

SPHY: Spatial Processes in Hydrology

Graphical User-Interfaces (GUIs)

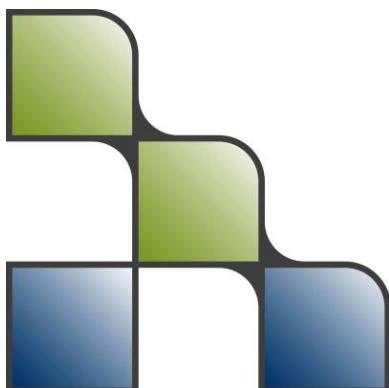
October 2015



Author

W. Terink
A.F. Lutz
W.W. Immerzeel

Report FutureWater: 143



FutureWater
Costerweg 1V
6702 AA Wageningen
The Netherlands

+31 (0)317 460050

info@futurewater.nl

www.futurewater.nl

Acknowledgements

The development and publication of the SPHY model source code, its binaries, GUIs, and case-studies has been supported through various (research) projects that were partly or completely funded by the following organizations:

- International Centre for Integrated Mountain Development (ICIMOD¹);
- European Space Agency (ESA²);
- Asian Development Bank (ADB³);
- World Bank⁴;
- Rijksdienst voor Ondernemend Nederland (RVO⁵)
- NUFFIC⁶

We are very grateful to these organizations that made the development of the SPHY model possible. We hope to continue to collaborate with these organizations in the future in order to further develop and improve the SPHY model and its interfaces.

¹ <http://www.icimod.org/>

² <http://www.esa.int/ESA>

³ <http://www.adb.org/>

⁴ <http://www.worldbank.org/>

⁵ <http://www.rvo.nl/>

⁶ <https://www.nuffic.nl/en>



Table of contents

Acknowledgements	2	
1	Introduction	9
2	Installation of GUIs	11
2.1	Additional software	11
2.2	SPHY model preprocessor v1.0	12
2.3	SPHY model plugin v1.0	14
3	SPHY model preprocessor v1.0	16
3.1	Overview	16
3.1.1	Introduction to the GUI	16
3.1.2	Using the preprocessor GUI for the first time	17
3.1.3	Top menu buttons	17
3.2	General settings	18
3.2.1	Folder selection	18
3.2.2	Coordinate system	19
3.2.3	Meteorological forcing period to process	19
3.3	Area selection	19
3.4	Modules	22
3.5	Basin delineation	23
3.6	Stations	28
3.7	Meteorological forcing	29
4	SPHY model plugin v1.0	32
4.1	Overview	32
4.1.1	Introduction to the GUI	32
4.1.2	Using the model GUI for the first time	33
4.1.3	Editing the SPHY model configuration file outside the GUI	34
4.2	Map canvas layers and GUI interaction	34
4.2.1	Interaction with the map canvas	34
4.2.2	Map canvas layout	34
4.2.3	Setting a background layer	35
4.3	Top menu buttons	36
4.3.1	New project	36
4.3.2	Open project	37
4.3.3	Save and Save As	38
4.4	General settings	38
4.4.1	Folder selection	38
4.4.2	Period of simulation	39
4.4.3	Coordinate system	39
4.4.4	Catchment settings	40
4.5	Climate	41
4.5.1	Meteorological forcing map-series	41
4.5.2	Meteorological parameters	42
4.6	Soils	43
4.6.1	Rootzone physical maps	43
4.6.2	Subzone physical maps	44
4.6.3	Root- and subzone parameters	44
4.7	Groundwater	45



4.7.1	Groundwater volume settings	45
4.7.2	Parameters	45
4.8	Land use	46
4.9	Glaciers	48
4.9.1	Glacier fraction settings	48
4.9.2	Glacier degree-day-factors	49
4.10	Snow	49
4.10.1	Snow storage	49
4.10.2	Snow parameters	50
4.11	Routing	51
4.11.1	Recession coefficient and flow direction	51
4.11.2	Initial values	52
4.12	Report options	53
4.13	Running the model	54
4.14	Visualizing model output	57
4.14.1	Time-series output	57
4.14.2	Map-series output	59
5	References	61
Copyright		62



Tables

Table 1: Catchment settings maps.....	40
Table 2: Overview of SPHY model input.....	63
Table 3: Overview of SPHY model output (Report options tab).....	64

Figures

Figure 1: Installation of QGIS	12
Figure 2: Manage and install plugins in QGIS.....	13
Figure 3: Selecting the experimental and deprecated plugins options in the QGIS plugin settings menu.....	13
Figure 4: Activating the SPHY model preprocessor inside QGIS.	14
Figure 5: SPHY model preprocessor interface button.....	14
Figure 6: Activating the SPHY model plugin inside QGIS.	15
Figure 7: SPHY model interface button.....	15
Figure 8: Overview of the SPHY model preprocessor GUI top menu (buttons in blue box) and tab widget, consisting of 6 tabs (red box).	16
Figure 9: SPHY model preprocessor GUI for first-time use.	17
Figure 10: Example of the structure of the Hindu Kush-Himalaya database.	18
Figure 11: Completing the folder selection part of the SPHY model preprocessor GUI.	19
Figure 12: Overview of the Area selection tab.	20
Figure 13: Showing the standard background layer.....	20
Figure 14: Selecting your area of interest.	21
Figure 15: Finalizing the Area selection tab.	21
Figure 16: Overview of the Modules tab.	22
Figure 17: Selecting multiple modules from the Modules tab.	22
Figure 18: Processing the initial maps in the Modules tab.	23
Figure 19: Overview of the Basin delineation tab.....	24
Figure 20: Creating a new shapefile layer.....	24
Figure 21: Setting the properties of the new Shapefile Layer.	25
Figure 22: outlets.shp layer in the layers overview.	25
Figure 23: Editing a layer in QGIS.	25
Figure 24: Adding features in QGIS.	26
Figure 25: Adding outlets to the outlets.shp layer in QGIS.	26
Figure 26: Example of 3 outlets that have been added to the outlets.shp layer.	26
Figure 27: Overview of the Basin delineation tab with the outlet(s) shapefile selected.	27
Figure 28: Basin delineation finished.	28
Figure 29: Overview of the Stations tab.	28
Figure 30: Overview of the Stations tab with the station(s) shapefile selected.	29
Figure 31: Overview of the Meteorological forcing tab.....	30
Figure 32: Setting the options in the Meteorological forcing tab, using precipitation data from the database and temperature data from user-defined stations.	30
Figure 33: Format of location csv-file, containing 5 stations. Elevation units are in MASL. Coordinates need to be provided in latitude (lat) and longitude (lon). Names can be dummy values.	31



Figure 34: Format of precipitation data csv-file, containing data for 5 stations. Precipitation units are in mm.....	31
Figure 35: Format of temperature data csv-file, containing data for 5 stations. The order is from left to right: average, maximum, minimum temperature. Units of temperature are degrees Celsius.....	31
Figure 36: Processing of meteorological forcing data.....	31
Figure 37: Overview of the SPHY model plugin top menu (buttons in blue box) and a tab widget, consisting of 11 tabs (red box).	33
Figure 38: SPHY model GUI for first-time use.....	34
Figure 39: Example of map canvas groups and layers layout.....	35
Figure 40: Activating the OpenLayers Plugin in QGIS.....	36
Figure 41: OpenLayers plugin in the QGIS menu.....	36
Figure 42: SPHY model interface after creating a new project.....	37
Figure 43: Example of SPHY model interface after opening an existing project.....	38
Figure 44: Overview of the General settings tab.....	39
Figure 45: Error message indicating that no sphy.py can be found in the selected folder.	39
Figure 46: Selecting a DEM map in the catchment settings.....	41
Figure 47: Overview of the Climate tab.....	41
Figure 48: Selecting the precipitation map-series.....	42
Figure 49: Overview of the Soils tab.....	43
Figure 50: Example of rootzone field capacity map.....	44
Figure 51: Overview of the Groundwater tab.....	45
Figure 52: Overview of the Land use tab.....	47
Figure 53: Example of a land use map with four land use classes.....	47
Figure 54: Example of crop coefficients lookup table in Notepad++.....	47
Figure 55: Overview of the Glaciers tab.....	48
Figure 56: Example of glacier fraction map.....	49
Figure 57: Overview of the Snow tab.....	50
Figure 58: Overview of the routing tab.....	51
Figure 59: Example of flow direction map.....	52
Figure 60: Values indicating the direction of flow in the flow direction map.....	52
Figure 61: Overview of the Report options tab.....	54
Figure 62: Overview or the Run Model tab.....	55
Figure 63: Example of log screen output during model run.....	55
Figure 64: Example log screen output of cancelled model run.....	56
Figure 65: Example log screen output of successful model run.....	56
Figure 66: Overview of Visualize results tab.....	57
Figure 67: Setting the Stations map layer (outlet) as active layer.....	58
Figure 68: Click on a point feature in the canvas to show a time-series.....	58
Figure 69: Example of time-series plot.....	59
Figure 70: Example of annual rainfall map that has been added to the map canvas.....	60
Figure 71: HydroSheds DEM included in the Hindu Kush-Himalaya database.....	66
Figure 72: HydroSheds streams included in the Hindu Kush-Himalaya database.....	67
Figure 73: Randolph Glacier Inventory 4.0 glacier outlines (blue) included in Hindu Kush-Himalaya database. RGI regions are indicated by green polygons.....	68
Figure 74: GlobCover domain included in the Hindu Kush-Himalaya database.....	69
Figure 75: HiHydroSoil saturated conductivity of the topsoil layer in the Hindu Kush-Himalaya database.....	69
Figure 76: HiHydroSoil field capacity of the topsoil layer in the Hindu Kush-Himalaya database.....	70



Figure 77: Latitude values for the Hindu Kush-Himalaya database.....	71
Figure 78: Average air temperature grid from WFDEI for the Hindu Kush-Himalaya database.	72
Figure 79: HydroSheds DEM included in the Southeast Africa database.	75
Figure 80: HydroSheds streams included in Southeast Africa database.....	76
Figure 81: River basins shapefile included in the Southeast Africa database.	77
Figure 82: GlobCover domain included in the Southeast Africa database.	78
Figure 83: HiHydroSoil saturated conductivity of the topsoil layer in the Southeast Africa database.....	79
Figure 84: HiHydroSoil field capacity of the topsoil layer in the Southeast Africa database.....	79
Figure 85: Latitude values for the Southeast Africa database.	80
Figure 86: Daily precipitation grid from FEWS RFE2.0 for the Southeast Africa database.	81
Figure 87: Daily air temperature grid from GSOD for the Southeast Africa database, interpolated at a zero MASL elevation plane, using a lapse rate of -0.0065 degree/meter.....	83





1 Introduction

The Spatial Processes in Hydrology (SPHY) model (Terink et al., 2015, 2015a) is a hydrological modeling tool suitable for a wide range of water resource management applications. SPHY is a state-of-the-art, easy to use, robust tool, that can be applied for operational as well as strategic decision support. The SPHY modeling package is available in the public domain and only uses open source software. SPHY is developed by FutureWater in cooperation with national and international clients and partners. Key features of the SPHY model can be summarized as:

- Robust scientific basis
- Combines strength of existing de facto hydrological models
- Modular setup in order to switch on/off irrelevant processes for computation efficiency
- Wide range of applicability in terms of regions, climates, modeling purposes, spatial and temporal scales
- Performs under data scarcity
- Linkable to remote sensing data
- Easy adjustment and application
- Graphical User Interfaces (GUIs) for QGIS
- Open source

The SPHY model has been applied and tested in various studies ranging from real-time soil moisture predictions in flat lands, to operational reservoir inflow forecasting applications in mountainous catchments, irrigation scenarios in the Nile Basin, and detailed climate change impact studies in the snow- and glacier-melt dominated the Himalayan region. Typical examples of SPHY applications are listed below:

- Climate change impact and adaptation
- Water and energy
- Operational services
- Irrigation management
- Snow- and glacier fed river basins

The SPHY model was originally developed to work with a configuration file in which the user can modify input, output and change parameter settings. This allows people with average hydrological and computer skills to work with the model. However, in order to make the model available to a larger user-group worldwide, it would be beneficial if the model is integrated in a Graphical User-Interface (GUI). A SPHY model GUI would enable the possibility of selecting input and output, running the model, and analyzing results by the simple click of a button.

Another difficulty that users may face is creating SPHY model input data in the required PCRaster format. In order to do this, users should be familiar with the PCRaster commands and they should know where to find the required data sources. Therefore, it will be beneficial if a SPHY model preprocessor GUI is available that allows the user to automatically generate the required SPHY model input data from a database, by only dragging a rectangle for the area of interest.

The objective of this manual is therefore to introduce and provide detailed information about two GUIs that have been developed for the SPHY model:

- SPHY model preprocessor GUI: “SphyPreProcess v1.0”
- SPHY model plugin GUI: “SphyPlugin v1.0”



Both GUIs have been developed as plugin for QGIS⁷, which is completely free and available in the public domain. Some case-studies have been developed to work with the SPHY model plugin GUI. These case-studies can be found in Terink et al. (2015b). This manual covers the installation of the required software (Section 2), a detailed description of the SPHY model preprocessor (Section 3), and the SPHY model plugin (Section 4).

The model source code is in the public domain (open access) and can be obtained from the SPHY model website free of charge (www.sphy-model.org). The peer-reviewed open-access publication of the SPHY model can be found at <http://www.geosci-model-dev.net/8/2009/2015/gmd-8-2009-2015.pdf> (Terink et al., 2015).

⁷ <http://www.qgis.org/en/site/>



2 Installation of GUIs

2.1 Additional software

Login credentials that are required to download software and data from the SPHY model website can be obtained using the link below:

<http://www.sphy.nl/software/download-sphy/>

In order to install the SPHY model plugin and SPHY model preprocessor GUIs, it is required to install QGIS. Before QGIS is installed, make sure that you have installed one of the SPHY model versions source codes:

- [v2.0](#) (Terink et al. (2015a))

OR

- [v2.1](#) (Terink et al. (2015c))

It should be noted that the SPHY model plugin ([SphyPlugin v1.0](#)) is only compatible with SPHY model v2.0. The SPHY model preprocessor ([SphyPreProcess v1.0](#)) can be used to create input data for both model versions.

NOTE: Microsoft Windows version 7 or higher is required to use the GUIs.

The installation of the SPHY model source code is described in Section 4.2.4 from Terink et al. (2015a). Also the additional software packages (Python, NumPy, and PCRaster) are required. The installation of this software is well described in Section 4.2 from Terink et al. (2015a).

Both SPHY model GUIs have been developed and tested using QGIS v2.8.2.1. QGIS can be downloaded and installed using the link below:

[Download QGIS v2.8.2.1](#)

Just double click the downloaded file and follow the steps in order to install QGIS (Figure 1).



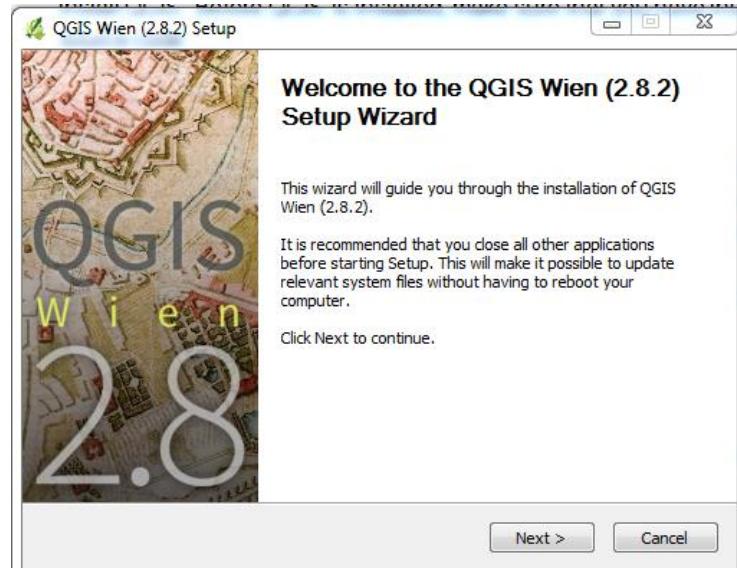


Figure 1: Installation of QGIS.

2.2 SPHY model preprocessor v1.0

The SPHY model preprocessor (SphyPreProcess) v1.0 can be downloaded using the link below:

[Download SphyPrecProcess v1.0](#)

In order to use this GUI inside QGIS, it is only required to extract the contents of the downloaded zip-file into the QGIS Python plugins directory. Generally, this directory is located on the following location on your hard disk:

c:\Users\XXXX\qgis2\python\plugins\

where XXXX should be replaced by the name of the PC user. If this folder does not exist, then create this folder manually. After unzipping the contents of **SphyPreProcess.zip** into this folder, the installation of the interface has been completed.

To activate the plugin in QGIS, follow the next steps:

- Launch QGIS.
- Go to “*Plugins*” -> “*Manage and Install Plugins...*” (Figure 2).
- Then in the window that pops up (Figure 3) you should select under “*Settings*”:
 - o Show also experimental plugins.
 - o Show also deprecated plugins.
- Go to “*All*” and type “*sphy processor*” (Figure 4) in the search bar, and select the SPHY preprocessor plugin that shows up.
- Click Close to close the Plugins menu.

If installation and activation has been successful, then the SPHY preprocessor interface logo (button) has been added to the toolbar (Figure 5). The use of the SPHY model preprocessor GUI is described in detail in Section 3.



