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ViewShed Analysis Documentation

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1. Overview:

The system is intended to calculate and present a line of sight (LOS) analysis from a set of pre-defined points (Antennas) to any point in a chosen geographical region (Transmitter). It provides several analysis tools such as the display of cumulative and intersection of LOS area from several antennas, as will be detailed below. The results Depend on the height of the antenna, the height of the transmitter and a Digital Elevation Map (DEM) file that represent the surface height in the region. This tool can either consider or neglect the effect of earth curvature. The tool was designed to support both terrestrial antenna arrays and aquatic antenna array. The package includes several actions:

a) Calculation of a Viewshed layer, a Boolean raster layer for a specific antenna and a transmitter height, it set a TRUE (visible) or FALSE (invisible) value to all points in a region (an area predefined by the user). This method includes a parallel calculation to increase the efficiency of the process.
b) Visualization of the cumulative viewshed. Using a set of precalculated raster layers and a choice of active antennae (this is the plural form for "antenna", it is a word of Latin origin), the function sums the number of observant antennae at any point and present this value on an interactive map.

c) Visualization of intersecting line of sight. Using a set of precalculated raster layers, a choice of observant antennae and blind antennae, the function identifies the points that obey these visibility conditions and present these on an interactive map.
d) The function can allow the user to choose an antenna and point on the map and present the surface height under a line connecting these two points. It also presents the detailed DEM at the vicinity of the line. This analysis allows the investigation of the obstacles between any two points to explain the LOS results

2. Installation

To run the program, one must have an installed R program (updated to 4.0.0 or newer) and RStudio IDE (interactive development environment), instructions for these steps can be found in https://rstudio-education.github.io/hopr/starting.html.

Using the application can be divided into two steps; **a)** Calculating viewshed layers, that requires a list of antennas location and height above ground, and some R programing capabilities and **b)** presenting**,** viewing, and analyzing the precalculated LOS layers, this step does not require any R programing capabilities. Our recommended approach is that step **a** can be done once for a specific array of antennas by a system-manager and shared among a group of users that can apply step **b**, without any deep knowledge of the system or **R**.

It is recommended to save the entire application in a single directory (commonly named “Viewshed”), containing a R project “Viewshed” (it is recommended to open the RStudio application using this R project file, this will define the active directory to search locally). The folder must contain several subdirectories (to allow the correct path for searching files) as follows (within the distribution, each directory contains some example data from the Harod valley, northern Israel):

- DEM_Files – a file containing the DEM files needed to compute the LOS analysis (needed only for the calculation step).
- ANT_Table_Files - a directory containing a csv file with antenna coordinates and height above ground analysis (needed only for the calculation step).
- LOSData – a directory containing the layers produced in the calculation step (as many as were created by the system operator). In order to present the data, the application requires 5 files for each choice of transmitter height, coverage area, antenna set and DEM resolution. The directory also contains the icons for antenna (See.jpg)
- Functions – a directory containing the set of functions required to calculate and present the analysis.
- Documentation – a directory containing this file 😊 (this subdirectory is not mandatory)

3. Calculation of viewshed layers

a. Preparing the system and required data.

This is a preparation step; the end-user can skip it to chapter 4 – Presentation. To initiate the calculation, one should open the script file “computeViewshed.R” (located in “functions” subdirectoryThe following paragraph will detail the fundamental functions and procedures a user should invoke (code is accentuated `distinguish font`) to complete the calculation, these commands are already part of the script and the user needs only to change specific input parameters that will be highlighted in the following lines. The script file contains a reasonable sequence of commands that will allow the calculation of the viewshed layers, not all of them are mandatory:

