screen of Python(x,y) with under 'Applications' the possibility IDLE. Lower right: the script as shown in IDLE.

Run *Radar to Catchment* by pressing *F5* in the script in *IDLE*. The tool should open now and it will ask whether the tool should *Get precipitation values for a pixel* or *Get precipitation values for an area / a catchment* (note that this could take approximately a minute the first time *Radar to Catchment* is used), which is also displayed in Figure 20. Make a choice between the two options and click on the desired function. The tool will automatically proceed now.

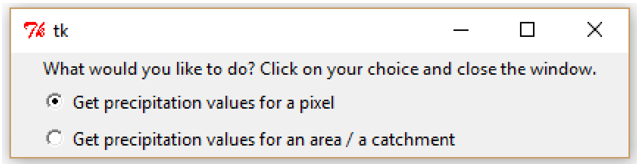

Figure 20: Opening question asked by the tool when the script is run.

4.2 Get precipitation values for a pixel

In the event that *Get precipitation values for a pixel* is chosen, the tool will automatically ask which data set will be supplied (see Figure 21). Type in the window next to the six possibilities which data set will be supplied and press *Enter*. Other data sets could also be used; this could especially be the case for the KNMI Data Centre data sets, but also for other sources. When other data sets are provided, fill in the number of the data set that resembles most to the provided data set and make sure the data has equal specifications as the chosen data set number, concerning the spatial resolution, the Spatial Reference System, the data format and pixel value.

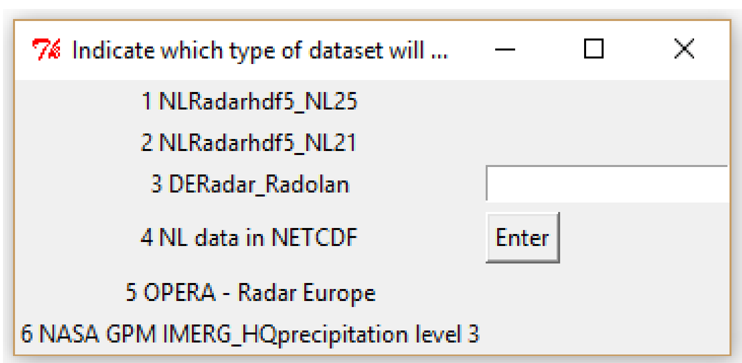

Figure 21: Indicate which data set will be supplied, or indicate to which data set the data resembles most, and press enter.

When the type of data set is given, the tool will ask to open the main folder with the data files and to press *OK*. Figure 22 gives an example of this process, for a case in which the first data set, *RAD_NL25_RAC_MFBS_5min*, was chosen. Search for the main directory of the data and open the main folder. Figure 22 displays what this main folder should look like.

The folder contains the subfolders '1' and '2', indicating January and February, with inside these folders the data files. It is also possible to have the separate files directly inside the main folder or in sub-directories within a sub-directory. *Radar to Catchment* can handle all of these possibilities. Furthermore, the folder contains the subfolders *RasterIn* and *Results*. When all prerequisites are met, as they are in the example, press *OK*.

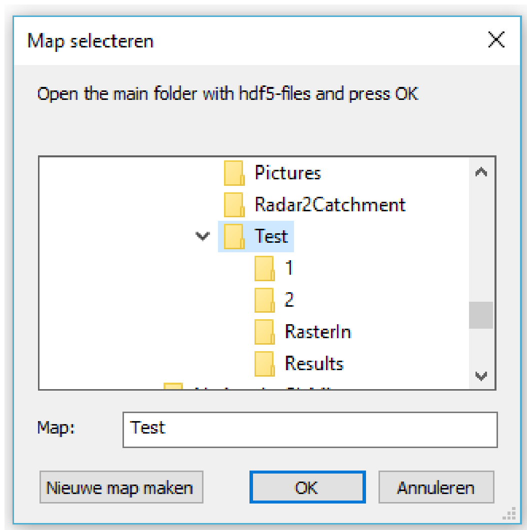

Figure 22: An example of a main folder called 'Test' which is opened. Give the path to this folder and when this folder meets the requirements, like in this example, press OK.