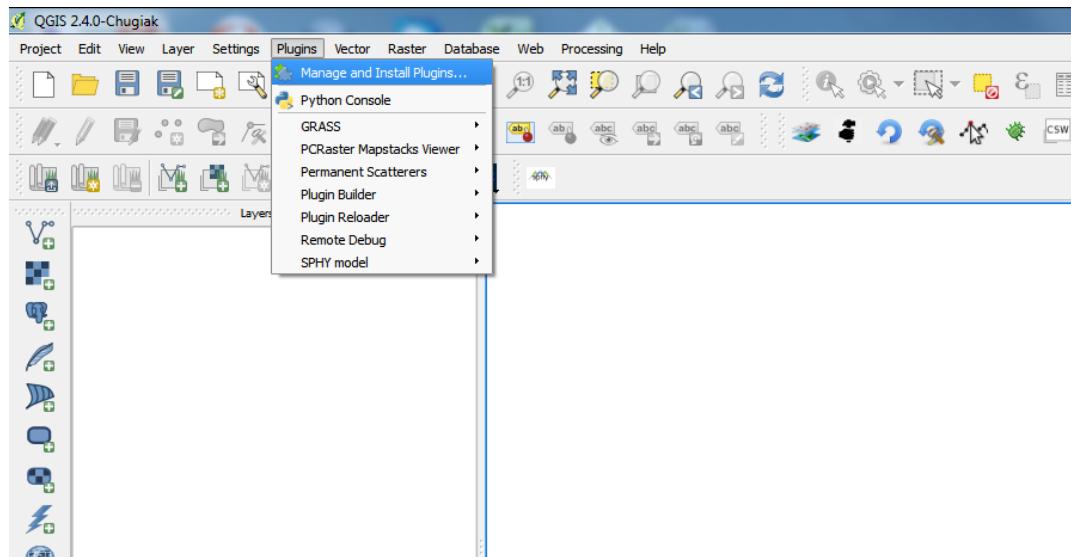


Figure 2: Manage and install plugins in QGIS.

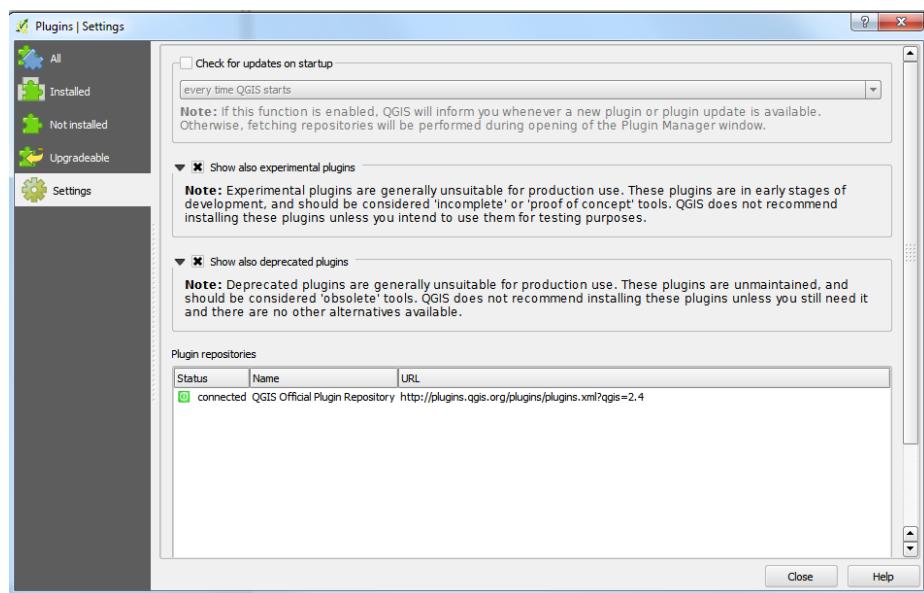


Figure 3: Selecting the experimental and deprecated plugins options in the QGIS plugin settings menu.



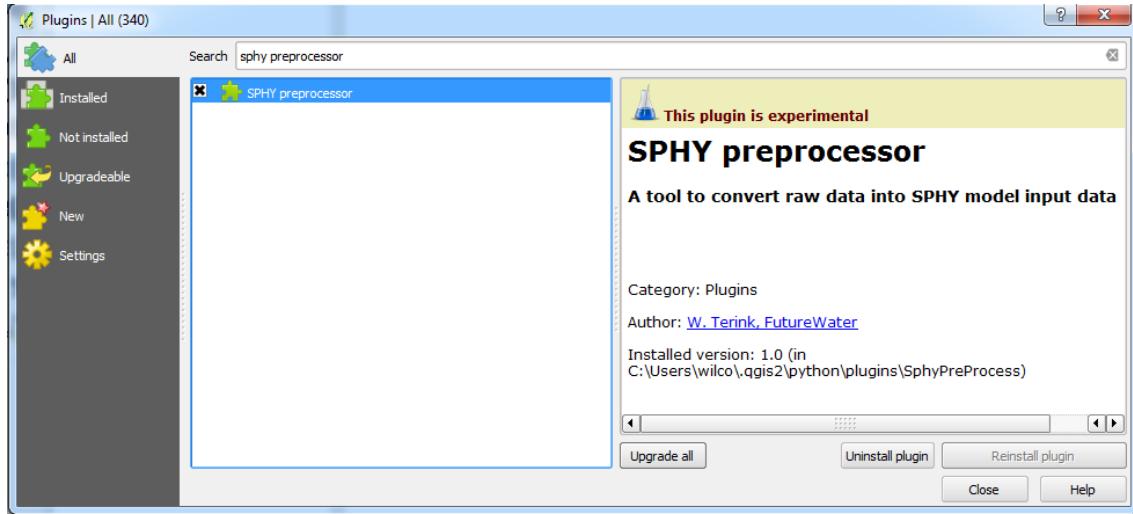


Figure 4: Activating the SPHY model preprocessor inside QGIS.

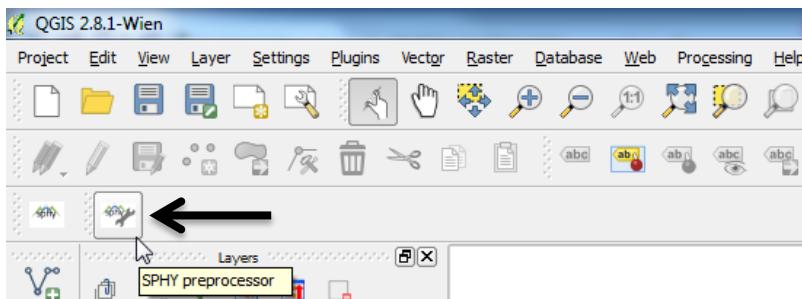


Figure 5: SPHY model preprocessor interface button.

2.3 SPHY model plugin v1.0

The SPHY model plugin (SphyPlugin) v1.0 can be downloaded using the link below:

[Download SphyPlugin v1.0](#)

In order to use this GUI inside QGIS, it is only required to extract the contents of the downloaded zip-file into the QGIS Python plugins directory. Generally, this directory is located on the following location on your hard disk:

c:\Users\XXXX\qgis2\python\plugins\

where XXXX should be replaced by the name of the PC user. If this folder does not exist, then create this folder manually. After unzipping the contents of **SphyPlugin.zip** into this folder, the installation of the interface has been completed.

To activate the plugin in QGIS, follow the next steps:

- Launch QGIS.
- Go to “*Plugins*” -> “*Manage and Install Plugins...*” (Figure 2).
- Then in the window that pops up (Figure 3) you should select under “*Settings*”:
 - o Show also experimental plugins.
 - o Show also deprecated plugins.
- Go to “*All*” and type “*sphy*” (Figure 6) in the search bar, and select the SPHY model plugin that shows up.



- Click Close to close the Plugins menu.
- If installation and activation has been successful, then the SPHY model interface logo (button) has been added to the toolbar (Figure 7).

You now can start using the interface by clicking the SPHY model interface button. The use of this interface is described in detail in the Section 4.

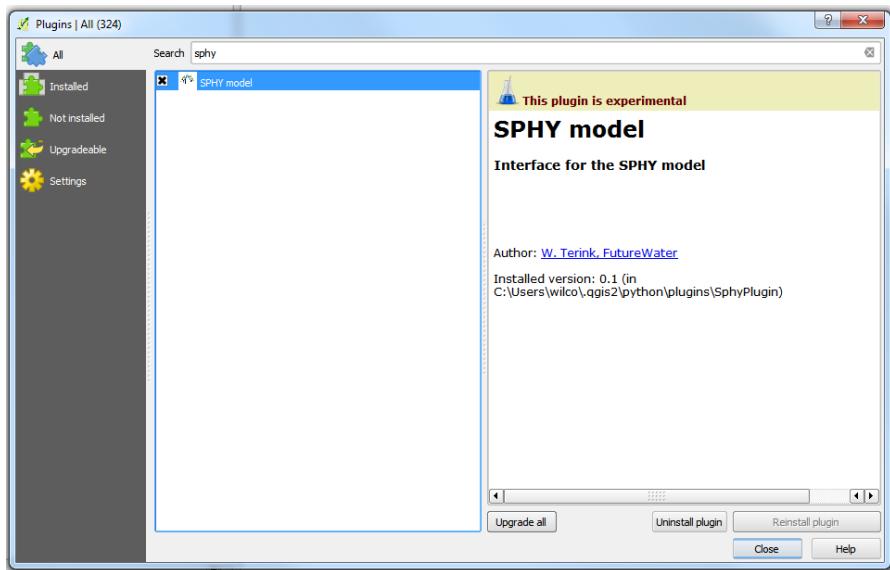


Figure 6: Activating the SPHY model plugin inside QGIS.

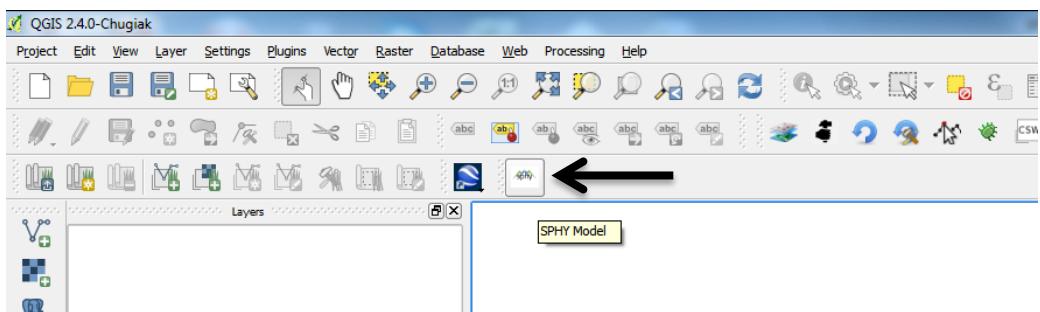


Figure 7: SPHY model interface button.



3 SPHY model preprocessor v1.0

3.1 Overview

3.1.1 Introduction to the GUI

The SPHY model preprocessor GUI has been developed with the goal to make the creation of SPHY model input data more user-friendly, and thus more applicable to a larger user-group world-wide.

The SPHY model preprocessor interface consists of a top menu with three buttons and a tab widget that contains 6 tabs (Figure 8). The use of the top menu buttons is explained in Section 3.1.3. When working on a SPHY model preprocessor project, the user has to go through the individual tabs: general settings, area selection, modules, basin delineation (if routing is enabled), stations, and meteorological forcing. The user has to complete these tabs in the order they appear: from left to right. The use of each of these tabs is described in detail in the Sections 3.2 through 3.7.

The current version of the SPHY model preprocessor GUI is compatible with the following databases/extents:

- [Hindu Kush-Himalaya](#) (Appendix 2)
- [Southeast Africa](#) (Appendix 3)

If it is the first time you use the SPHY model preprocessor GUI, then please first read Section 3.1.2 before continuing with the other sections.

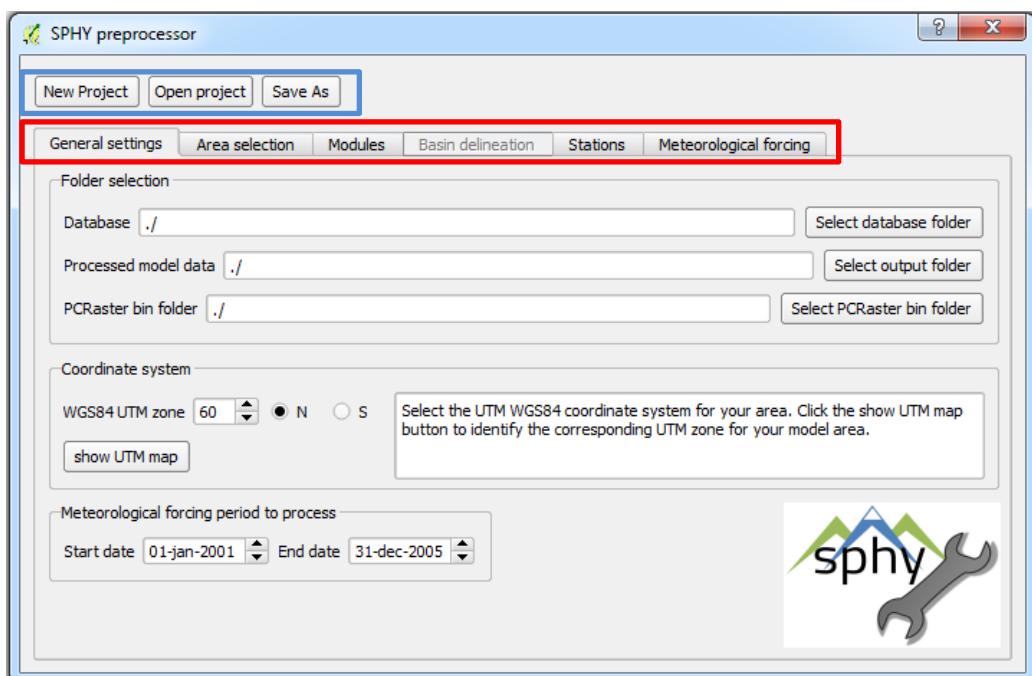


Figure 8: Overview of the SPHY model preprocessor GUI top menu (buttons in blue box) and tab widget, consisting of 6 tabs (red box).



3.1.2 Using the preprocessor GUI for the first time

The SPHY model preprocessor GUI is always **started** by clicking the SPHY model preprocessor GUI button (Figure 5). Since it is the first time you use the interface, the registry settings will be empty. This means no previous SPHY preprocessor projects can be found by the interface. If this is the case, then the interface looks like Figure 9. The only options available are:

- New project
- Open project

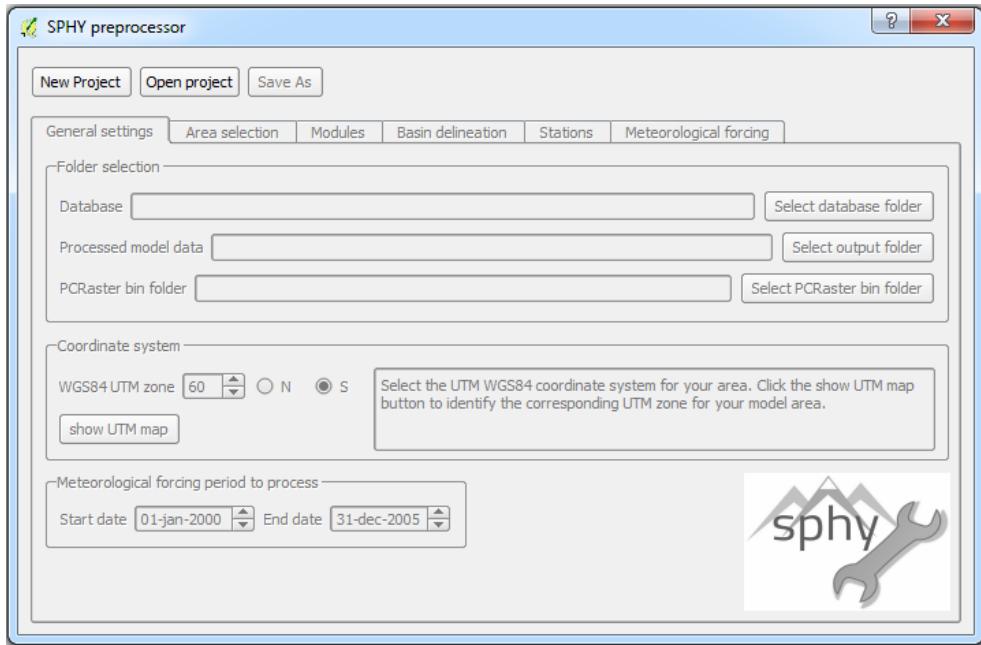


Figure 9: SPHY model preprocessor GUI for first-time use.

The *New Project* button logically asks the user to save a new SPHY model project, whereas the *Open Project* button asks the user to open an existing SPHY model project. After one of these options has been selected, the tabs will be activated (Figure 8) such that the user can go through these tabs to complete preprocessing input data.

3.1.3 Top menu buttons

A SPHY model preprocessor project involves editing a SPHY preprocessor configuration file (*.cfg). If the *New Project* button is clicked, then the user is asked where to save the new project and to provide a filename (XXXX.cfg) for the project. You can choose any filename, but make sure you do not choose the same filename as you will use later for the SPHY model GUI project (Section 4). If a current SPHY model preprocessor project was open in QGIS, then it will be asked to save the current project first before creating a new project.

After creating a new project, the GUI looks like Figure 8. The user may now continue completing the different tabs.

Opening an existing project allows you to continue with a previous SPHY model preprocessor project. By clicking the *Open Project* button you will be asked to select a *.cfg project file to be opened. If a current SPHY model preprocessor project was open in QGIS, then it will be asked



to save the current project first before opening another project. All model settings present in the *.cfg file will be added to the SPHY model preprocessor GUI.

When working on an active preprocessor project, all the changes you make in the GUI will automatically be saved to the *.cfg file. The Save As button allows you to save the SPHY model preprocessor project under another filename.

3.2 General settings

3.2.1 Folder selection

After starting a new project the user first needs to select the folder where the database can be found. This is the folder where the **metadata.cfg** file of the corresponding database is located. Figure 10 shows the structure of the folder where the Hindu Kush-Himalaya database is located. Select this folder or the folder from another database by clicking the *Select database folder* button.

 GlobCover2009_landuse	13-7-2015 16:33	File folder
 HiHydroSoil	8-7-2015 15:06	File folder
 HydroSheds_SRTM_dem	9-7-2015 9:39	File folder
 Latitude	17-6-2015 9:34	File folder
 RGI4_glaciers	8-6-2015 14:26	File folder
 WFDEI_meteo_forcing	5-10-2015 9:57	File folder
 metadata	1-10-2015 11:56	CFG File

Figure 10: Example of the structure of the Hindu Kush-Himalaya database.

The second step involves creating a folder on your hard disk where you want the processed model input data to be created. A logical folder name would be **linput** and create it inside your SPHY model source folder, e.g. **c:\SPHY2.0**. Of course you are free to create a different folder name on a different location on your hard disk. Now select the created folder by clicking the *Select output folder* button.