- `source('functions/Viewshed.R')`
  - All functions are in the "Viewshed.R" file and are attached by this command.
- `setEnv()`
  - This function source external libraries and define several constants, several warnings usually appear in this process.
  - If an error appears: Error in library("XXX") : there is no package called 'XXX', the user is required to install the following package: `install.packages("XXX")` (the code is designated to install all required packages automatically but still these errors sometimes appear in the first operation of the code).
  - It is required to update your R version to 4.0.0 or later!
- `box <- data.frame(lat=c(32.38,32.68),lon=c(35.27, 35.68))`
  - The coverage map is calculated only within a predefined region, here the geographical coordinates of two diagonal corners of the region should be set.
  - Note that larger area requires larger computational effort and therefore longer calculation times. (see section **b, Invoking the calculation** for calculation time approximations)
  - The coordinate system should be WGS84 (EPSG:4326, World Geodetic System 1984)
- `DEM_name<-"DEM_Files/DEM_Harod.tif"`
  - If the user has the elevation data of the region (digital elevation map- DEM) on a geographic grid, he can specify it here, other wise the data can be freely download from the web by specifying `type="web"` in the `getDEM` command (this usually provide a DEM with 3 arc resolution (~ 90 m) from the SRTM mission).
  - The DEM should be given in TIFF format, see *Obtaining DEM data* section for more details.
  - The DEM coordinate system must be WGS84 (EPSG:4326, World Geodetic System 1984)
- `ANTfilename <- "` ANT_Table_Files/`HarodANTSLoc.csv"`
  - Path to the antenna location csv file. The file should contain antenna locations and must include the following variables:
    - "ANTName" – name in English letters, numbers and spaces are allowed.
    - "ID" – an integer number specifying the antenna.
    - "LAT", "LON" – geographical coordinates (geographical projection, wgs84 datum)
    - "Towerheight" – antenna height above ground in meters

- The file can also include “AntRadius” variable – the reception range of each antenna (in meters)

- `DEM <- getDEM(type="file",box,filename=DEM_name)`
  - Retrieve and cut DEM from the tiff file, in case the user wants to reduce the resolution, an argument `resoluton = XXX` where XXX is the required resolution in meters can be added to the `getDEM` function.
  - In a case where the user doesn't have a high-resolution DEM file, the DEM can be obtained from the web: `DEM <- getDEM(type="web",box)`, this usually provide a DEM with 3 arc resolution (~ 90 m)
  - The accuracy and resolution of the DEM depends on its source. The same is true for question whether the DEM include buildings and trees (the most widespread source, STRM was create by radar signal to the international space-station, thus it includes buildings (although not accurately because of its resolution) and only dense vegetation.
  - Note that the provided resolution has a dramatic effect on the calculation time and file size. Therefore, before dispatching the calculation with maximal resolution it is strongly recommended to begin with a low-resolution run.
- `ANTS.df <- setANTS(ANTfilename,DEM)`
  - Reads and prepares the antenna details file. The file should contain all antenna locations and must include the following variables:
    - "ANTName" – name in English letters, numbers and spaces are allowed.
    - "ID" – an integer number specifying the antenna.
    - "LAT", "LON" – geographical coordinates (geographical projection, wgs84 datum)
    - "Towerheight" – antenna height above ground in meter
  - The file can also include “AntRadius” variable – the reception range of each antenna (in meters)
  - The function returns a SpatialPointsDataFrame object (see sp package for details) in the geographic, wgs projection, with the added variable “GroundASL” which is the ground altitude at the antenna position (in meters)
- `viewSetup(ANTS.df,DEM)`
  - presenting the system setup: antennas, region map, and DEM. Click an antenna to see its details.

b. Invoking the calculation

After setting the required variables the system is ready for the calculation of the line-of-sight layers (LOSlayer) and saving it. As mentioned before, the provided resolution and region-size has a dramatic effect on the calculation time and file size. Therefore, before dispatching the calculation with maximal resolution it is strongly recommended to begin with a low-resolution, small region run.

Gross approximation of calculation time:

- While calculating Harod system we used a laptop (i5 core)

- The size of the region was 40km*40km
- when using a 500m resolution DEM, calculating a layer took 1.5 seconds (for a single transmitter height and a single antenna)
- when using a 30m resolution DEM, calculating a layer took 8 minutes (for a single transmitter height and a single antenna)
- Note that the R studio IDE signifies that the command is working by a red sign in the top of the console window. A user can wait or cancel the command by hitting “esc”.

The calculation can be launched either as serial calculation or parallel calculation (whenever a large computational power is available) the calculation run for a set of defined antennae and a set of transmitter heights and saves several required files for each transmitter height. This is being done once per setup and can take up to several hours, (but then you do not need to do it again 😊)

The serial code:

- `SerialComputeViewShed(layername=Layername,DEM,ANTS.df,transAlts,ANTlist=ANTlist,includeCurv=F,seaLevel = NA)`

The parallel code:

- `ParallelComputeViewShed(layername=Layername,DEM,ANTS.df,transAlts,ANTlist=ANTlist,includeCurv=F,seaLevel = 0)`

The input variables for both these functions are:

- `layername="XXX"`
  - A name for the files produced by this procedure (the same files will be used to present the LOS analysis). The function produces several files for each transmitter height (TransAlt0.3m as an automatic prefix for the 0.3 m high transmitter, for example):
    - *ANTS_TransAlt0.3mXXX*
      - A csv file containing the details for the calculated antenna.
    - *DEM_TransAlt0.3mXXX*
      - The DEM file used for the calculation (raster file).
    - *LOSLayers_TransAlt0.3mXXX*
      - A stack of raster layers, each layer corresponds to a single antenna and contains TRUE / FALSE for each grid point according to the line of sight clearance.
- `DEM`
  - The DEM raster variable.
- `ANTS.df`
  - The antenna detailes variable as produced by the `setANTS` procedure
- `ANTlist <- c("1","2","3"),`
  - A list of antenna ID’s to run the calculation on, The default is running the calculation for all antennas in the antenna csv file (can be specified explicitly by: `ANTlist <-as.character(ANTS.df$ID))`
- `transAlts <- c(-2,0.3, 2, 5,10)`
  - list of transmitter heights to calculate, each height will be calculated for all antennas and saved as a single presentation set (5 different files).

- Since the DEM has a finite accuracy and resolution we do not recommend to use 0 height.
- When working on aquatic systems (`seaLevel` parameter is not NA), negative `transAlts` can also be specified, this option interprets the value as meters below sea level see Fig 1 for details

- `includeCurv`
  - Logical parameter (TRUE / FALSE).
  - Determine weather to include earth curvature in the LOS calculation
  - Default value is FALSE
- `includeCurv`
  - Numeric value, sets the water surface elevation for aquatic systems
  - Affects the transmitter Altitude parameter and the invalid areas parameter, ignored when set to NA (default value)
  - See Figure 1 for detailes

it is recommended to run the following line before invoking the parallel calculation.

- `detectCores()`
  - detects how many cores are available on your machine.
- `registerDoParallel(3)`
  - assigns X processes for the following calculation.

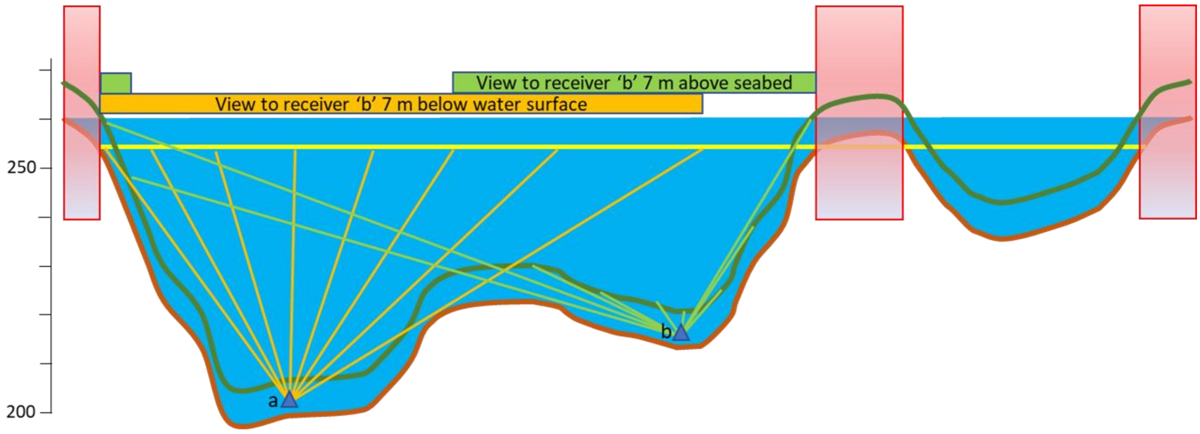

Figure 1: the transAlts **parameter effect for aquatic system. When** seaLevel **is set to any number (not NA) the system is treated as aquatic: positive** transAlts **values will be interpreted as meters above the seabed (green line) negative values will be interpreted as meters below water surface (yellow line). Areas where the LOS calculation is invalid (marked as red rectangles) will be marked as black patches during any visualization.**

c. Editing LOS files after calculation

The calculation of a complete set of antennas might become demanding, especially at large region sizes and high DEM resolutions. Therefore the ability to edit a LOSlayers set is required, this ability includes the addition, removal as well

as changing names (antenna name and ID) without recalculation of viewshed.
substituting a single antenna:

- `AddRmAnts(final_name,base_str_name,add_str_name,ANTID2rm,ANTID2add)`
  - The function edit the `base_str_name` file, (note that you need only to provide the kernel name, without the "ANTS", "LOSLayers" or "DEM" prefix), it removes `ANTID2rm` antennas and adds `ANTID2add` from the file `add_str_name`
  - See code snippet below for example.
  - The function will not protect you from combining files that were calculated for different transmitter height (It will give you a warning if both strings begin with different name ("TransAlt").
  - The function cannot overwrite the previous files.
- `listLOSFiles()`
  - List of viewshed files available in the LOSDATA directory, it trims the prefix (it shows only csv files, and doesn't check that indeed all required files are present "ANTS", "LOSLayers" or "DEM")
- `listAnts(str_name)`
  - List the calculated antennas in a set of LOS files for a given file-name
- An example editing procedure:

`listLOSFiles()` print available files

`str_name <- "TransAlt3m_Res900a1-6"` choosing a file to edit
(an explanation for the name: the "TransAlt3m" represents the height of the transmitter and "Res900a1_6" was a user specific name that represent the resolution of the DEM and the active antennas)

`str_name_new <- "TransAlt0.3m_Res900a11-16"` choosing a source file for new antennas.

`str_name_out <- "TransAlt0.3m_Res900new-a11-16"` setting a new name for the edited file.

`listAnts(str_name)` listing the antennas in the original file

`listAnts(str_name_new)` listing the antennas in the additional file

```
AddRmAnts(final_name=str_name_out,base_str_name=str_name,…
add_str_name=str_name_new,ANTID2rm = c(2,3),ANTID2add = c(15,12))
```

activating the editing for the previous choices

- `UpdateAntnames(final_name,base_str_name,initial_ANTID, newANTID,newANTname)`
  - Updates the names and ID's of antennas.
  - Required parameters:
    - Final name to save the adited LOS files (`final_name`)
    - Source file name (`base_str_name`)
    - List of initial ID's (`initial_ANTID`)

- new ID's, after the editing (`newANTID`)
- New names (`newANTname`)
- `newANTID` and `newANTname` can also be omitted if only the ID or only the name should be changed.

o Be careful not to give an ID that already exists!

4. Presentation

After the layers have been calculated, files are automatically saved to the designated folder. The application is ready for presenting the data.
It is recommended to share the entire directory (including a single R project file) with the possible users of the application. Thus, any user of the program with installed R program can use the application by simply executing the command:
`source('functions/ShinyViewshed.R').`
Basically, upon launching the program a "load data" tab will be opened, the user should choose a LOSdata set from the drop-menu and hit "Load file" button. The user can than choose the different analysis tab: "Cumulative viewshed", "Subtractive viewshed", or "Line of sight" as will be detailed below!
To terminate the process a user is just required to press "esc" in the R console, and to close the web viewer, no saving is required. This is sometimes required after the system has been ideal for stuck.

a. Loading a precalculated layer

Upon launching this command a web browser window will open:

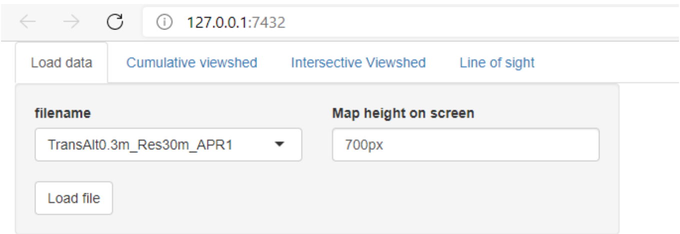

Figure 2: A screenshot, the user interface after launching the program.

1. The user should choose a set of precalculated antenna file from the available list and hit "Load file"
2. The system will present the calculated region and antenna, clicking an antenna will present its details:

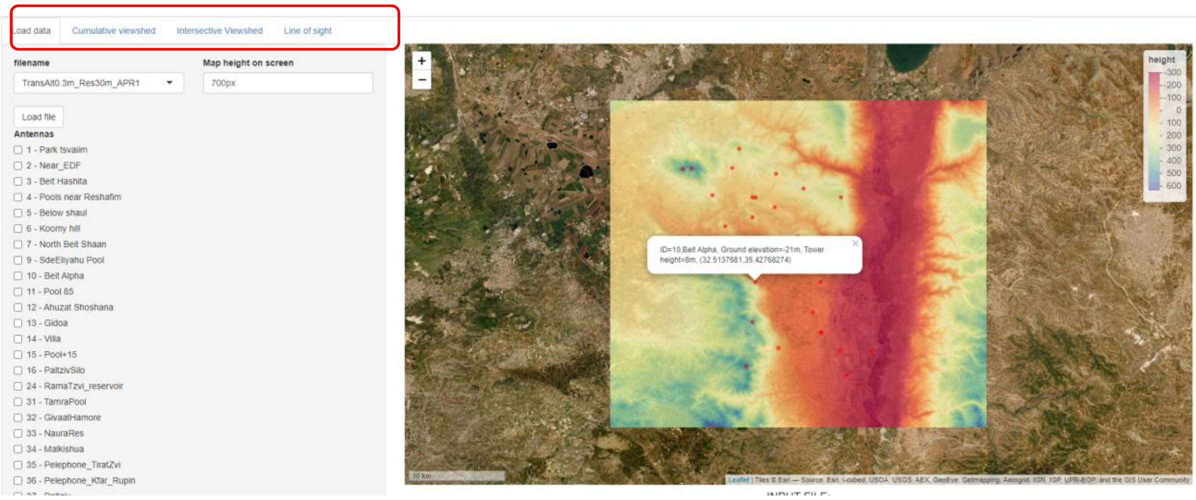

Figure 3: An overview of the loading data tab, after a LOSdata file was chosen. A red square was added to the top of the screenshot to signify the tab selection.

3. The “Map vertical size on screen” input allows the user to present the map on the eniter screen for larger screens
   After verifying the basic data is as required, the user can navigate between the different tabs and present / analyze the data.

b. Cumulative Viewshed

Here the user can choose the antennae that contribute and present the number of visible antennae at any point in the region (this calculation is valid for the pre-defined transmitter height)
The map will update when the “Recalc” button is clicked (top red square on Fig. 3)!
The participating antennae are marked as stars on the map.
The output can be exported (to other application, e.g. google earth) in a kmz format to “file name” by clicking “Save to kmz” at the bottom of the page (bottom red square on Fig. 3)!