The next step will be to provide a column number and a row number of the desired cell (see Figure 23). These column and row numbers are equal to the column and row numbers in the provided data set. Hence, a 500 x 500 dataset can have no values larger than 500 for both the column and row number. After filling in both the column and row number, press *Enter*. The final step, before the tool will start its calculations, is to choose whether or not the data values have to be converted from dBZ to millimeters (see Figure 24). Answer with yes or no and press *Enter*. If no is answered, no conversion will take place. If yes is answered, another window will pop up (see Figure 25) that asks for the temporal resolution of the data in minutes. So, in the case the data has a temporal resolution of five minutes, fill in '5' and press *Enter*. Note that the user can change the parameters of the Z-R relationship in the script of the tool.

It is time for the tool to do the work now: the tool will obtain the pixel values for every data file. The resulting file is a time-series with the pixel values, called *PixelPrec.csv*, and can be found in the Results of the main folder. Inside this file, two columns are present: the first column indicates the name of the file and the second column indicates the pixel value for the given column and row number. The header line states that this value is in millimeters, but this could be any unit that was present in the data.

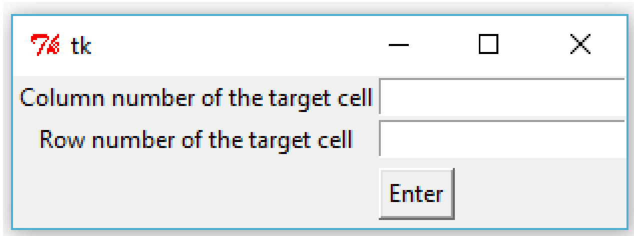

Figure 23: Give the column number and row number of the desired cell and press Enter.

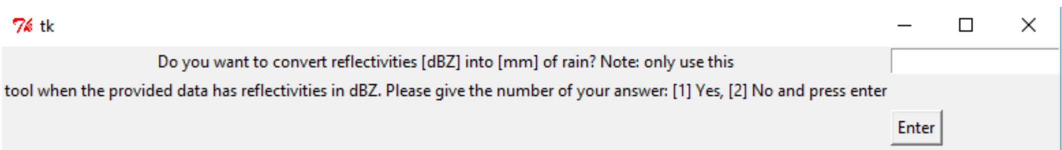

Figure 24: Final question of the tool. If the data is in dBZ and a conversion to mm is desired, answer 'yes'. Otherwise, answer 'no' and press enter.

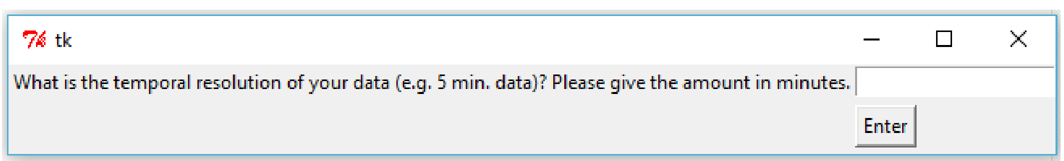

Figure 25: If the answer in Figure 9 is 'yes', this will be the follow-up question. Please provide the temporal resolution of the data set in minutes and press enter.

4.3 Get precipitation values for an area / a catchment

If the main functionality of this tool, *Get precipitation values for an area / a catchment*, is chosen, the tool will start and it will ask to choose a shapefile of the study area (see Figure 26). Locate the shapefile of the study area and press *Open*. Make sure that the following files are present in the folder, where the .shp file is located, to be able to properly open the shapefile:

- A *.dbf* file.
- A *.prj* file.
- A *.qpj* file.
- A *.shx* file.

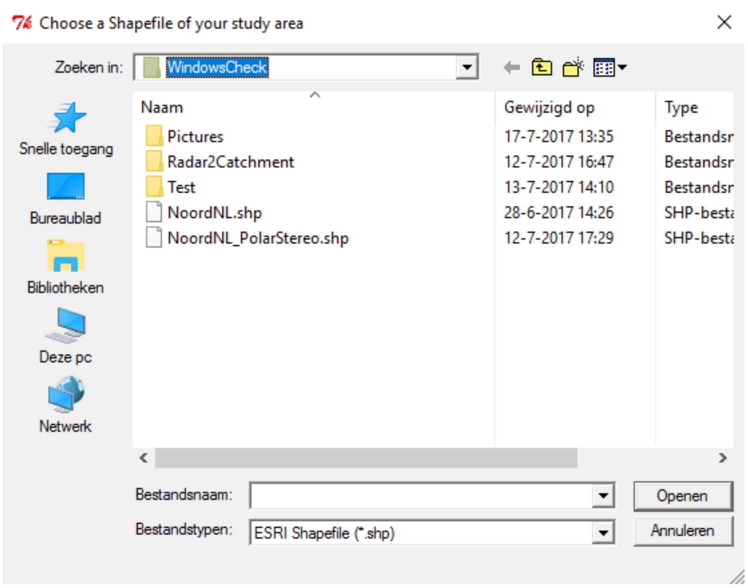

Figure 26: Locate the shapefile of the study area (e.g. a catchment) and click on Open.