The final step is to select the PCRaster bin folder. The location of this folder can easily be found using Section 4.2.3 from Terink et al. (2015a). Select this folder by clicking the *Select PCRaster bin folder*.

After completing the *Folder selection* part the GUI should look something like Figure 11. Folders may look different depending on the locations you have selected on your computer.



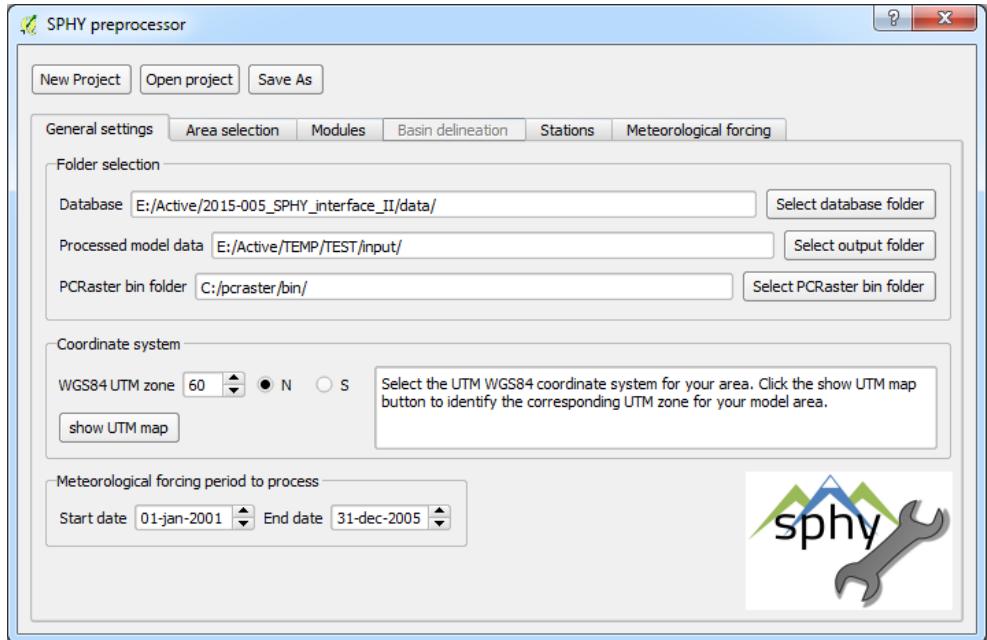


Figure 11: Completing the folder selection part of the SPHY model preprocessor GUI.

3.2.2 Coordinate system

The next step is about defining the Coordinate Reference System (CRS). Since the SPHY model has been developed to work with a WGS84 UTM zone CRS, you need to specify the UTM zone for your area of interest. If you do not know in which UTM zone your area of interest is located, then you click the *show UTM map*. This will pop-up an image containing UTM zones. After you have defined the UTM zone for your area of interest you can use the spinbox to set the value and the radio button to specify north (N) or south (S).

3.2.3 Meteorological forcing period to process

If you want the GUI to create a meteorological forcing dataset, then you need to specify the start and end date for the period you want to run the model for. You need to make sure that the selected period is covered by the database (check Appendix belonging to the database) that you have selected. If you decide to use your own station data for creating the meteorological forcing data (Section 3.7), then you need to make sure that the selected period is covered by the data specified in your *.csv files.

You can leave defaults here if you do not plan to use the GUI to create forcing data.

3.3 Area selection

After completing the *General settings* you can go to the *Area selection* tab (Figure 12). This part of the GUI is the most important, since here you define the extent and spatial resolution of your area of interest. If no area has been selected before, then your GUI looks like Figure 12. Now it is time to select your area of interest by dragging a rectangle. For better orientation it is possible to show the standard background layer by checking the *Show background layers* checkbox (Figure 13). This background layer contains the Countries and Shaded Relief layers from the



Natural Earth dataset⁸. Of course you can add your own background dataset for better orientation.

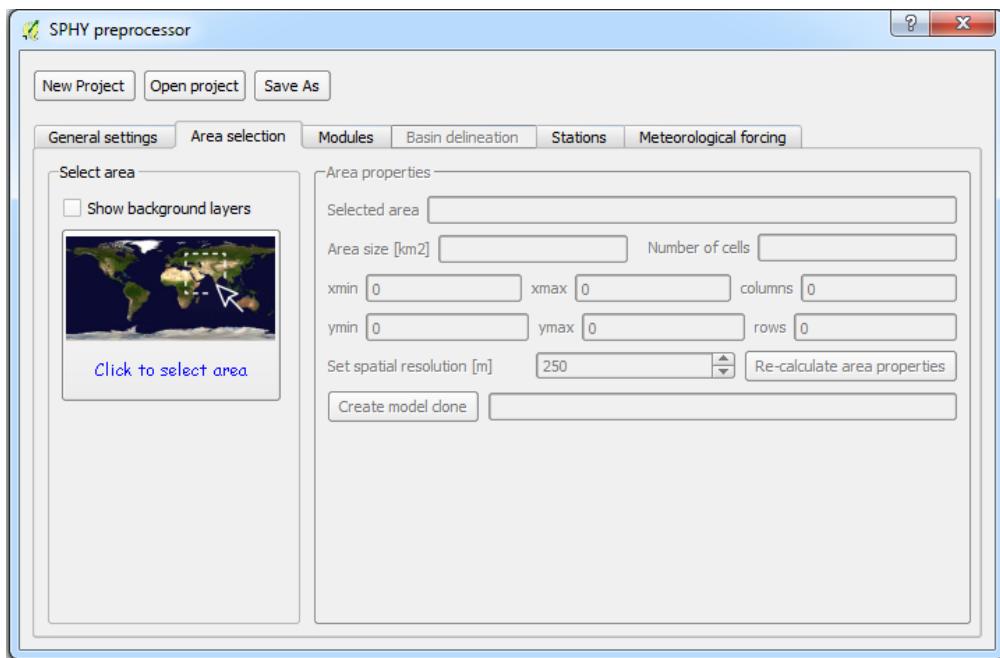


Figure 12: Overview of the Area selection tab.

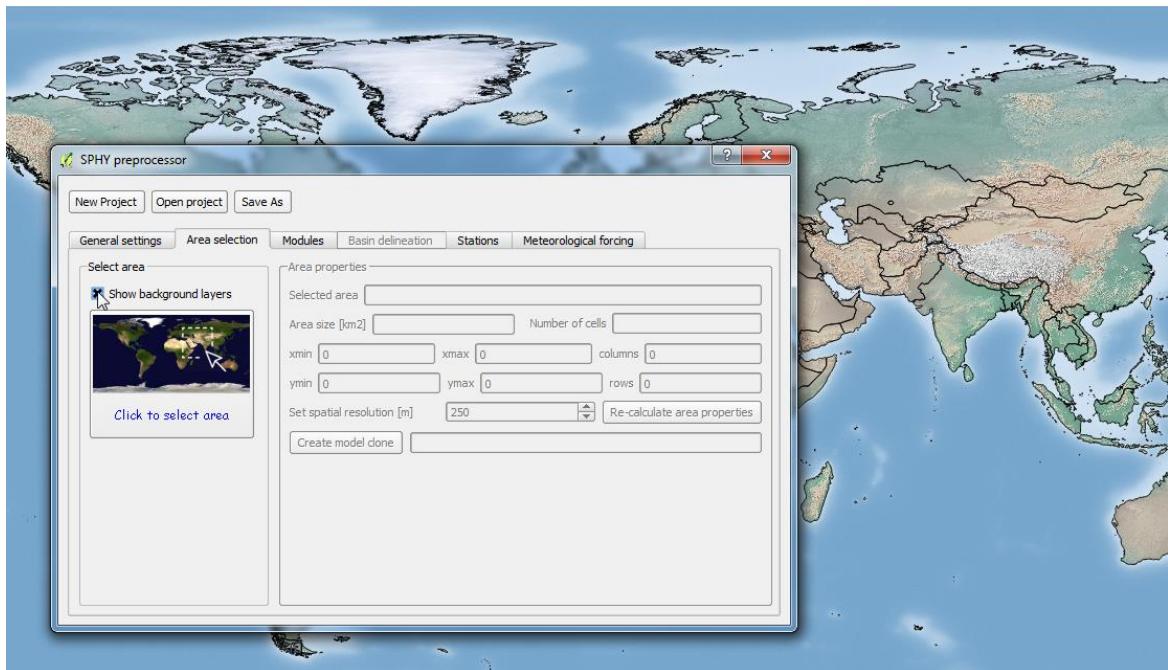


Figure 13: Showing the standard background layer.

Select your area of interest by clicking the *Click to select area* button. This will temporarily hide the GUI which allows you to drag a rectangle. After you have dragged a rectangle for your area of interest, a red rectangle is shown and the GUI is shown again with the *Area properties* being filled in (Figure 14). If your selected area is too large in combination with the model resolution, then a warning will appear that hints for choosing a coarser spatial resolution.

⁸ <http://www.naturalearthdata.com/downloads/>



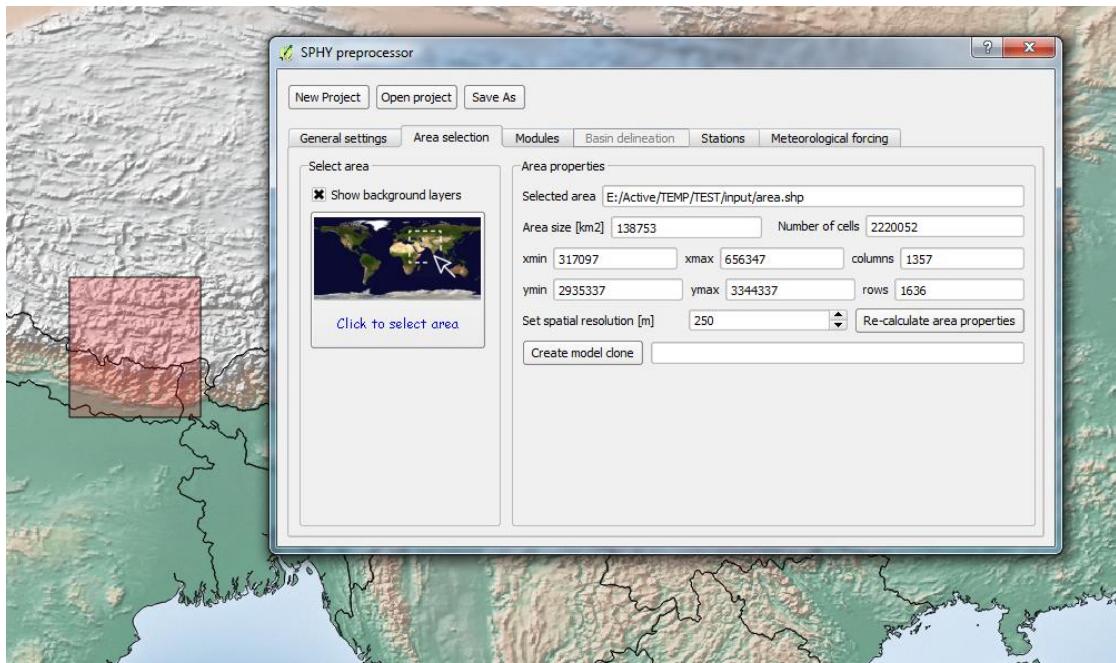


Figure 14: Selecting your area of interest.

You can change the model resolution under *Set spatial resolution [m]*. Each time you change the value in this box you need to click the *Re-calculate area properties* button. If you are happy with the selected area and its properties, then finish this step by clicking the *Create model clone* button. After finalizing this step your GUI may look something like Figure 15.

You can always go back to this tab of the GUI later on if you're unsatisfied with the result and want to re-select or fine-tune your area of interest.

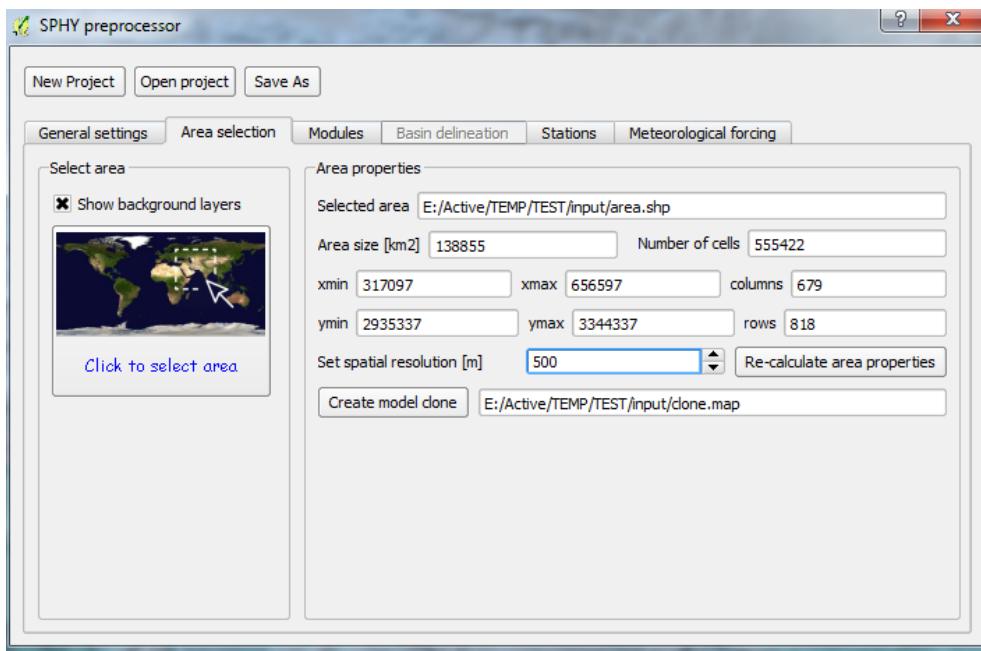


Figure 15: Finalizing the Area selection tab.



3.4 Modules

The next tab in the GUI is the *Modules* tab. In this tab you need to select the SPHY model modules for which you want to create input data. The input maps that are created are shown in the *Maps to process* log window. If no modules are selected, then the 12 maps as shown in Figure 16 will be created by default. After selecting one or more modules more maps that need to be processed are shown in log window (Figure 17)

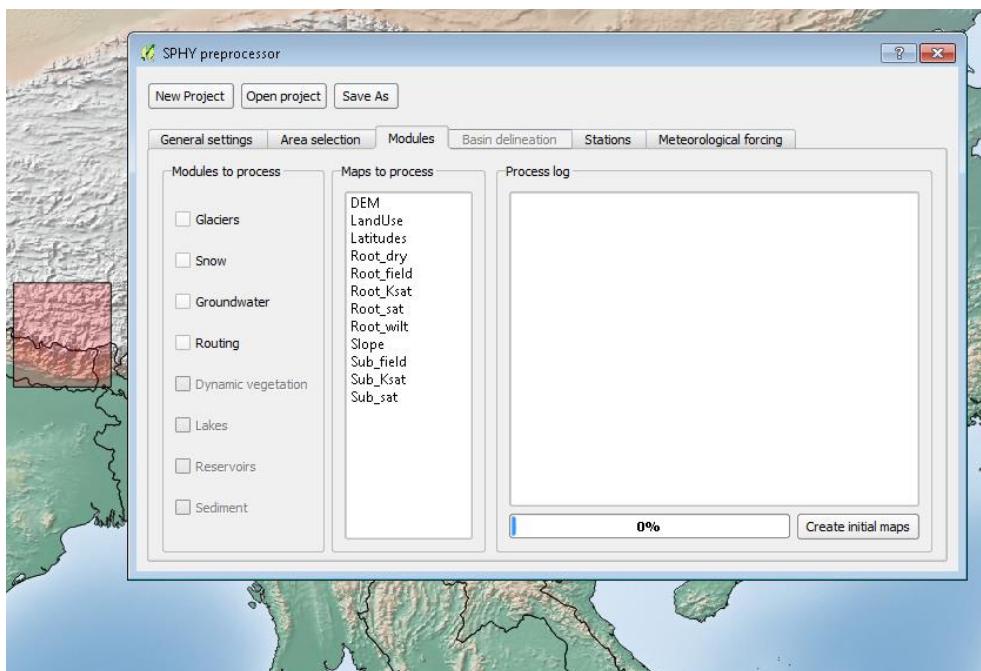


Figure 16: Overview of the Modules tab.

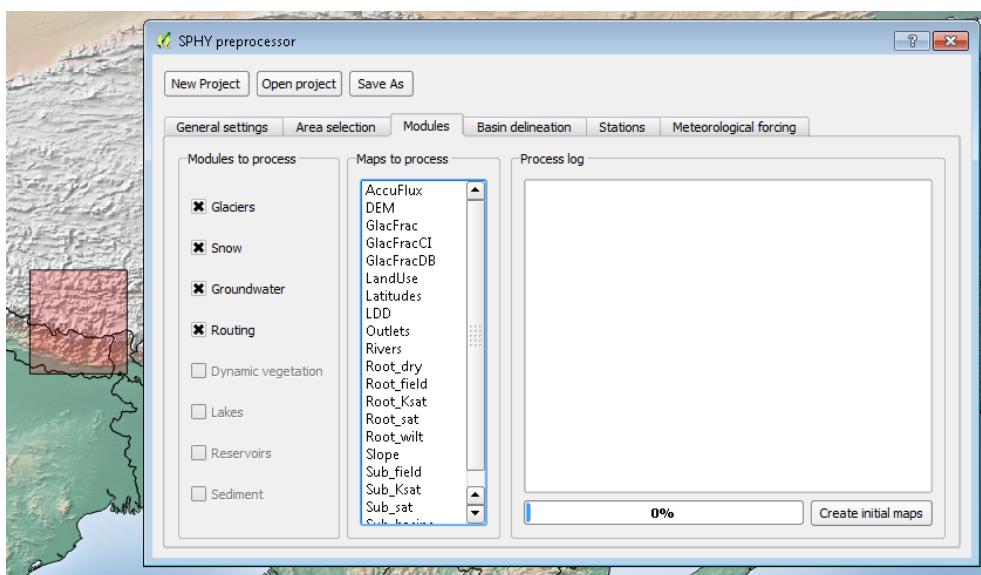


Figure 17: Selecting multiple modules from the Modules tab.