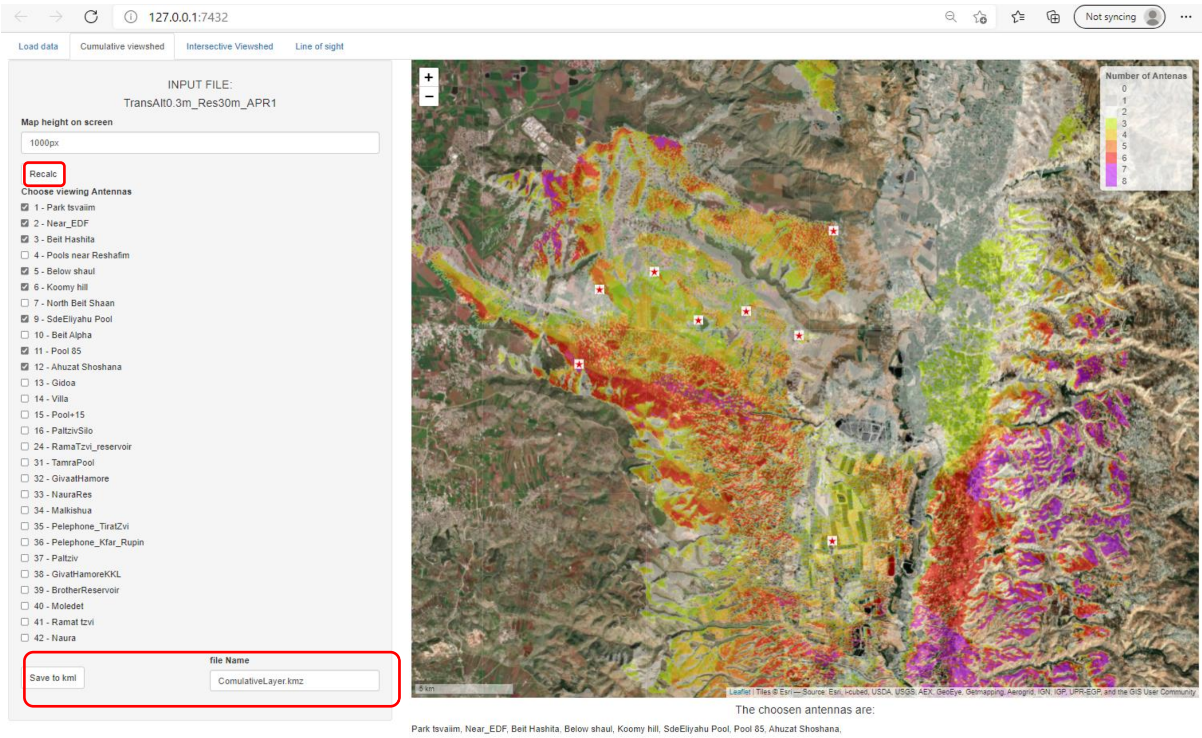

Figure 4: A cumulative viewshed example, after several antennae have been chosen and recalculted. Red squares were added to the screenshot: top to signify the "Recalc" option and bottom to signify the "save to kmz" option.

c. Subtractive Viewshed

Here the user can present the intersection between **in-site** (with LOS) and **blind** (without LOS) antennae. The user can choose multiple antennas for each side, but the list has to be exclusive (none of them can appear in both lists). Note that this calculation is true for the pre-defined transmitter height.

The map will update when the "Recalc" button is clicked, area that agree with the defined condition will be colored yellow!

The **in-site** antennae are marked as stars (★) on the map, while the blind are marked by circled cross (⊗)

The output can be exported in a kmz format to "file name" by clicking "Save to kmz" at the bottom of the page!

Figure 5: An subtractive viewshed example, after several antennae have been chosen and recalculated, the yellow patches mark the areas were all conditions agree.

d. LOS analysis

This tab allows some detailed analysis of the area and terrain. It plots the ground elevation under a line between two points. It also presents the DEM values in a square around this line (with user-chosen shoulders), this option allows a high resolution inspection of the input DEM.

- Both points of the line can be inserted manually as a geographic wgs84 coordinates in the “LAT” and “LON” text input fields. Their elevation above ground can also be inserted manually.
- A second option for Antenna position input is to choose a predefined antenna from the underlying file.
- A second option for Transmitter position input is via the icon ( ) in the map. This icon will allow the user to point a location and will copy its coordinates and ground altitude to the corresponding fields.
- The “`DEM shoulders(m)`” value defines the margins around the DEM map.

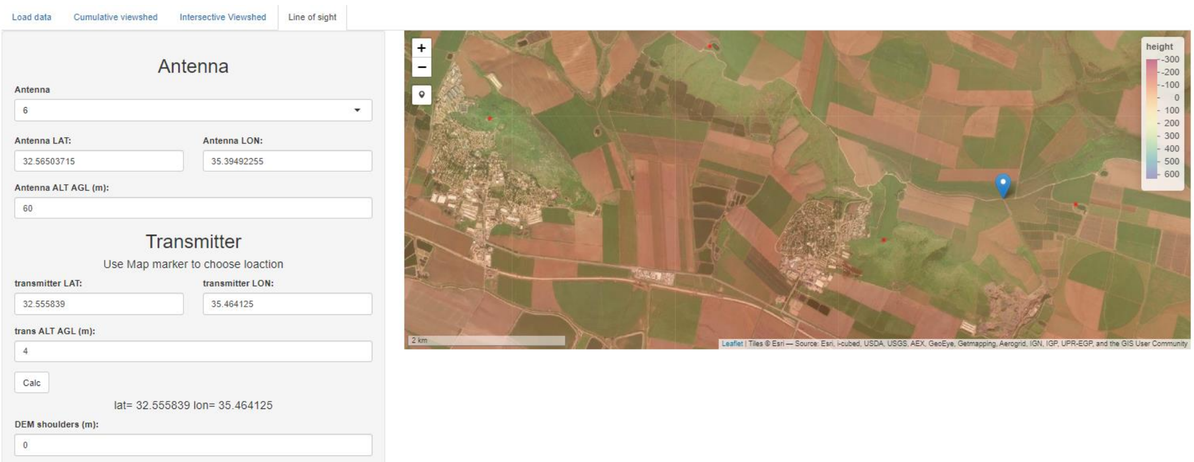

Figure 6: Line of sight analysis tab before the "Calc" button was pressed. Antenna 6 was chosen and its details appear, and the marker was set on an arbitrary position (blue =marker)

Upon clicking the "Calc" button, the line of sight between the two points will be displayed in a separate plot (red line signify no LOS and green signify clear LOS), and a map that includes the zoom-in DEM around the line.