Normally, these files, which carry the same name as the .shp file, are present for shapefiles, but it is important to have them in the same folder as the .shp file. Note that it does not matter for *Radar to Catchment* which Spatial Reference System the shapefile has.

When the shapefile is opened, the tool will proceed to ask which type of data set will be supplied (see Figure 21 in subsection 4.2). Type in the window next to the six possibilities which data set will be supplied and press *Enter*. Other data sets could also be used; this could especially be the case for the KNMI Data Centre data sets, but also for other sources. When other data sets are provided, fill in the number of the data set that resembles most to the provided data set and make sure the data has equal specifications as the chosen data set number, concerning the spatial resolution, the Spatial Reference System, the data format and pixel value.

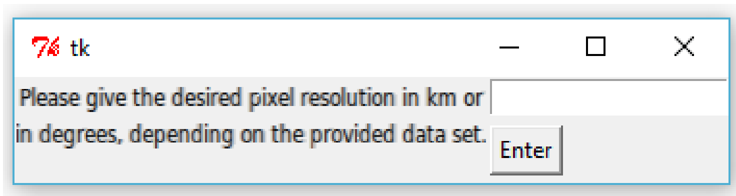

Figure 27: Fill in the desired pixel resolution of the output files and press Enter.

Important to note is that *Radar to Catchment* will use the Spatial Reference System of the supplied dataset (see section 2 for the Spatial Reference Systems of the supported data sets) as main projection for the resulting files. Next, *Radar to Catchment* asks for the desired pixel resolution of the output files (see Figure 27). This is in km or in degrees depending on the used unit, meters or degrees, in the Spatial Reference System of the chosen data set. Hence, the value that is given here, will be the pixel resolution of the output files after the clipping has taken place. If no particular spatial resolution is desired, it is recommended to use the spatial resolution of the data set. Fill in a pixel resolution and press *Enter*.

Radar to Catchment will convert the chosen shapefile into a raster with the indicated pixel size now. In this way, so by using a raster, the clipping of the data sets will always result in the same area and pixel locations for the resulting files. The tool will now ask to open the main folder with the data files and to press *OK*. Figure 22 in subsection 4.2 gives an example of this process, for a case in which the first data set, *RAD_NL25_RAC_MFBS_5min* was chosen. Search for the main directory of the data and open the main folder. Figure 22 in subsection 4.2 displays what this main folder should look like. The folder contains the subfolders '1' and '2', indicating January and February, with inside these folders the data files. It is also possible to have the separate files directly inside the main folder or in sub-directories within a sub-directory. Furthermore, the folder contains the subfolders *RasterIn* and *Results*. When all prerequisites are met, as they are in the example, press *OK*.

Both the shapefile and data set are known to the tool now. Before starting the 'clipping' process, the tool will ask one last question regarding a possible conversion from dBZ to millimeters (see Figure 24 in subsection 4.2). In the event the data is in dBZ and a conversion to millimeters is desired, answer with yes (please give the number of your answer). Otherwise, answer with no. If no is answered, no conversion will take place. If yes is answered, another window will pop up (see Figure 25 in subsection 4.2) that asks for the temporal resolution of the data in minutes. So, in the case the data has a temporal resolution of five minutes, fill in '5' and press *Enter*.

Rader to Catchment will run and after all data files are clipped, a window will pop-up telling that 'the clipping was successful'. Next, the tool gives the possibility to calculate statistics (minimum, maximum and mean) per time-step for the resulting raster files (see Figure 28).

Indicate whether or not *Radar to Catchment* should calculate statistics for the resulting files and press *Enter*. If no is answered, nothing will happen and the tool will proceed. If yes is answered, the tool will ask to locate the folder with results. Open the folder *Results* in the main directory of the data set and press *Enter* (see Figure 29). *Radar to Catchment* will then calculate the above stated statistics for the given area on every time step. The result is a .csv file, called *stats.csv*, which is placed in the folder *Results*.