If you are finished selecting the required modules, then click the *Create initial maps* button to start processing these maps. This may take some time depending on the extent, spatial resolution, and number of modules that have been selected. During processing of the input maps, the *Process log* window of the *Modules* tab looks like Figure 18. After each map has



been processed it will be added to the QGIS canvas automatically. After processing has been completed the message “*Processing is finished*” will appear. You can change the colors/layout of each layer if you wish by clicking the right mouse button on the layer and then pressing *Properties*.

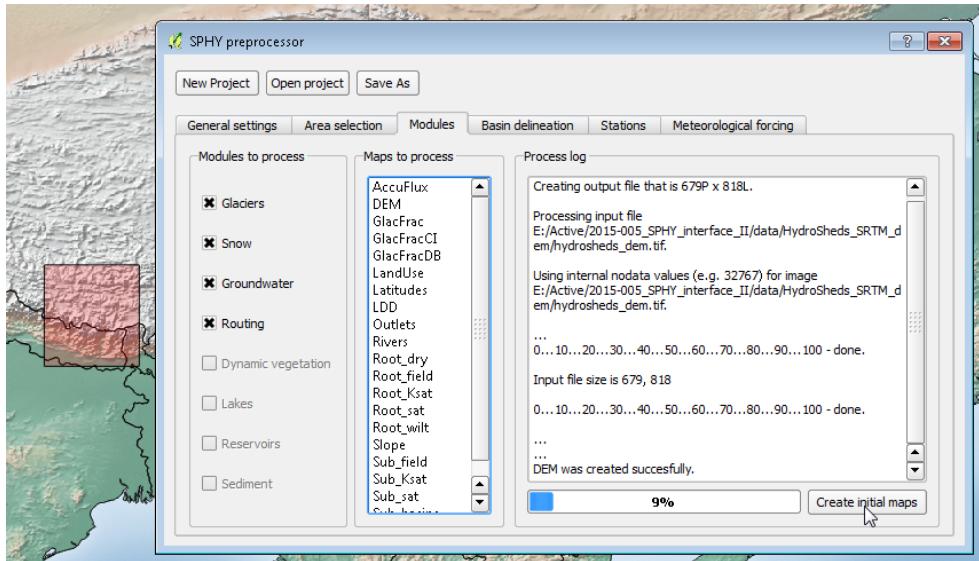


Figure 18: Processing the initial maps in the Modules tab.

If you are satisfied with the processed maps you can continue to the next tab. This next tab is *Basin delineation* (Section 3.5) if you have selected the *Routing* module. If this module has not been selected, then the *Basin delineation* tab is inactive and you can continue to the *Stations* tab (Section 3.6). If you do not need the SPHY model to report time-series output, then you also can skip the *Stations* tab and move on to the *Meteorological forcing* tab (Section 3.7).

3.5 Basin delineation

The next step involves delineating your river basin. Note that this step is only required if the routing module has been selected from the *Modules* tab. An overview of the *Basin delineation* tab is shown in Figure 19. Before you can delineate your basin, you need to have an **outlets.shp** shapefile, representing the outlet(s) of your basin(s). If you do not have this file, then you can create it using QGIS and following the steps below:

1. Create a new shapefile layer by clicking the *New Shapefile Layer* button (Figure 20).
2. Make sure you select *Point* as *Type* in the window that pops-up (Figure 21) and that you select the correct CRS (see Section 3.2.2).
3. Click *Ok*.
4. Give it the name **outlets.shp** and save it somewhere on your hard disk. It is recommended to save this file under the *Processed model data* folder you have set in Section 3.2.1. After saving this layer it will appear in the QGIS map canvas (Figure 22).
5. Now start editing this layer by clicking the *Toggle Editing* button (Figure 23). Make sure that the *outlets* layer is selected before clicking this button.
6. Now start adding the outlets by clicking the *Add Feature* button (Figure 24).
7. Make sure you can accurately determine the location of your river network. This can be done by looking at the *accuflux* layer and choosing an appropriate color layout. Now start adding one or more outlets to this layer by clicking on the desired locations of your river network (Figure 25). Each time you click a location you need to enter a value. Start with 1, and continue numbering until the number of outlets you desire.



- Figure 26 shows an example of having 3 outlets added to the **outlets.shp** layer. The attribute table can be shown by right clicking on this layer and then *Open Attribute Table*.
- If you are finished with adding outlets you can click again on the *Toggle Editing* button (Figure 23). Next click *Save* to save your edits to the **outlets.shp** layer. Now you are finished with creating an outlet(s) layer shapefile.

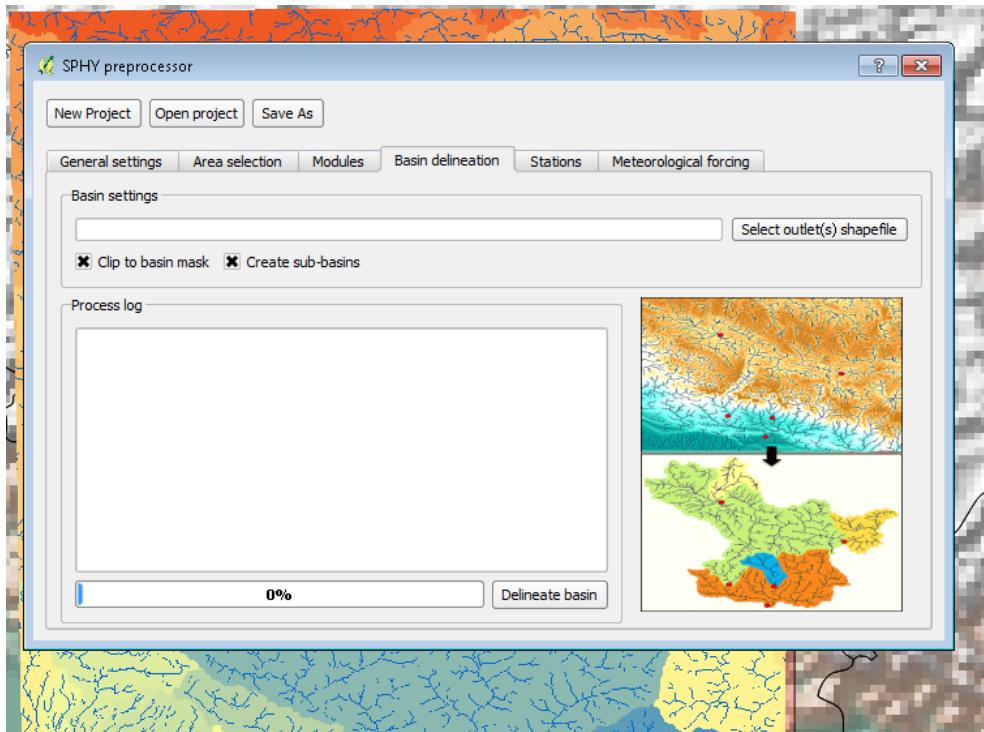


Figure 19: Overview of the Basin delineation tab.

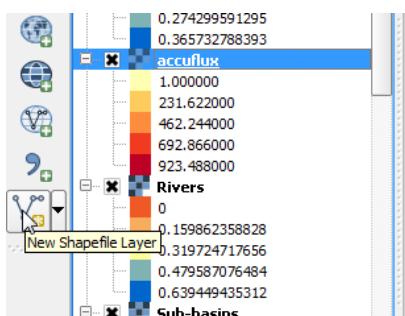


Figure 20: Creating a new shapefile layer.



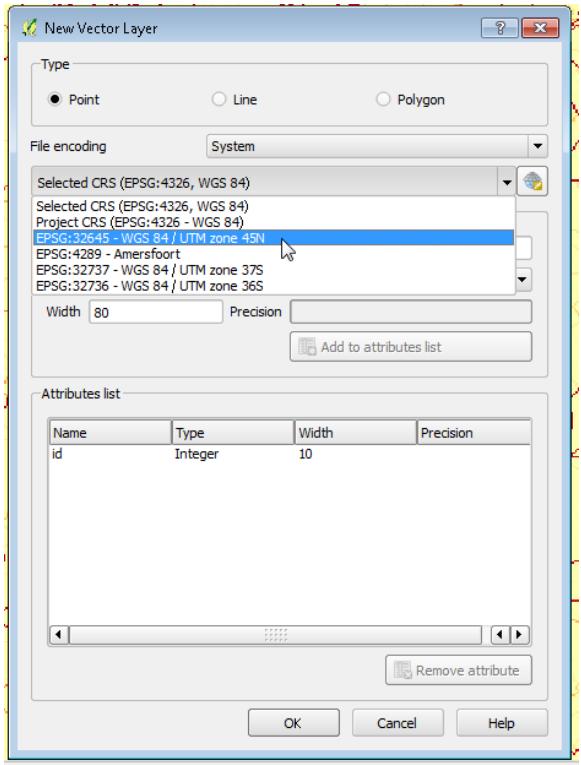


Figure 21: Setting the properties of the new Shapefile Layer.

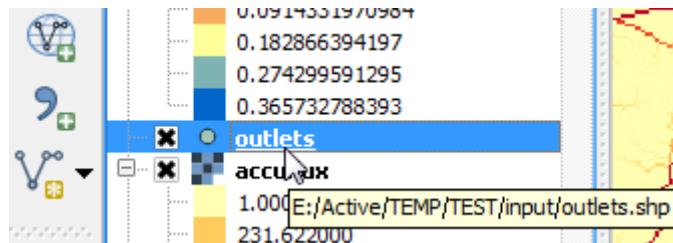


Figure 22: outlets.shp layer in the layers overview.

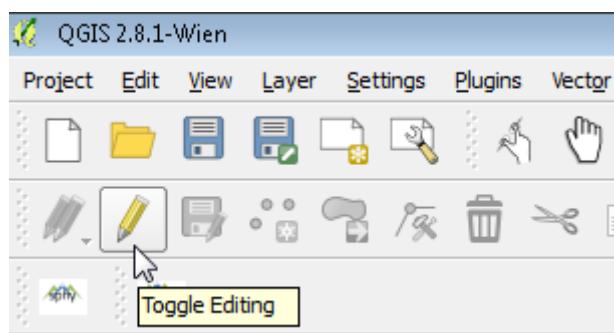


Figure 23: Editing a layer in QGIS.



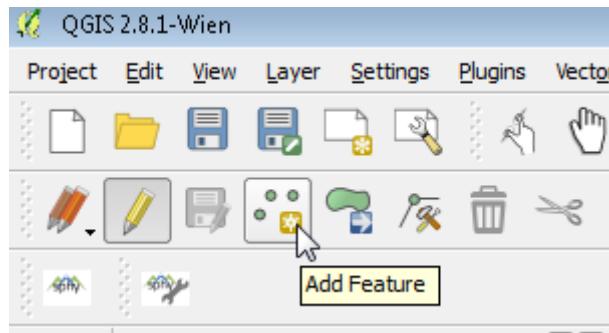


Figure 24: Adding features in QGIS.

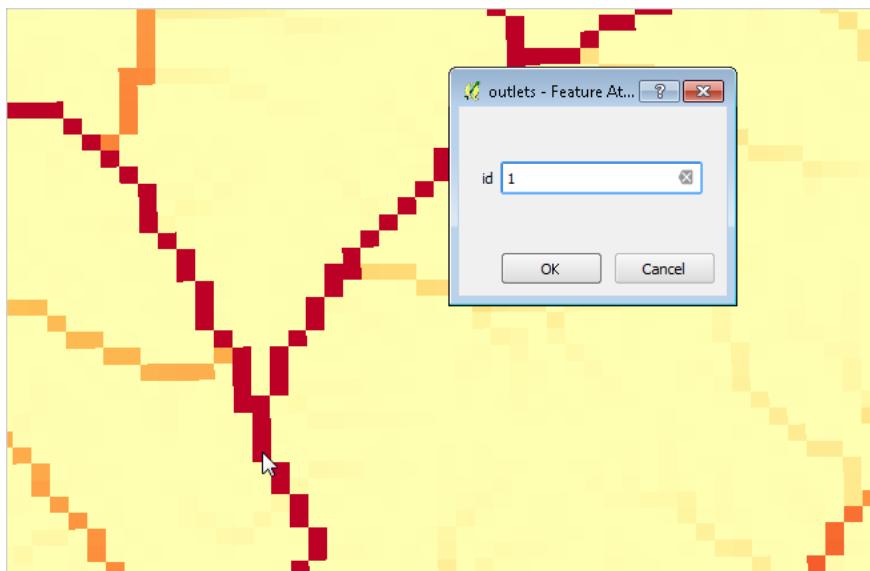


Figure 25: Adding outlets to the outlets.shp layer in QGIS.

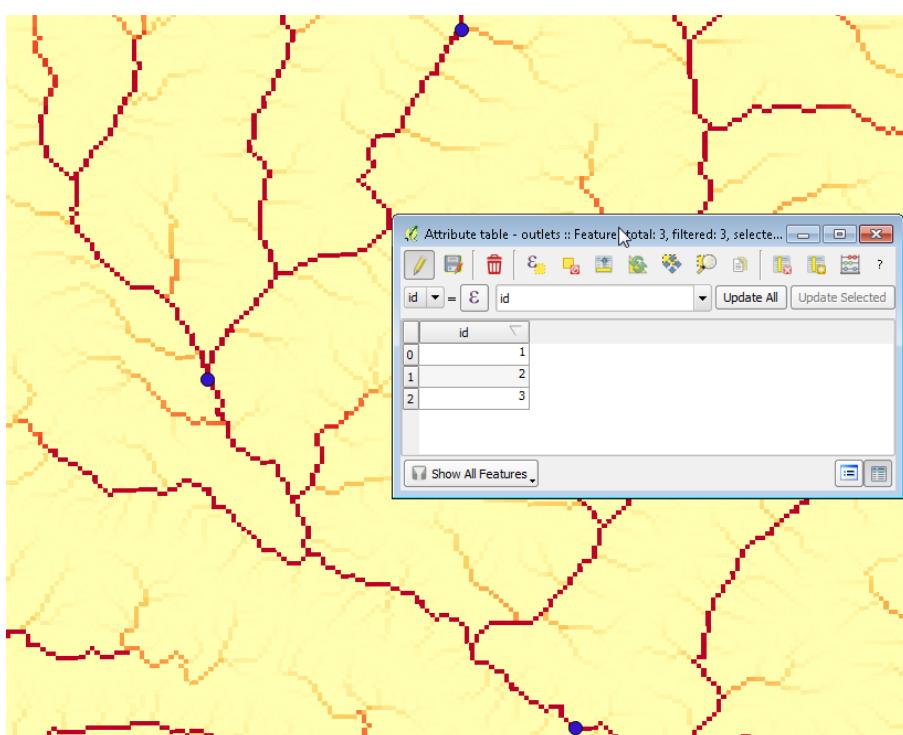


Figure 26: Example of 3 outlets that have been added to the outlets.shp layer.



Now select the **outlets.shp** file by clicking the *Select outlet(s) shapfile* button (Figure 19). Your GUI now may look like (Figure 27).

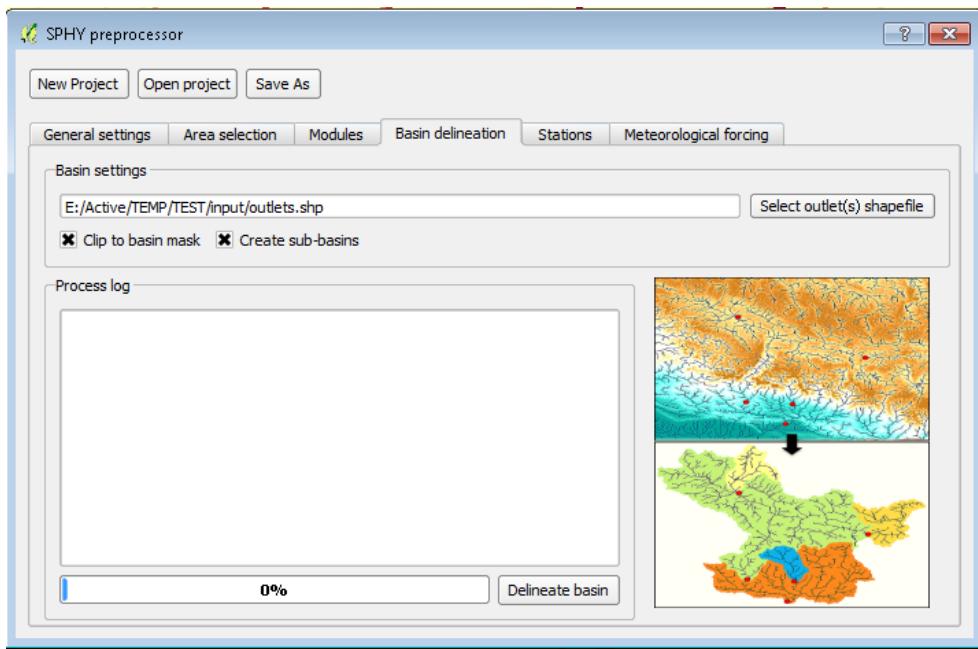


Figure 27: Overview of the Basin delineation tab with the outlet(s) shapefile selected.

There are now two additional options available for delineating your basin:

- Clip to basin mask: all SPHY model input maps will be clipped to the extent of your delineated basin. This result in smaller input map sizes and reduced model runtime.
- Create sub-basins: sub-basins will be created for outlets that are located inside the basin outline of your most downstream outlet.

Select or de-select these options, and click *Delineate basin* to start the basin delineation. Basin delineation may take a while, and during delineation several maps will be removed and added to the QGIS map canvas. After delineation has been completed the GUI may look something similar like Figure 28.

Note that the *Delineate basin* button has become inactive if you have selected the *Clip to basin mask* option. This means you only can redo basin delineation after going back to the *Modules* tab and click the *Create initial maps* button again. Or you may start over with the *Area selection* tab if you are not happy with the results of the delineated basin(s).