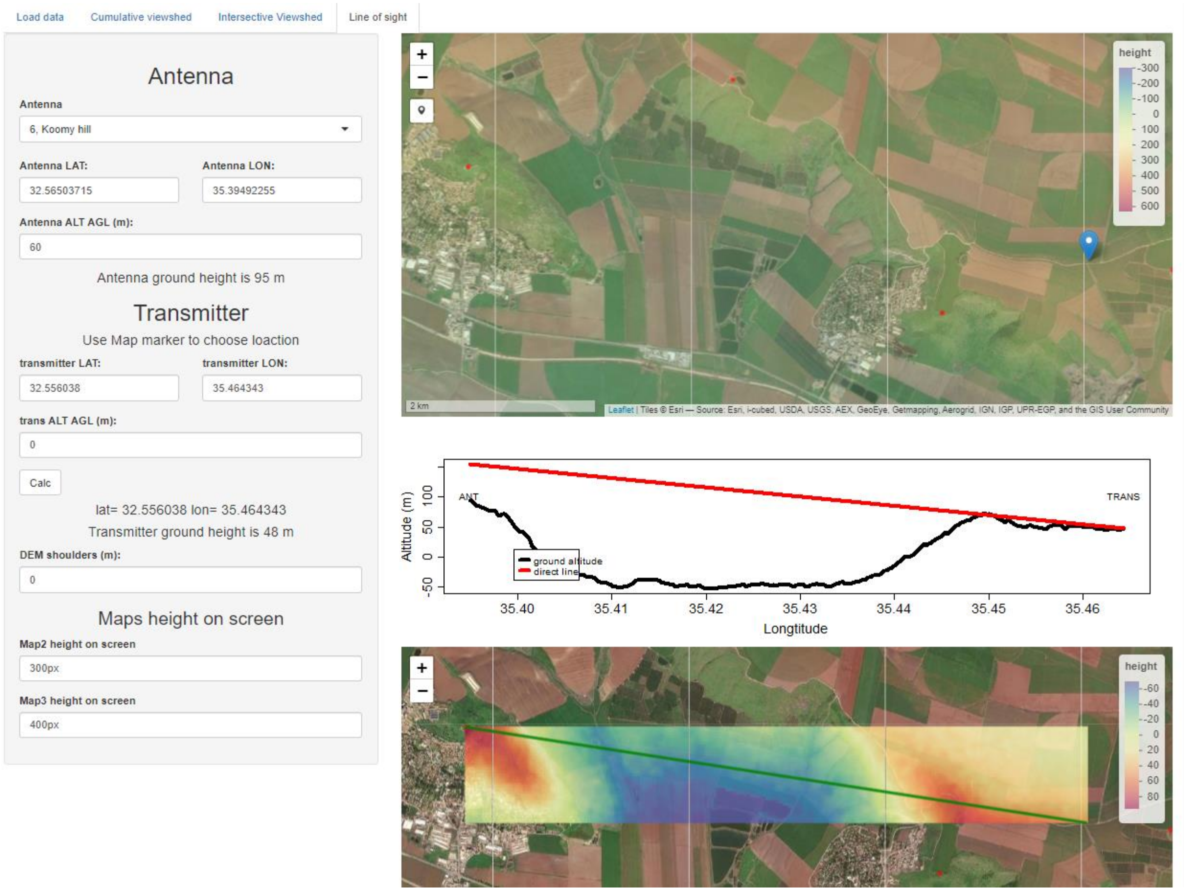

Figure 7: Line of sight analysis tab after the "Calc" button was pressed. A plot has been added to the screen that shows the altitude below the chosen line. Another map was added that shows the detailed DEM in the vicinity of the line.

5. Obtaining DEM data

1 arc resolution (~ 30 meter) DEM files are available at http://sendimage.whu.edu.cn/res/DEM_share/SRTM1/N30,E30/ , a user can download his region of interest (as geographical anchored TIFF file) and then provide it to the `DEM <- getDEM(type="file",box,filename=DEM_name)` command. Some basic concatenating and saving commands might also be useful:

1. Read a TIFF file

```
imported_raster1 <- raster(DEM_name1)
```

2. Concatenate two DEM files

```
imported_raster <-
merge(imported_raster1,imported_raster2)
```

3. save a merged raster file locally for further use:

```
writeRaster(imported_raster, filename="DEM_Harod.tif",
format="GTiff")
```