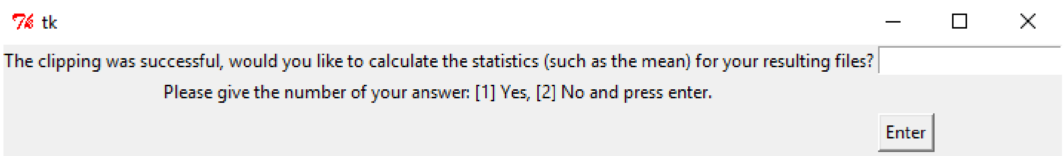

Figure 28: Indicate whether or not Radar to Catchment should calculate statistics for the resulting files. Fill in '1' for yes and '2' for no, and press Enter.

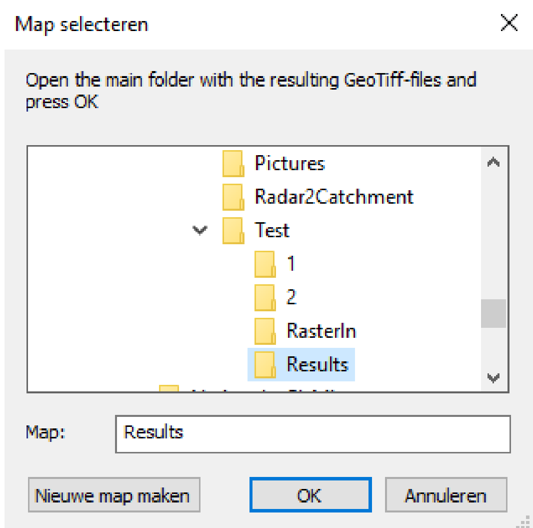

Figure 29: Open the folder with results, as displayed in this figure, and press enter.

The resulting data files have the same Spatial Reference System as the (chosen) input data set. It is, however, possible to change this Spatial Reference System and the tool will ask for that (see Figure 30). Answer with '1' for yes or '2' for no and press *Enter*. Note that this function is time consuming and it will delete the previous raster files with the old projection. If no is chosen, nothing will happen. If yes is chosen, the tool will ask to give the desired spatial projection of the resulting files (see Figure 31).

The possibilities are:

- WGS 84
- Amersfoort RD New
- ETRS 89 Europe
- ETRS 89/LCC Germany (N-E)
- OSR-OGR: 6971 UK National Grid
- EPSG:2062 Madrid 1870 Spain
- WGS 84 Arctic Polar Stereographic

These are, however, only a couple of the many possible Spatial Reference Systems. It is possible to add other Spatial Reference Systems by opening the script and adding another Spatial Reference System (preferably in PROJ4 code) in the list. Fill in the number of the desired Spatial Reference System and press *Enter*. Again, *Radar to Catchment* will ask for the folder with the results, which is the same folder as displayed in Figure 29. Open this folder and press *Enter*. The files will be re-projected and placed in the folder *Results* with *_Reprojected* at the end of the name. Be aware of the fact that the results with the old projection will be deleted in this process.

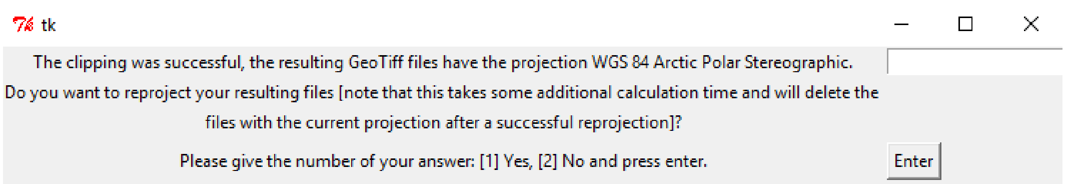

Figure 30: Choose whether or not the resulting raster files should be re-projected and press enter.

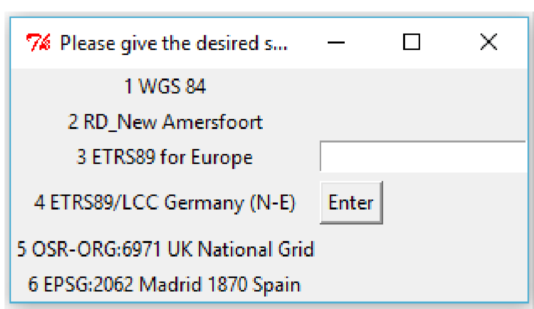

Figure 31: Pop-up window with possible Spatial Reference Systems. Choose one projection, fill in the number and press Enter.