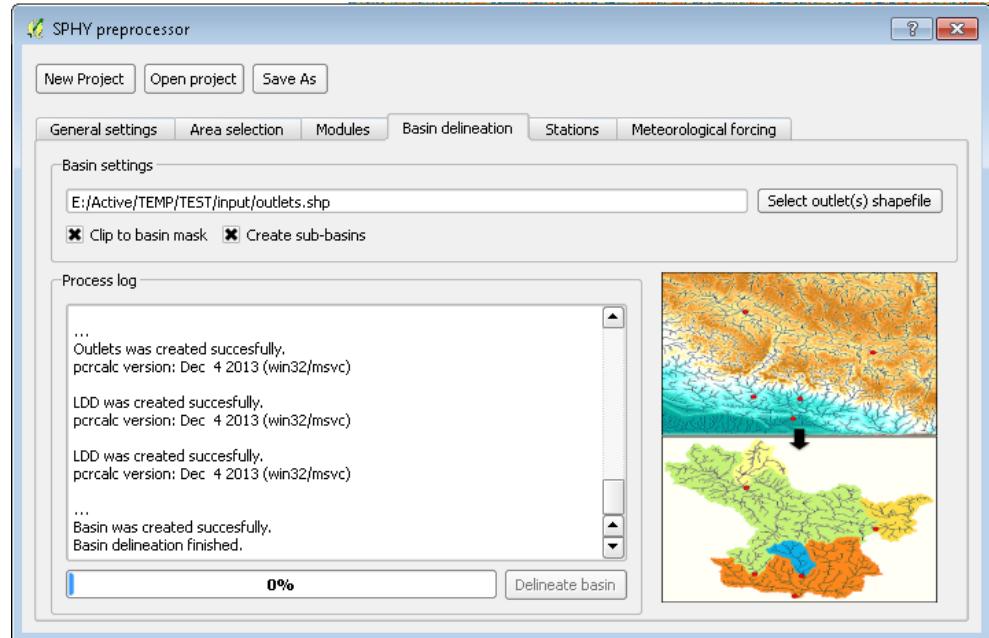


Figure 28: Basin delineation finished.

3.6 Stations

An overview of the **Stations** tab is shown in Figure 29. This tab creates a **stations.map** file that is used by the SPHY model to report time-series output. In order to create this file you need to have a **stations.shp** shapefile. If you do not have this file, then you need to create it by following the same steps as done for the **outlets.shp** file (step 1-9, Section 3.5) but now naming it **stations.shp** instead of **outlets.shp**. For the stations it is not mandatory to place them on the river network if you are interested in other fluxes besides river flow. If you like the same locations for your stations as are present in the outlets, then you can simply save the **outlets.shp** as **stations.shp**.

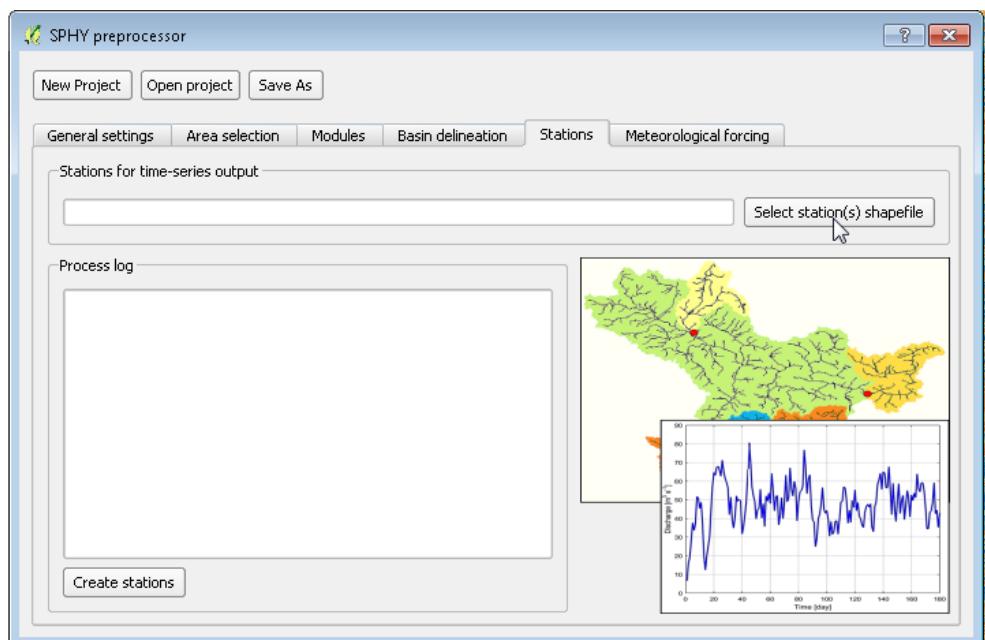


Figure 29: Overview of the Stations tab.



After creating the **stations.shp** shapefile you can click the *Select station(s) shapefile* button and select the **stations.shp** shapefile. Now the GUI may look something similar like Figure 30. Finally press the *Create stations* button to create the **stations.map** file. This process normally runs very quickly. Now move on to the *Meteorological forcing* tab.

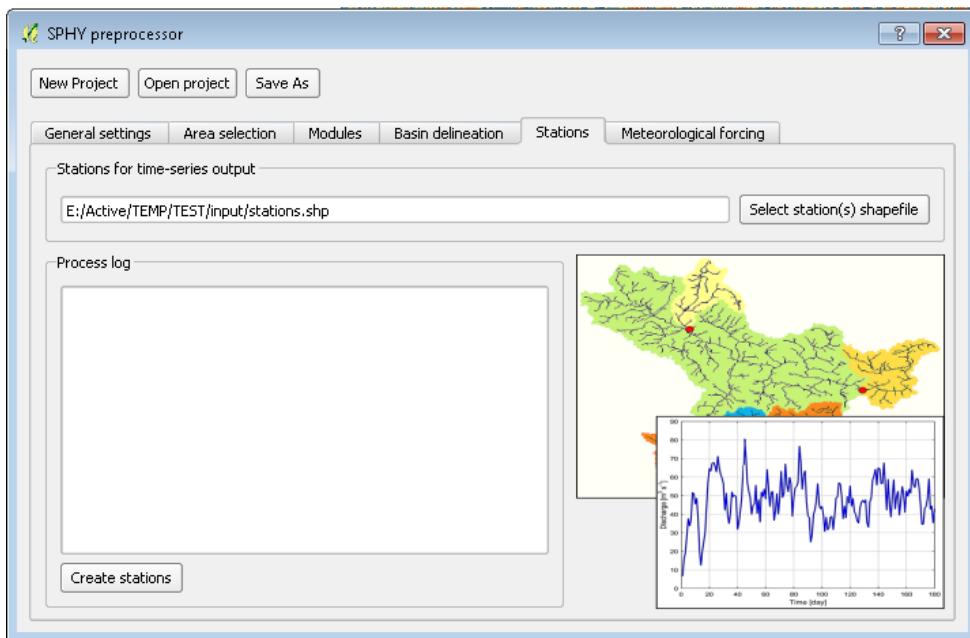


Figure 30: Overview of the Stations tab with the station(s) shapefile selected.

3.7 Meteorological forcing

Within this tab (Figure 31) you need to specify which meteorological forcing variables you want to create for the SPHY model:

- Precipitation
- Temperature (average, maximum, and minimum)

If you already have created your own forcing data manually, then you can skip this section. Otherwise start by selecting the variables that you need to process (precipitation and/or temperature). After this step you need to tell the GUI where to find the data for your forcing variable. This can either be database based, or based on user-defined station data. For more information regarding the source of the database forcing data we refer to the Appendices. Temperature data is calculated using a lapse rate of $-0.0065\text{ }^{\circ}\text{C}/\text{meter}$ elevation increase. Both precipitation and temperature data are interpolated using bilinear⁹ interpolation

The example of Figure 32 shows that both precipitation and temperature forcing will be created using the GUI, whereas precipitation data will be based on the database, and temperature data will be based on user-defined station data. If you select to use station data, then you need to select a station location csv-file, and a station data csv-file. It is important that the number of stations in the location file match the number of stations in the data file. The required csv file format is shown in Figure 33 through Figure 35. Make sure that the selected forcing period to process (Section 3.2.3) is covered by the database and/or user-defined station data. Finally click the *Create forcing* button to start creating the forcing data. This may take a while depending on the length of the period to process, and the extent and spatial resolution of your

⁹ https://en.wikipedia.org/wiki/Bilinear_interpolation



selected area. During processing the GUI may look something similar like Figure 36. After this step has been completed you are done with processing all SPHY model input data.

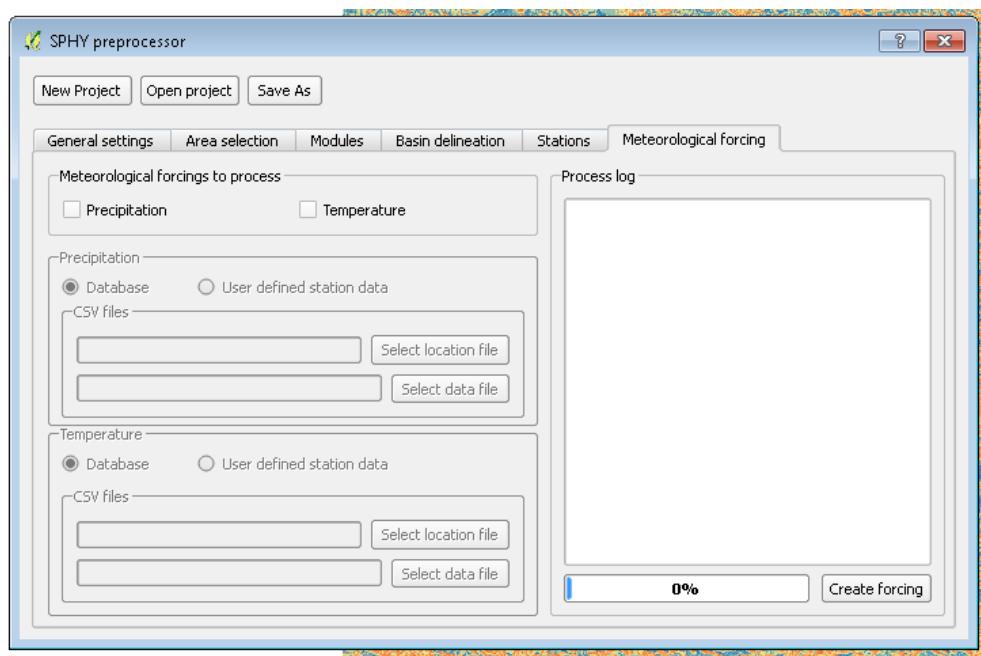


Figure 31: Overview of the Meteorological forcing tab.

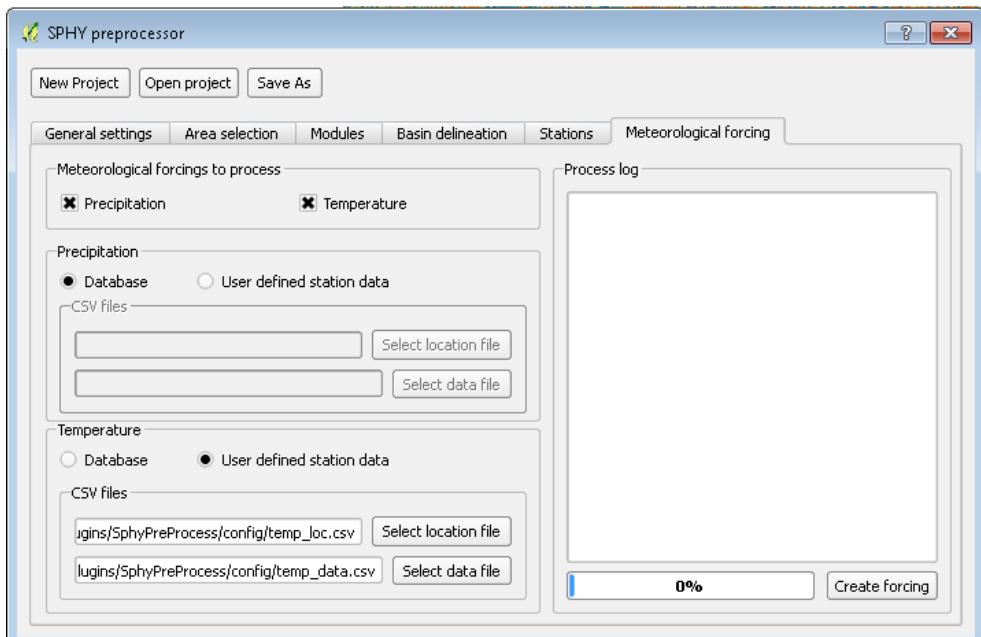


Figure 32: Setting the options in the Meteorological forcing tab, using precipitation data from the database and temperature data from user-defined stations.



	A	B	C	D	E	F
1	ID	Name	Lat	Lon	Elevation	
2	1	dummy	30.05	82.84	4455	
3	2	dummy	28.16	84.91	4200	
4	3	dummy	29.08	84.42	2000	
5	4	dummy	28.76	82.81	5000	
6	5	dummy	29.2	83.7	3000	

Figure 33: Format of location csv-file, containing 5 stations. Elevation units are in MSL. Coordinates need to be provided in latitude (lat) and longitude (lon). Names can be dummy values.

	A	B	C	D	E	F	G
1	DATE	1	2	3	4	5	
2	1-1-2001	3.705587	8.238709	0.083706	1.491564	4.100707	
3	2-1-2001	6.226049	9.936424	9.843851	5.403994	9.781127	
4	3-1-2001	7.443758	2.375468	0.037047	3.484891	9.984137	
5	4-1-2001	5.354188	1.177539	4.462445	3.151409	9.384312	
6	5-1-2001	5.286025	2.827377	7.729253	2.454813	3.210216	
7	6-1-2001	6.601565	6.876879	7.381467	7.911656	9.889859	
8	7-1-2001	6.210354	3.882653	1.280547	5.159928	1.423997	
9	8-1-2001	2.758112	7.243028	9.836882	0.265866	4.557234	

Figure 34: Format of precipitation data csv-file, containing data for 5 stations. Precipitation units are in mm.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	DATE	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	
2	1-1-2001	3.705587	8.238709	0.083706	1.491564	4.100707	5.705587	10.23871	2.083706	3.491564	6.100707	2.705587	7.238709	-0.91629	0.491564	3.100707	
3	2-1-2001	6.226049	9.936424	9.843851	5.403994	9.781127	8.226049	11.93642	11.984385	7.403994	11.78113	5.226049	8.936424	8.843851	4.403994	8.781127	
4	3-1-2001	7.443758	2.375468	0.037047	3.484891	9.984137	9.443758	4.375468	2.037047	5.484891	11.98414	6.443758	1.375468	-0.96295	2.484891	8.584137	
5	4-1-2001	5.354188	1.177539	4.462445	3.151409	9.384312	7.954188	9.177539	6.462445	5.151409	11.98431	4.354188	0.177539	3.462445	2.151409	8.384312	
6	5-1-2001	5.286025	2.827377	7.729253	2.454813	3.210216	7.286025	4.827377	9.729253	4.454813	5.210216	4.286025	1.827377	6.729253	1.454813	2.210216	

Figure 35: Format of temperature data csv-file, containing data for 5 stations. The order is from left to right: average, maximum, minimum temperature. Units of temperature are degrees Celsius.

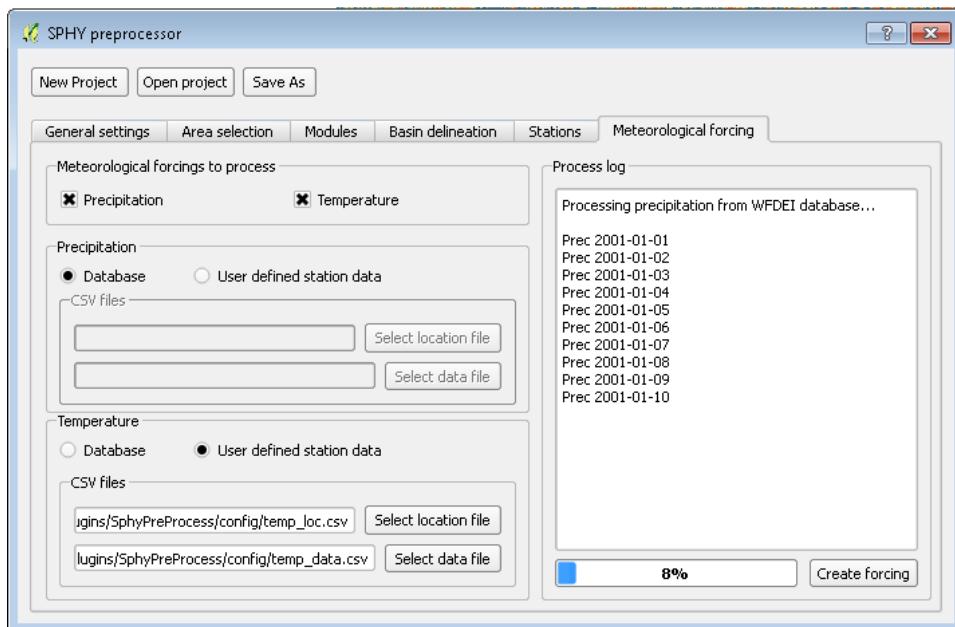


Figure 36: Processing of meteorological forcing data.



4 SPHY model plugin v1.0

4.1 Overview

4.1.1 *Introduction to the GUI*

The SPHY model plugin has been developed with the goal to make the use of the SPHY model more user-friendly, and thus more applicable to a larger user-group world-wide. Using the SPHY model plugin has several advantages above the use of SPHY as stand-alone application:

- Easy creation of new projects, and opening/modifying existing projects.
- Quick overview of all your SPHY model settings.
- Easy to select model input and output, and to modify model parameters.
- Default parameter values and parameter ranges prevent the use of physically wrong parameters values.
- Model output reporting options can be easily managed.
- The model can be executed inside the GUI, meaning that command line execution is history. A progress bar shows model execution progress.
- Visualization of the model in- and output can be done inside QGIS. This provides the user with a clear overview of the maps that are used as model input. Model output can be added as spatial map, or can be analyzed using time-series plots.
- The GUI uses the registry, meaning that your last project (settings) will be saved and loaded upon the next time you continue to work with your model (project).

The SPHY model interface consists of a top menu with four buttons and a tab widget that contains 11 tabs (Figure 37). The use of the top menu buttons will be explained in detail in Section 4.3. When working on a SPHY model project, the user has to go through the individual tabs and complete the required information, which can be related to model input maps, parameter values, reporting options, running the model, and visualizing results. The user has to complete these tabs in the order they appear: from left to right. The last steps always are running the model and thereafter visualizing the model results. The use of each of these tabs is described in detail in the Sections 4.4 through 4.14. The effect of changing parameter settings is only briefly described in Sections 4.4 through 4.14. For a detailed description of parameters and theory, we refer to the SPHY manual (Terink et al., 2015a). A detailed overview of the model input and output can be found in Appendix 1.

If it is the first time you use the SPHY model GUI, then please first read Section 4.1.2 before continuing with the other sections.



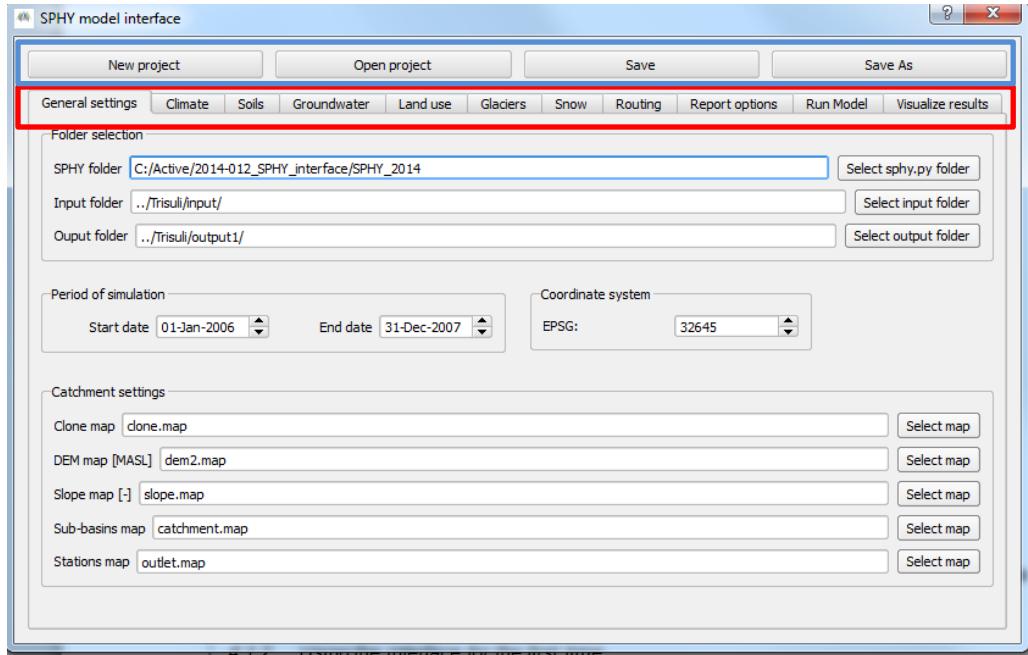


Figure 37: Overview of the SPHY model plugin top menu (buttons in blue box) and a tab widget, consisting of 11 tabs (red box).

4.1.2 Using the model GUI for the first time

The SPHY model GUI is always **started** by clicking the SPHY model interface button (Figure 7). Since it is the first time you use the interface, the registry settings will be empty. This means no previous SPHY projects can be found by the interface. If this is the case, then the interface looks like Figure 38. The only options available are:

- New project
- Open project

The New project button logically asks the user to save a new SPHY model project, whereas the Open project button asks the user to open an existing SPHY model project. After one of these options has been selected, the tabs will be activated such that the user can go through these tabs to complete model setup.



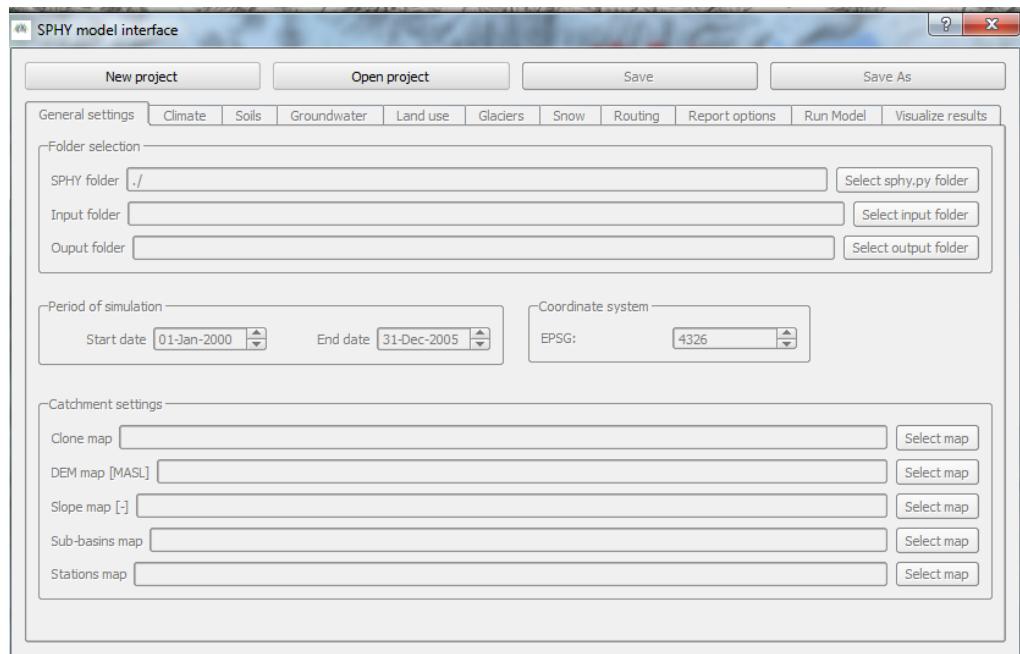


Figure 38: SPHY model GUI for first-time use.

4.1.3 *Editing the SPHY model configuration file outside the GUI*

The current version of the SPHY model GUI (version 1.0) is the first version that has been developed. It therefore does not include all SPHY model settings that are included in SPHY v2.0. This version of the SPHY model GUI has especially been developed to be applicable in glaciated river basins. However, the user is still able to change model settings that cannot be done throughout the GUI. This can be done by editing the SPHY model configuration file (*.cfg) that is created when creating a New project (see Section 4.3.1).

4.2 Map canvas layers and GUI interaction

4.2.1 *Interaction with the map canvas*

During model setup in the GUI, the QGIS map canvas will be extended with more and more layers that are added by setting model input maps and evaluating model output maps. The user can modify layer legends to its own preferences, because this does not have an effect on the model results. You are also free to add additional layers or remove layers from the QGIS map canvas. Both actions will not affect model results; because the maps that are used in the model are always shown in the text lines in the GUI (see for example the catchment settings in Figure 43). If you select a model input map in the GUI, this map will automatically be added to the QGIS map canvas. If this layer name already existed in the map canvas, then it will be overwritten with the new selected layer.

4.2.2 *Map canvas layout*

The map canvas is built using several layer groups. At the beginning of each new project the map canvas is empty. The layer groups are built after model map layers have been selected and added to the canvas. The layer group layout is shown below:

- Input
 - General
 - Climate
 - Soils



- Land-use
- Glaciers
- Snow
- Routing
- Output
 - Annual
 - Monthly
 - Daily

An example of this layer group (with layers) layout is shown in Figure 39. The Input layer groups correspond with the GUI tab widgets that need to be completed by the user during Section 4.4 through Section 4.14. The Output layer groups are built during the last step of the GUI: Visualize results.

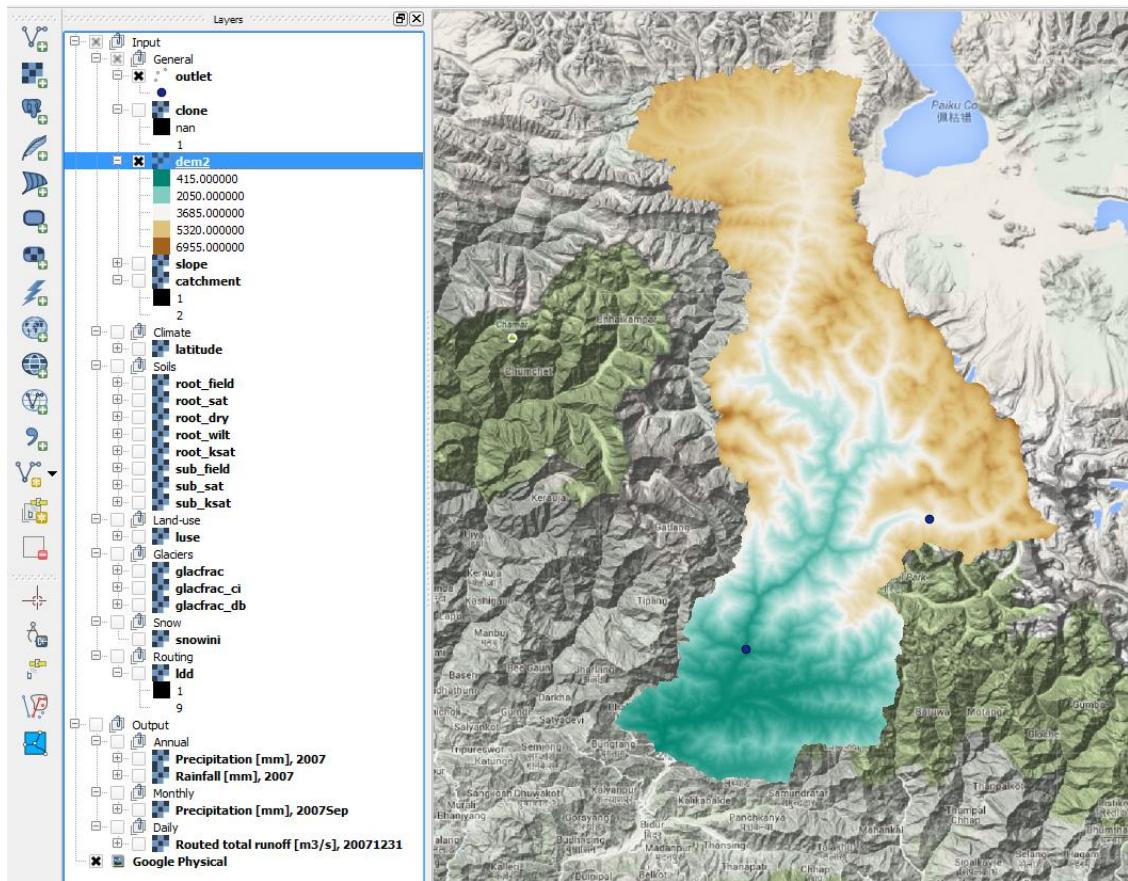


Figure 39: Example of map canvas groups and layers layout.

4.2.3 Setting a background layer

As can be seen from Figure 39, a Google Physical background has been added to the canvas. Background layers in QGIS, such as the Google Physical background layer, are available as plugins. The Google Physical background layer, together with layers as OpenStreetMap, Bing maps and other Google maps, are part of the OpenLayers plugin. This plugin can be installed and activated in a similar way as the SPHY model plugin was activated (see Figure 2, Figure 6, and Section 2.3). You can search for this plugin by typing google in the search window (Figure 40). Then select the OpenLayersPlugin and click Install plugin and after installation click Close. You are now able to set any background map from the OpenLayersPlugin you like (Figure 41).



It should be noted that setting and viewing a background layer requires an internet connection. Because of the continuous connection with internet, the use of background layers may slow down processes such as panning and zooming inside QGIS.

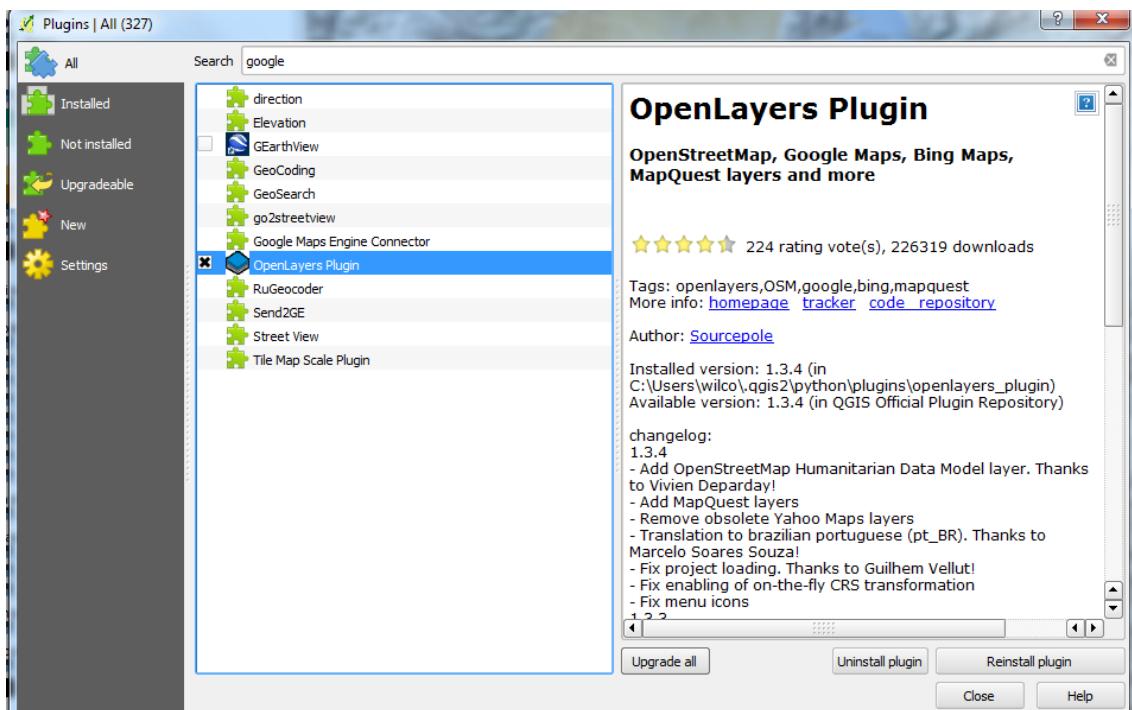


Figure 40: Activating the OpenLayers Plugin in QGIS.

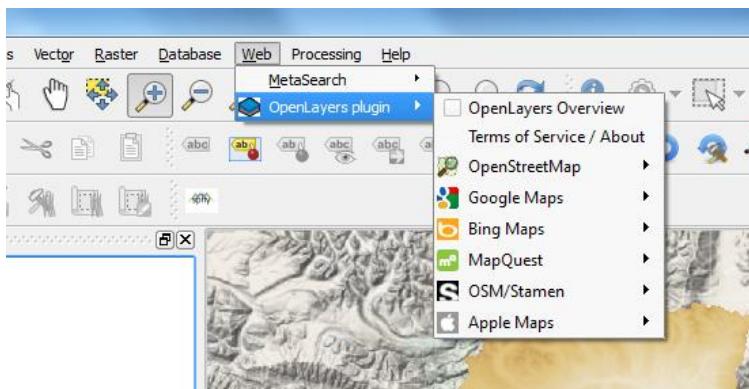


Figure 41: OpenLayers plugin in the QGIS menu.

4.3 Top menu buttons

4.3.1 New project

A SPHY model project always involves two files, being the SPHY model configuration file (*.cfg) and the SPHY model project file (*.qgs). The *.cfg file contains the SPHY model configuration, and is the same file that is used when running SPHY as a standalone application. The *.qgs is a QGIS project file, and contains the layers and map canvas view settings.

If the New project button is clicked, then the user is asked where to save the new project and to provide a filename (XXXX.cfg) for the project. You can choose any filename, except "sphy_config.cfg". If a current SPHY model project was open in QGIS, then it will be asked to save the current project first before creating a new project. It is mandatory to save the new



project to the same disk where the SPHY model source code has been installed. Otherwise an error will occur.

After creating a new project, the map canvas will be emptied and the GUI looks like Figure 42. The user may now continue completing the different tabs.

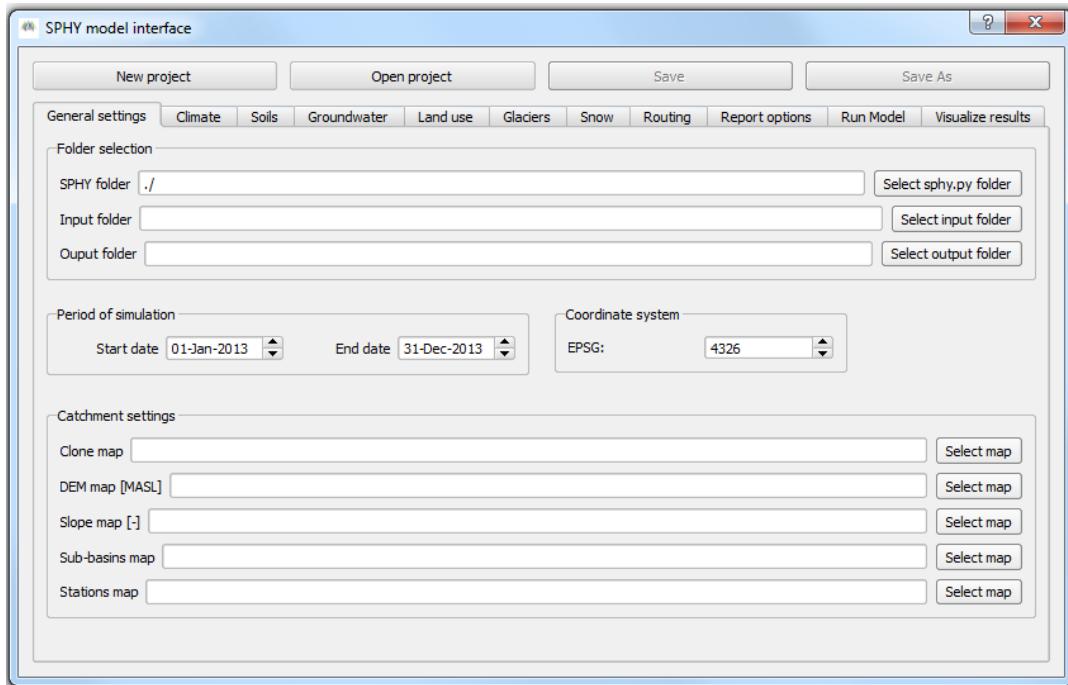


Figure 42: SPHY model interface after creating a new project.