The resulting files are GeoTiff files, but *Radar to Catchment* gives the user the possibility to change this into ASCII files (see Figure 32). Fill in the number of the choice and in the event a change to ASCII files is chosen, *Radar to Catchment* will ask for the folder with the results. This folder is still the same as displayed in Figure 29. Open this folder and press *Enter*. Now, the ASCII files will be produced and the GeoTiff files will be removed.

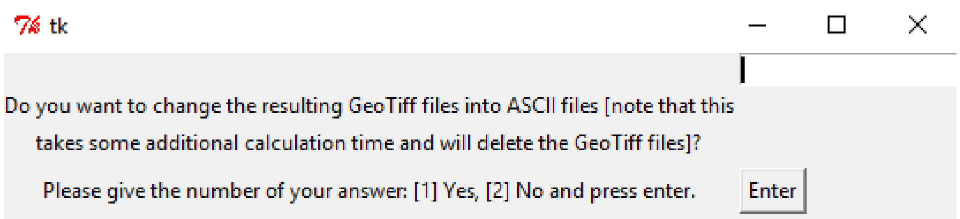

Figure 32: Indicate whether or not Radar to Catchment should convert the GeoTiff files into ASCII files. Fill in '1' or '2' and press Enter.

As a last question, *Radar to Catchment* gives the possibility to plot one or many of the resulting files on a map for visual inspection (see Figure 33). If the user chooses for a visualisation, a window will open that asks for a resulting file. Go to the *Results* folder and select one of the resulting files and click on *Open*. *Radar to Catchment* will plot and save the raster (in a PNG format in the *Results* folder) and, subsequently, the tool will ask the same question (Figure 33) again. This gives the possibility to make more visualisations or to end the script. Eventually, after answering with 'no', the script will end.

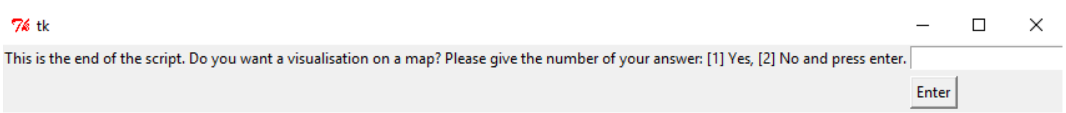

Figure 33: Indicate whether or not a visualisation on a map is desired. Fill in '1' or '2' and press enter.

5 Technical Details - How it works

In this section, the technical details of *Radar to Catchment* are described. *Radar to Catchment* consists of two parts: *Get precipitation values for a pixel* and *Get precipitation values for an area / a catchment.* The first one, *Get precipitation values for a pixel*, does not need an elaborate description of its technical details, since this option mainly consists of an extraction of pixel values for a given row and column number. These pixel values are then placed together in a .csv-file, in which they, together, represent a time series of precipitation values for a given pixel.

Table 1, below, gives insight into estimated run-times for the option *Get precipitation values for a pixel.* This option runs reasonably fast and a distinction is made between smaller files, e.g. *RAD_NL25_RAC_MFBS_5min* with data only for the Netherlands, and larger data files, e.g. *Radolan Germany* or the *NASA GPM IMERG HG Precipitation* with data for larger areas such as parts of Europe or worldwide data. Due to the difference in data sizes, the smaller files will run faster, as is also visible in Table 1. The differences are, however, not enormous, since the larger data files often run on a coarser temporal resolution. Note also the substantial difference in run-time between Linux and Windows.

Table 1: Estimated run-times of both a small and a larger data set area (e.g. small for the Netherlands and large for Europe) for the option 'Get precipitation values for a pixel'. Three possibilities are displayed: a data set with one month of data, a data set with one year of data and a data set with ten years of data.