4.3.2 Open project

Opening an existing project allows you to continue with a previous SPHY model interface project. By clicking the Open project button you will be asked to select a *.cfg project file to be opened. If a current SPHY model project was open in QGIS, then it will be asked to save the current project first before opening another project. Opening an existing project results in the QGIS canvas to be cleared, and the layers present in the *.qgs file to be added to the canvas. All model settings present in the *.cfg file will be added to the SPHY model GUI. Your SPHY model interface could now look something comparable to Figure 43.



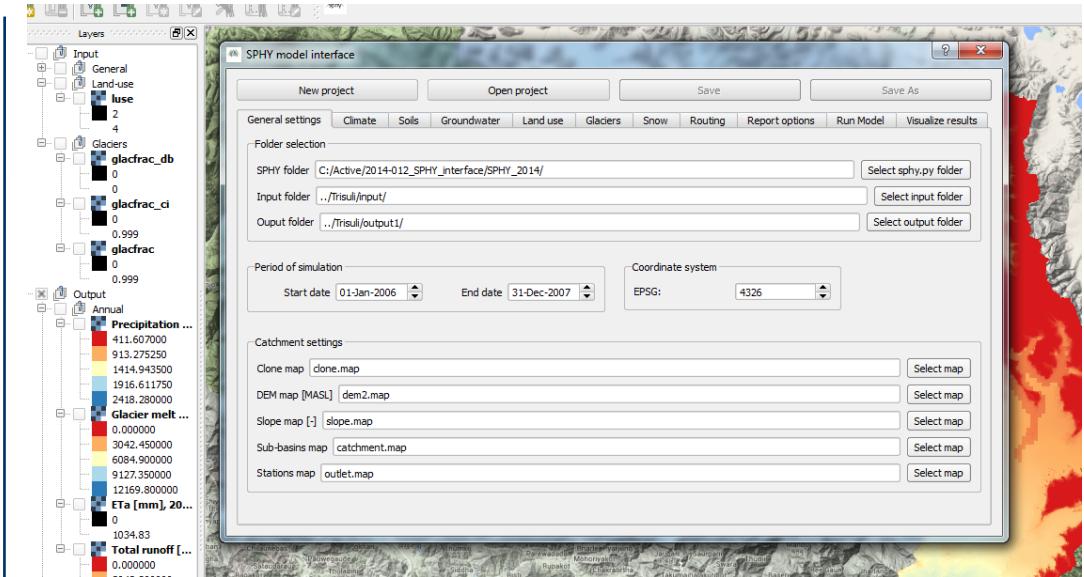


Figure 43: Example of SPHY model interface after opening an existing project.

4.3.3 Save and Save As

The GUI allows you to save your SPHY model project. After clicking the Save or Save As buttons, these buttons will become unavailable (see Figure 43) until you change something (e.g. a parameter setting) in the GUI. This means these buttons are also an indicator of recent changes to the interface. As soon as you change/modify something in the GUI, these buttons will become available again. It should be noted that running the model automatically results in saving your SPHY model project before the model is executed. This accounts for all GUI model settings to be saved in the *.cfg file and to run the model with these GUI settings.

The Save and Save As buttons save the GUI settings to the *.cfg file and the map canvas layers and view settings to the *.qgs file. The Save As button allows you to save the SPHY model project under another filename. This may be useful if you need to study for example the effect of a parameter change without losing your previous model run settings and output.

4.4 General settings

4.4.1 Folder selection

Figure 44 shows an overview of the General settings tab. As soon as you start a new project, the folder selection settings should be completed first. If this is not set correctly, then errors will show up. First of all, the GUI needs to know where your SPHY model source code is located. By clicking the Select sphy.py folder you are asked to select the folder in which the sphy.py file can be found. If you select a folder in which no sphy.py file can be found, then you will receive a notification as is shown in Figure 45. As was mentioned in Section 4.3.1, it is mandatory to have the SPHY model source code on the same disk as your SPHY model interface project.

The next step is to set your SPHY model input and output folders. The in- and output folders should be on the same disk as your SPHY model source code because these folders are used as relative paths in the model. All the model input data (maps, tables, etc.) that is used throughout setting up your model in the GUI should be located inside the Input folder.

The output folder is the location where all the model output will be saved during execution of the model. The model output data in this folder will be parsed to the Visualize results tab, which



allows you to select certain output to be added to the map canvas. This is described in detail in Section 4.14.

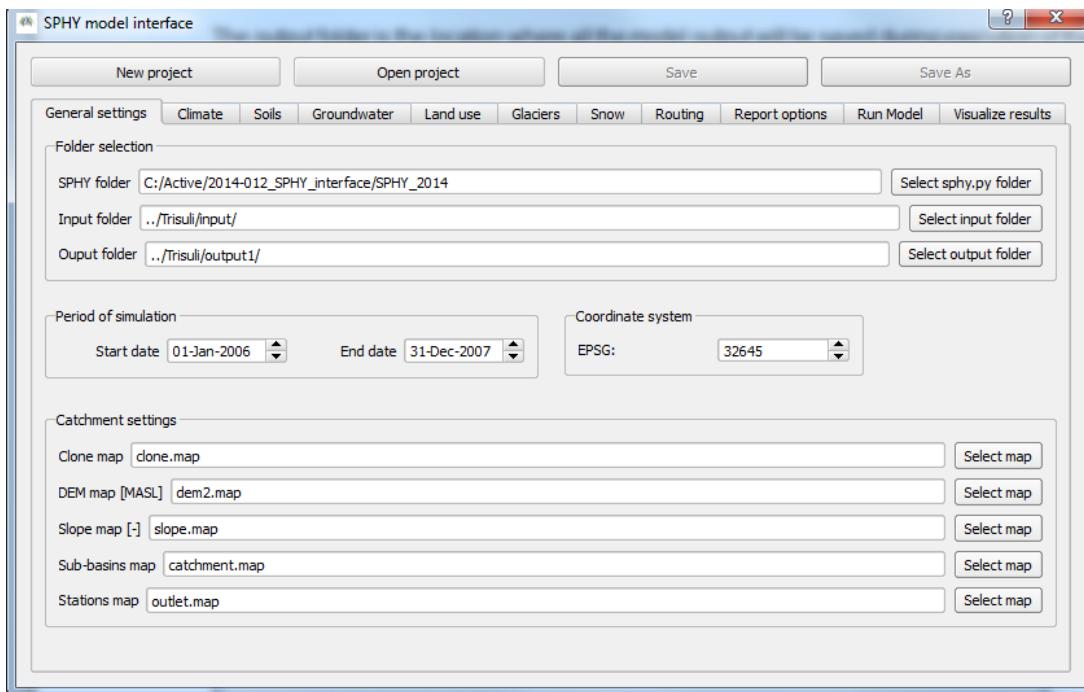


Figure 44: Overview of the General settings tab.



Figure 45: Error message indicating that no sphy.py can be found in the selected folder.

4.4.2 Period of simulation

The period of simulation allows you to change the start and end date of your simulation. It should be noted that the start date always has to correspond with the first climate forcing file (*.001). Setting the end date is an interesting option if the user only wants to model/study for example the first year out of a period of 20 years of data. This may be used to check if all the model input is correctly set before executing the entire period of 20 years, which can take a long time.

4.4.3 Coordinate system

In order to present the model input and output map correctly in the QGIS map canvas, you need to specify the coordinate system of your area of interest. The coordinate system has to be specified in EPSG. You can search for the corresponding EPSG number on this website: <http://spatialreference.org/ref/epsg/>

The default coordinate system used in the SPHY model GUI is WGS 84. This corresponds with EPSG:4326. It is important to specify the coordinate system at the beginning of your SPHY model project, and keep this coordinate system throughout the SPHY model project. If you change the coordinate system halfway your project, then maps will not align in QGIS.



4.4.4 Catchment settings

The catchment settings basically define the shape and orography of your river basin. The user has to select five spatial maps that define the basin of interest. Table 1 provides an overview of these maps. Each of these 5 maps can be selected and added to the map canvas by clicking the Select map button. After clicking this button you will be referred to the Input folder that has been set under Section 4.4.1. Within this folder you are asked to select the map of interest and to click on Open to add the map to the GUI and the QGIS map canvas. This is illustrated in Figure 46 for the DEM map.

After these 5 maps have been set, the user can continue with the next tap: Climate.

Table 1: Catchment settings maps.

Map name	Description
Clone map	Mask of catchment. Defines the basin for cells being True.
DEM map [MASL]	Digital Elevation Model. Defines for each cell the elevation in Meters Above Sea Level [MASL].
Slope map [-]	Defines for each cell the slope [-], based on the DEM.
Sub-basins map	Map with cells belonging to the same sub-basin having the same unique ID. Used for calculation of sub-basin fluxes in mm.
Stations map	Nominal map with unique IDs for cells identified as being a location where time-series output is required. Non-station cells have zero value.



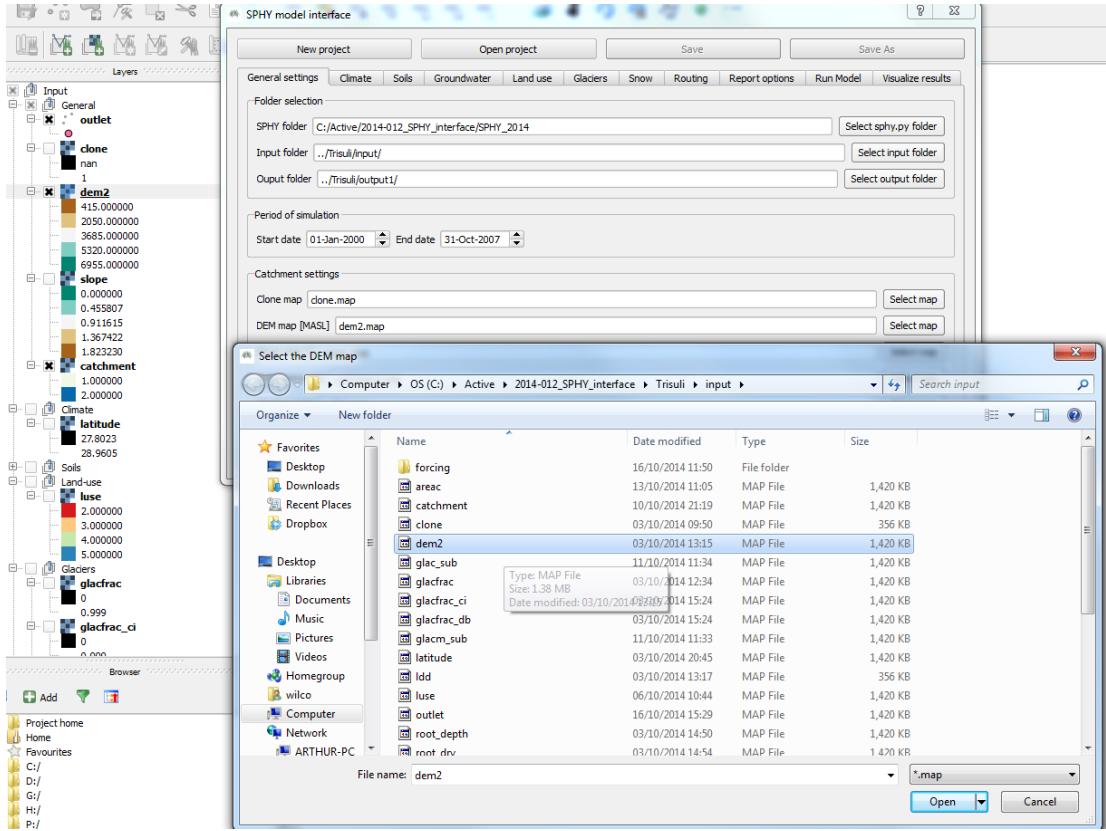


Figure 46: Selecting a DEM map in the catchment settings.

4.5 Climate

4.5.1 Meteorological forcing map-series

Figure 47 provides an overview of the Climate tab. In this tab the user has to specify the model forcing input map-series, containing precipitation, and the average, maximum and minimum daily temperature.

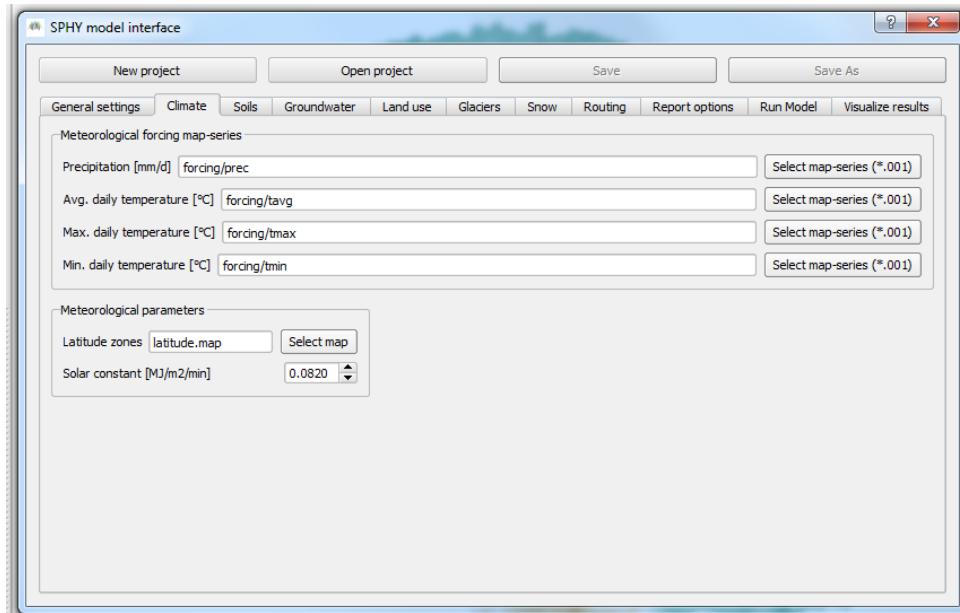


Figure 47: Overview of the Climate tab.



A map-series in SPHY consists of a spatial map for each time-step in the model. This means that if your model has 365 daily time-steps, then you also need 365 maps of climate forcing for each of the four forcing variables.

A map-series in PCRaster always starts with the *.001 extension, corresponding with the start date of your model simulation period. The format of each individual forcing file should have eight characters before the dot, and 3 characters after the dot. If your model has for example 3542 time-steps, then your first precipitation forcing file could look like:

prec0000.001

and your last precipitation forcing file:

prec0003.542

After clicking the Select map-series (*.001) button for each of the four climate variables, the user will be asked to select the first map of the meteorological forcing map-series. An example of this is shown in Figure 48. It can be seen that the meteorological forcing is inside another folder (“forcing”) within the Input folder. This can be done without any issues as long as the folder is created inside the Input folder, meaning that the Input folder will always be the *parent* folder of all model input data. Figure 47 shows that the “forcing” folder will just be added before the variable name.

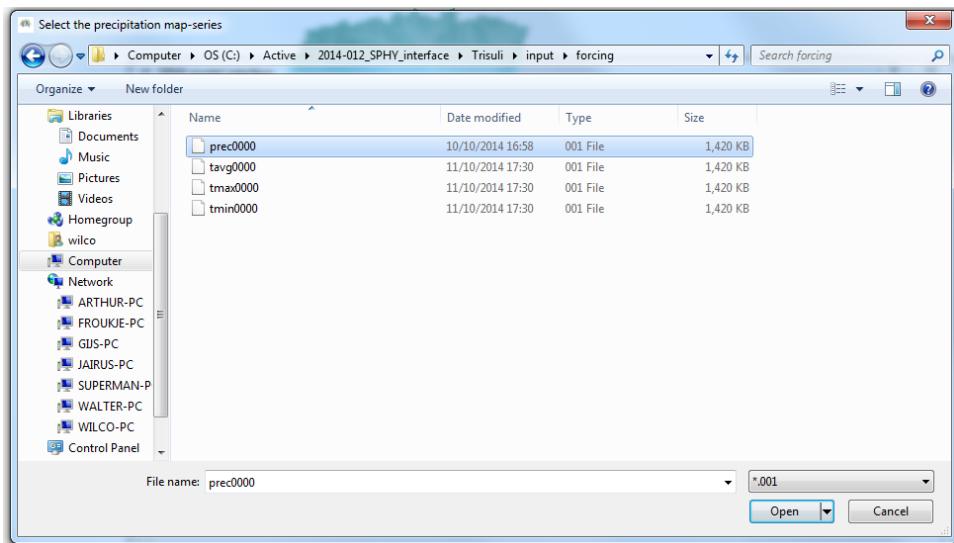


Figure 48: Selecting the precipitation map-series.

4.5.2 Meteorological parameters

The second part of the Climate tab involves setting the parameters for calculating the terrestrial radiation, which is eventually used in the Hargreaves method to calculate the reference evapotranspiration. To calculate the terrestrial radiation the user needs to select a map with latitude zones. This map can be select by clicking the Select map button. After selecting the latitude zones map, this map will be added as a layer to the map canvas.



Additionally, the user needs to provide a single floating number for the solar constant. The default value of $0.0820 \text{ MJ m}^{-2} \text{ min}^{-1}$ is generally applicable for most areas world-wide, but may be changed if needed.

After completion of the Climate tab, the user can continue with the Soils tab.

4.6 Soils

4.6.1 Rootzone physical maps

An overview of the Soils tab is shown in Figure 49. The rootzone physical maps refer to the physical soil properties of the first soil layer, where the subzone physical maps refer to the second soil layer's physical properties. The settings in this tab significantly affect soil water processes in the root- and subzone, such as e.g. lateral flow, surface runoff, percolation, and evapotranspiration. Details regarding these processes can be found in the Terink et al. (2015a). The user needs to select the following five rootzone physical maps:

- Field capacity [mm/mm]
- Saturated content [mm/mm]
- Permanent wilting point [mm/mm]
- Wilting point [mm/mm]
- Saturated hydraulic conductivity [mm/d]

These maps can be selected and added to the map canvas by clicking the Select map buttons. It is important to check that the cell values should increase from permanent wilting point to wilting point to field capacity, and with saturated content having the highest cell values.

Figure 50 shows an example of a field capacity map for the rootzone, showing more details in the upstream part than the downstream part.