Name of Data set	Run-time one month of data [h]	Run-time one year of data [h]	Run-time ten years of data [h]
Small areas - Linux	00:00:30	00:06:00	01:00:00
Small areas - Windows	00:03:30	00:42:00	07:00:00
Larger areas - Linux	00:03:30	00:42:00	07:00:00
Larger areas - Windows	00:05:30	01:06:00	11:00:00

The remaining part of this section continues with some technical details of the second option of *Radar to Catchment*: *Get precipitation values for an area / a catchment.* The first step of this option, is to provide *Radar to Catchment* with a shapefile. The Spatial Reference System of this shapefile does not matter, however, the shapefile is always re-projected to the reference system of the provided data set. To know this Spatial Reference System, the tool will first proceed with asking for the type of dataset that will be supplied. The supported data files are described in section 2, but it is important to note that the tool was made to give the output values in millimeters. This means, that if a data set normally has data with a temporal resolution of half an hour and pixel values in mm/h (this is e.g. the case for the *NASA GPM IMERG HQ Precipitation* data), the tool is designed to convert this into millimeters. Be aware of this potential effect, when supplying other data sets than the ones indicated on the list of supported data sets.

After providing the tool with a shapefile and the data set, the shapefile is rasterized to a raster with the spatial resolution in km^2 or degrees (depending on the unit of the Spatial Reference System of the data set) that was given by the user. This raster is never completely identical to the polygon of the shapefile, but the advantage is that every possible output file has the same area and pixel size as the rasterized shapefile. Since the tool is initially meant for hydrological purposes, it is assumed that a raster as output is sufficient for a distributed model. Also when the user wants to obtain catchment or area averaged values, the model calculates these statistics in millimeters based on the raster. Hence, if a part of a raster cell falls outside the original polygon of the area, also this part of the raster is still taken into account. For large areas, this is insignificant, but for small areas it is important to be aware of this effect.

Moreover, *Radar to Catchment* will continue with the provided data set and the tool will place it on a raster with a Spatial Reference System that is identical to the one of the original data set. Hence, up to this point cell sizes and positions are the same as they are in the original data set. Then, *Radar to Catchment* will re-project this raster to the raster of the area / catchment (the rasterized shapefile which has the same reference system now) with the Python function *gdal.ReprojectImage.* If also the spatial resolution of the original data set was the same as the chosen spatial resolution, nothing will change. Hence, the grid is still exactly the same as that of the original data. Otherwise, if the spatial resolution of the original data set is not the same as the chosen spatial resolution, upscaling or downscaling has to take place.

For upscaling, an average will be used of the cells that will become part of the new and bigger cell. For downscaling, cubic spline will be used, which means that a new cell gets a weighted value (weighted with distance) from the sixteen cells around it. This value could potentially be higher or lower than the maximum or minimum in the original data set, since it is possible that a maximum or minimum is expected to be found at that particular new cell. This is a useful tool for downscaling, but it is possible that a cell falls completely within a bigger cell. In such a case, that cell ideally gets the value of the bigger cell. Or, if a cell is situated on the border of two bigger cells, ideally that cell will get a weighted value depending on only those two cells. Hence, this is a recommendation for future versions of the tool. After these steps, the data set will be clipped and the desired subset of the data is there.

Finally, *Radar to Catchment* provides the possibility to re-project the resulting files, using the Python function *gdalwarp.* This function automatically corrects for difference in the vertical cell size between two grids [4]. The possible Spatial Reference Systems are described in sections 3 and 4 (and other reference systems could also be implemented in the script).

Also for this part, estimated run-times are available, see Table 2. Again, a distinction is made between smaller and larger data files. Between Linux and Windows, a substantial difference in run-time is still present. Although an expected effect, note the increase in run-time in 2 compared to Table 1.

Table 2: Estimated run-times of both a small and a larger data set for 'Get precipitation values for an area / a catchment'. Three possibilities are displayed: a data set with one month of data, a data set with one year of data and a data set with ten years of data.

Name of Data set	Run-time one month of data [h]	Run-time one year of data [h]	Run-time ten years of data [h]
Small areas - Linux	00:03:10	00:38:00	06:20:00
Small areas - Windows	00:10:00	02:00:00	20:00:00
Larger areas - Linux	00:05:20	01:04:00	10:40:00
Larger areas - Windows	00:10:50	02:10:00	21:40:00

6 Suggested improvements for next versions

With the current amount of data sets, it was not possible to implement and support all data sets. It goes without saying that with increasing the amount of supported data sets, the tool will be applicable to more situations, types of research or comparison studies. This increase in amount of supported data sets, should be an important aim of every new version. The same holds for the amount of offered Spatial Reference Systems for re-projection.

Moreover, there is a small difference between *Radar to Catchment* in Linux and in Windows. The user interface gives pop-up windows that give the user the possibility to make choices and to tell the tool what to do. Linux is able to close these windows as soon as the script has finished, but Windows is not. In Windows it seems like the tool gets stuck at the end, while it actually does not, and the user has to close the Python Shell to close all the pop-up windows. Preferably, this problem is solved in new versions.

Ideally, the function *Get precipitation values for a pixel* does not ask for a column and row number, but for coordinates. This would mean that a user inserts coordinates in a chosen Spatial Reference System, and from those coordinates *Radar to Catchment* extracts the pixel values. Therefore, it is recommended to make this option available is new versions of *Radar to Catchment*.

Also, in the development of the tool it was assumed that, when no re-projection and change in spatial resolution has taken place, the output data is identical to the original data set. Many Spatial Reference Systems have changing cell sizes and/or forms with increasing latitude. During the development of *Radar to Catchment*, an elaborate study to compare the original data set and the output data set on grid cell sizes and values, has not taken place. Hence, to make sure whether or not the output is exactly identical to the original data set, this should be studied in the future.

Finally, *Radar to Catchment* offers the possibility to change the resulting GeoTiff files into ASCII files. This is useful for a lot of occasions, but choosing for this conversion might have a long run time when used for large data sets. Hence, it is desirable that this functionality starts before the 'clipping' process in order to potentially give the results in ASCII files, instead of resulting with GeoTiff files that might have to be converted to ASCII files.

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References

[1] Clark, P.M., Nijssen, B., Lundquist, J.D., Kavetski, D., Rupp, D.E., Woods, R.A., Freer, J.E., Gutmann, E.D., Wood, A.W., Brekke, L.D., Arnold, J.R., Gochis, D.J. and Rasmussen, R.M. *A unified approach for process-based hydrologic modeling: 1. Modeling concept.* Water Resources Research, Volume 51, Issue 4, pp. 2498-2514, 2015.

[2] DWD (Deutsche Wetterdienst - German Weather Service). *Hoch aufgelöste Niederschlagsanalyse und –vorhersage auf der Basis quantitativer Radar- und Ombrometerdaten für grenzüberschreitende Fluss-Einzugsgebiete von Deutschland im Echtzeitbetrieb.* DWD-Hydrometeorologie, Frankfurter Straße 135, 63067 Offenbach, 2016.

[3] EUMETNET. *OPERA*. Obtained at July 14, 2017, source: *http://eumetnet.eu/activities/observations-programme/current-activities/opera/*, 2017.

[4] GDAL. *gdalwarp: image reprojection and warping utility.* Obtained at July 18, 2017, source: *http://www.gdal.org/gdalwarp.html*, 2017.

[5] Huffman, G.J., Bolvin, D.T. and Nelkin E.J. *Integrated Multi-satellitE Retrievals for GPM (IMERG) Technical Documentation.* NASA documentation, obtained at July 14, 2017, source: *https://pmm.nasa.gov/sites/default/files/document_files/IMERG_technical_doc_3_22_17.pdf*, 2017.

[6] Kirchner, J.W. *Getting the right answers for the right reasons: Linking measurements, analyses, and models to advance the science of hydrology.* Water Resources Research, Volume 42, Issue 3, pp. 1-5, 2006.

[7] KNMI (Koninklijk Nederlands Meteorologisch Instituut - Royal Netherlands Meteorological Institute). *Long term average 1981-2010 - Average monthly precipitation.* Obtained at July 14, 2017, source: *https://data.knmi.nl/datasets/Rd3/4?q=neerslag&dtend=2017-07-13T23:59Z*, 2017.

[8] Melsen, L.A., Teuling, A.J., Torfs, P.J.J.F., Uijlenhoet, R., Mizukami, N. and Clark, M.P. *HESS Opinions: The need for process-based evaluation of large-domain hyper-resolution models.* Hydrology and Earth System Sciences, Volume 20, pp. 1069-1079, 2016.

[9] Overeem, A., Holleman, I. and Buishand, A. *Derivation of a 10-Year Radar-Based Climatology of Rainfall.* Journal of Applied Meteorology and Climatology, Volume 48, pp. 1448-1463, 2008.

[10] Overeem, A. *Beschrijving_5min_1uur_dagsom.* Complementary description of dataset in KNMI ftp-server (Dutch only), 2014.

[11] USGS. *HydroSHEDS: Hydrological data and maps base on Shuttle Elevation Derivativese at multiple Scales.* Obtained at July 14, 2017, source: *https://hydrosheds.cr.usgs.gov/*, 2017.