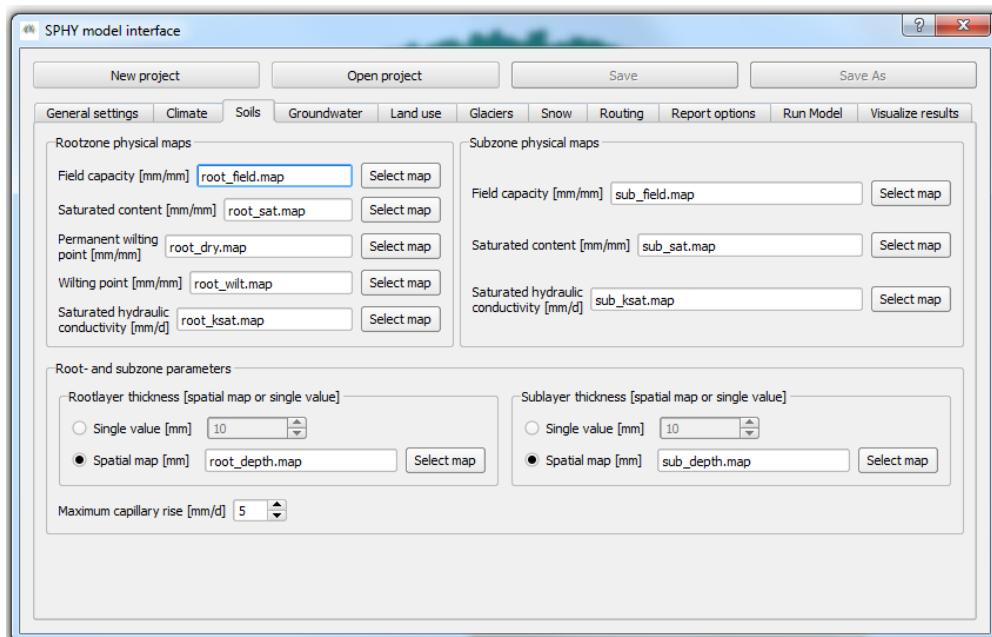


Figure 49: Overview of the Soils tab.



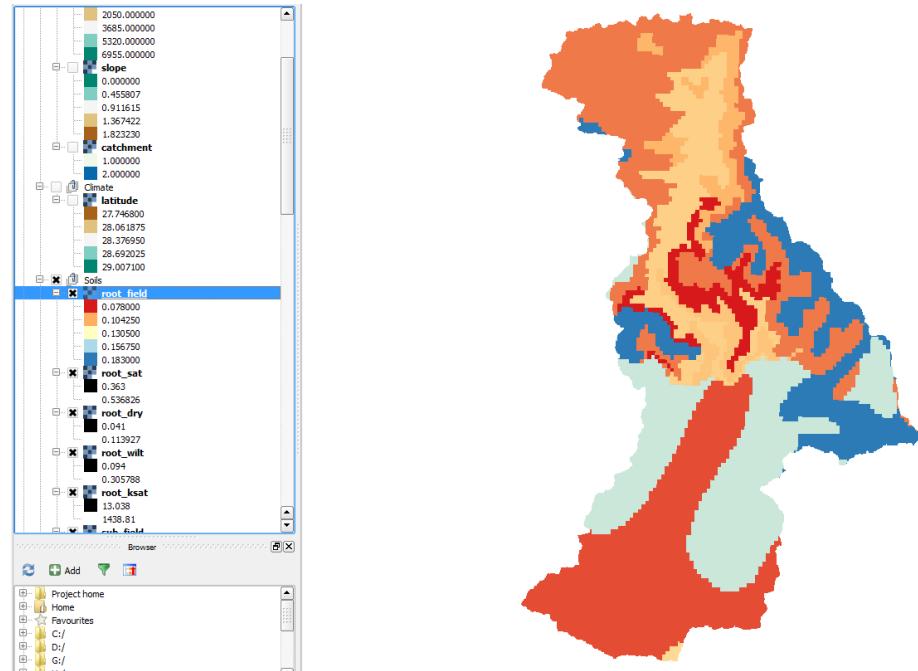


Figure 50: Example of rootzone field capacity map.

4.6.2 Subzone physical maps

For the subzone physical maps the user has to select the following three maps:

- Field capacity [mm/mm]
- Saturated content [mm/mm]
- Saturated hydraulic conductivity [mm/d]

These maps can be selected and added to the map canvas by clicking the Select map buttons. For the subzone physical maps it is important to check that the cell values of the saturated content map are higher than for the field capacity map.

4.6.3 Root- and subzone parameters

The last section of the Soils tab involves setting the soil layer thickness for both the root- (left part) and subzone (right part). The user can opt to provide a homogeneous rootzone and/or subzone soil depth for the entire basin, or to provide a spatial map with a spatially distributed soil depth over the entire basin. In Figure 49 we chose to select a spatially distributed soil depth map for both the root- and subzone. These maps can be selected and added to the canvas by clicking the Select map button.

If you prefer to have a homogeneous soil depth for the entire basin, then a default value of 500 mm for the rootzone, and 1500 mm for the subzone are good values to start with.

The final setting in the Soils tab involves setting a value for the maximum capillary rise. This value affects the maximum amount of water that can travel from the subzone to the rootzone on a daily basis due to evapotranspiration demand.

After completing all settings in the Soils tab the user can continue with the next tab: Groundwater.



4.7 Groundwater

4.7.1 Groundwater volume settings

The settings in the groundwater tab substantially affect groundwater recharge and baseflow. An overview of the groundwater tab is shown in Figure 51. The left part contains the volume settings and the right part involves setting three parameters.

In the groundwater volume settings the user can opt to provide a single value or a spatial map for each setting. If a single value is chosen, then this value is taken as homogeneous for the entire catchment. Using a spatial map can be useful to differentiate between different groundwater volume settings spatially in your basin.

The following three groundwater volume settings have to be provided:

- Groundwater layer thickness [mm]
- Saturated groundwater content [mm]
- Initial groundwater storage [mm]

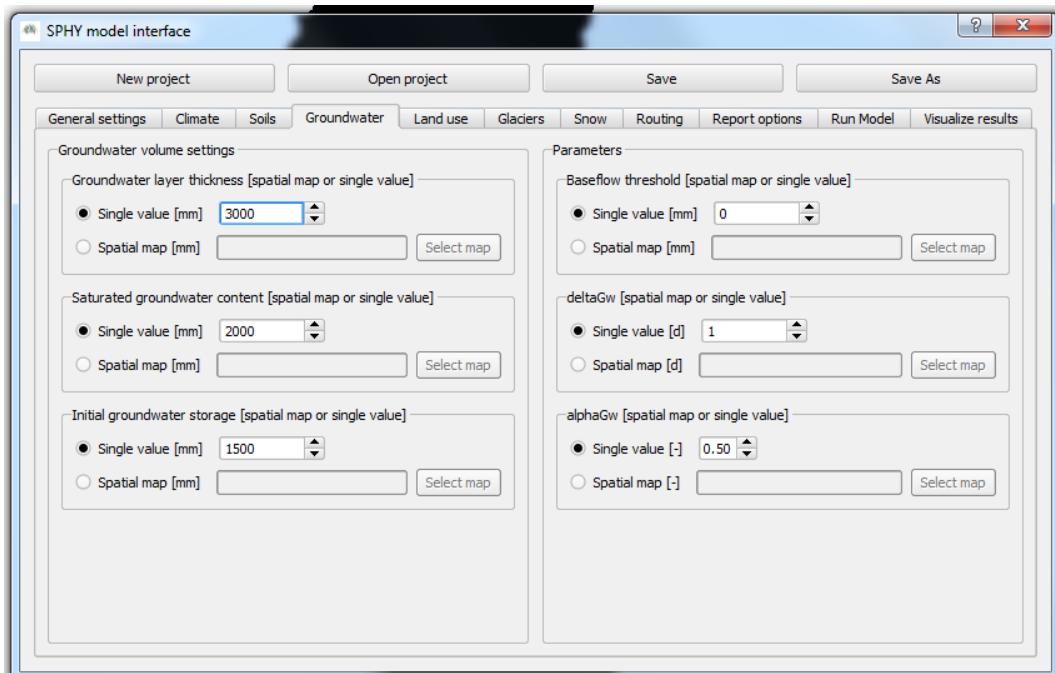


Figure 51: Overview of the Groundwater tab.

Spatial maps can be selected and added to the GUI by clicking the Select map button. It is required that the groundwater layer thickness is higher than or equal to the saturated groundwater content, and that the initial groundwater storage is equal to or smaller than the saturated groundwater content.

It should be noted that if you choose a small or zero initial groundwater storage, it may take a long time before baseflow occurs. Therefore, it is recommended to have substantial initial groundwater storage in order to have baseflow.

4.7.2 Parameters

The parameter settings mainly affect the groundwater recharge and baseflow release from the third soil layer (groundwater layer). The parameters that need to be set are:



- Baseflow threshold [mm]
- deltaGw [d]
- alphaGw [-]

The user can opt for a single value or a spatial map for each of the three parameters. If a single value is chosen, then this value is taken as homogeneous for the entire catchment. Otherwise, a spatially distributed map may be chosen.

If during model simulation the actual groundwater content is below the baseflow threshold parameter, then no baseflow occurs. The default value for the baseflow threshold is set to zero, meaning that baseflow always occurs. The user may choose to have baseflow only if the actual groundwater content is above a certain threshold. For this it is required to set a value or single map for the baseflow threshold parameter. It is required to have a baseflow threshold value that is lower than the saturated groundwater content.

deltaGw affects the duration of the percolated water from the second to the third layer to reach the groundwater store, and alphaGw affects the baseflow recession curve. The default value for deltaGw is 1 day, and for alphaGw 0.5. deltaGw can have values from 1 to many days, and alphaGw ranges between 0 and 1. More details regarding the groundwater processes can be found in Terink et al. (2015a).

After completing all settings in the Groundwater tab the user can continue with the next tab: Land use.

4.8 Land use

Figure 52 provides an overview of the Land use tab. Settings in the Land use tab affect the calculation of the potential evapotranspiration. In this tab the user has to select a land use map and a lookup table containing crop coefficients for each land use class.

The land use map is a nominal map with land use classes which can be selected and added to the map canvas by clicking the Select map button. An example of a land use map that has been selected and added to the canvas is shown in Figure 53.

A table with a crop coefficient for each land use class defined in the land use map can be added to the GUI by clicking the Select table button. After clicking this button you will be asked to select a *.tbl file inside the Input folder. Figure 54 shows an example of the format of a crop coefficients lookup table that corresponds with the land use map of Figure 53.



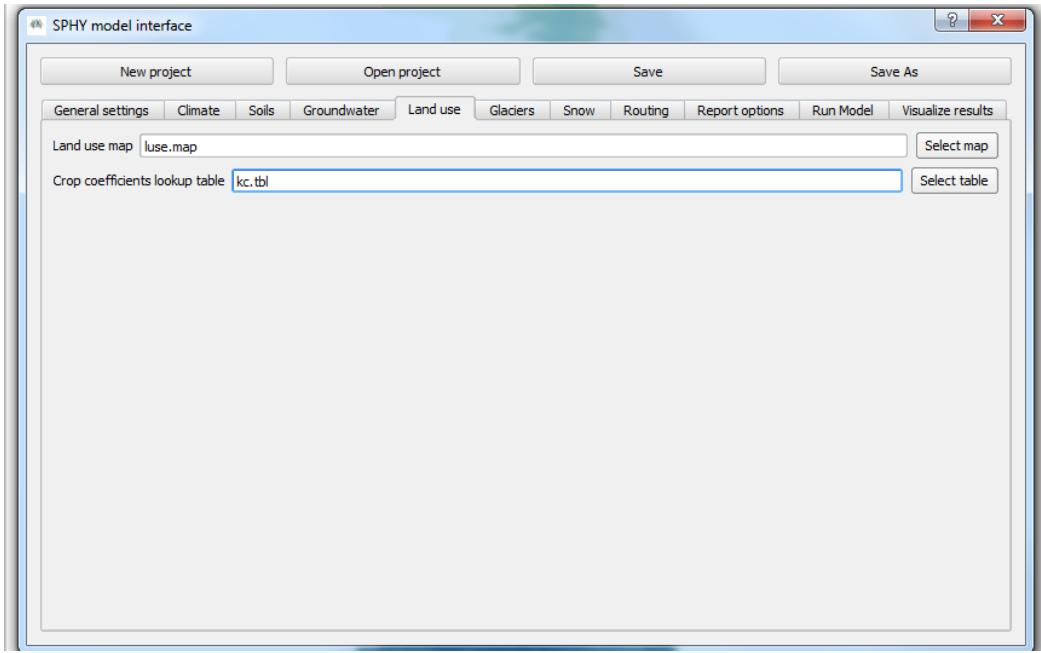


Figure 52: Overview of the Land use tab.

After completion of the settings in the Land use tab the user can continue with the next tab: Glaciers.

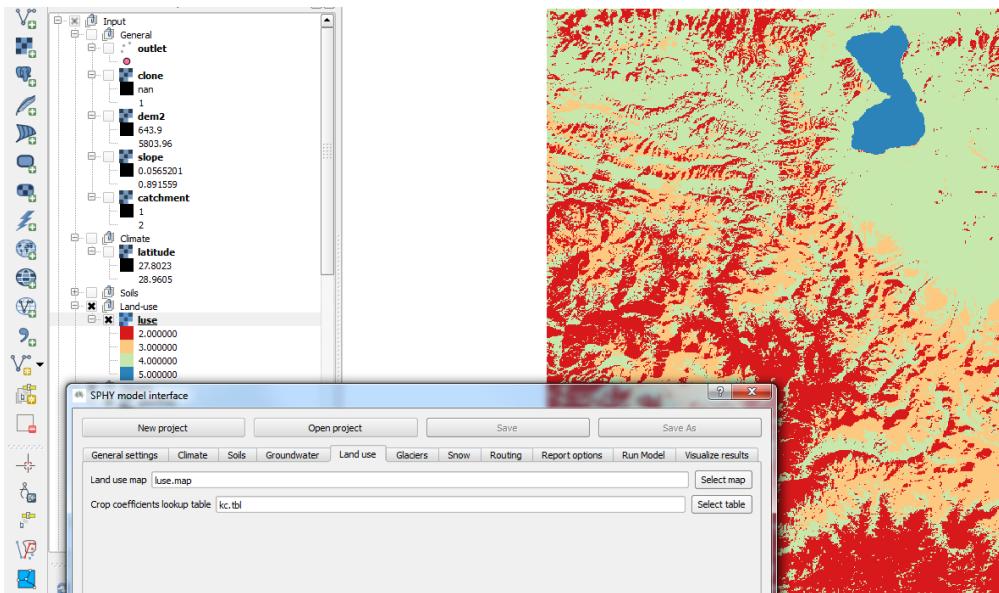


Figure 53: Example of a land use map with four land use classes.

kc.tbl	
1	2 1.2
2	3 0.5
3	4 1.0
4	5 1.0
5	
6	

Figure 54: Example of crop coefficients lookup table in Notepad++.



4.9 Glaciers

An overview of the settings in the Glaciers tab is shown in Figure 55. A distinction has been made between glacier fraction settings and the setting of glacier degree-day-factors.

4.9.1 Glacier fraction settings

In the glacier fraction settings the user has to select the following three spatial maps:

- Initial glacier fraction [-]
- Clean ice glacier fraction [-]
- Debris covered glacier fraction [-]

These maps can be selected and added to the canvas by clicking the Select map button. The initial glacier fraction map defines for each cell the fraction that is covered by glaciers. Values for this map can range between zero and one. An example of a glacier fraction map is shown in Figure 56.

The clean ice and debris covered glacier fraction maps define for each cell the fraction covered by clean ice and debris covered glaciers, respectively. Values of these maps range between zero and one, and the sum of the fractions covered by clean ice and debris covered glaciers should always equal one.

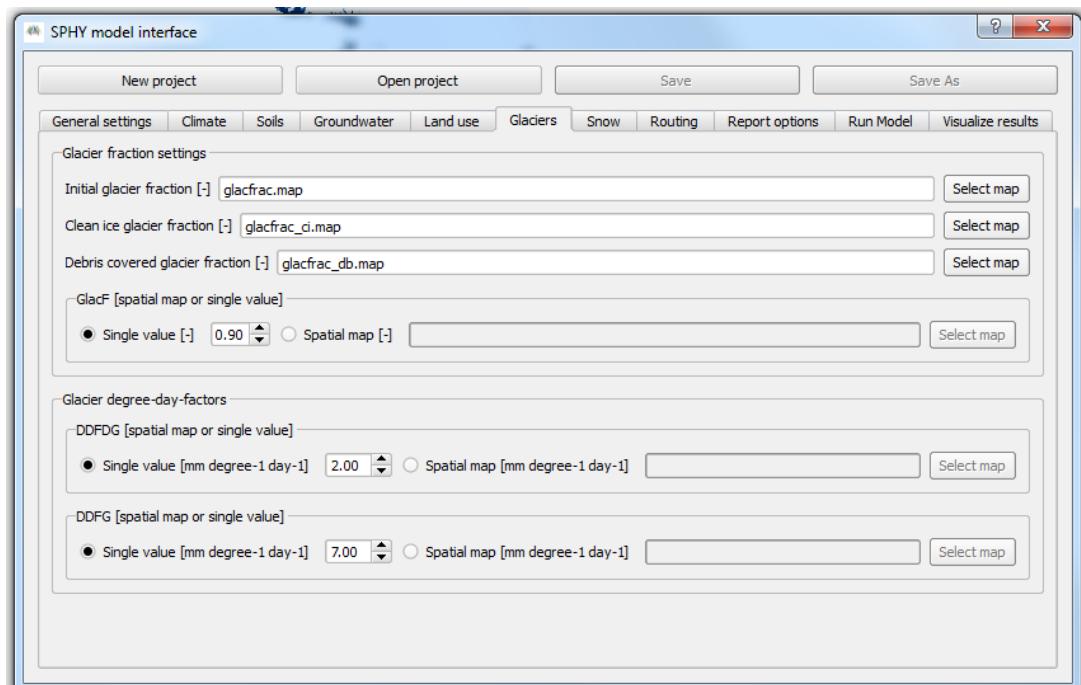


Figure 55: Overview of the Glaciers tab.



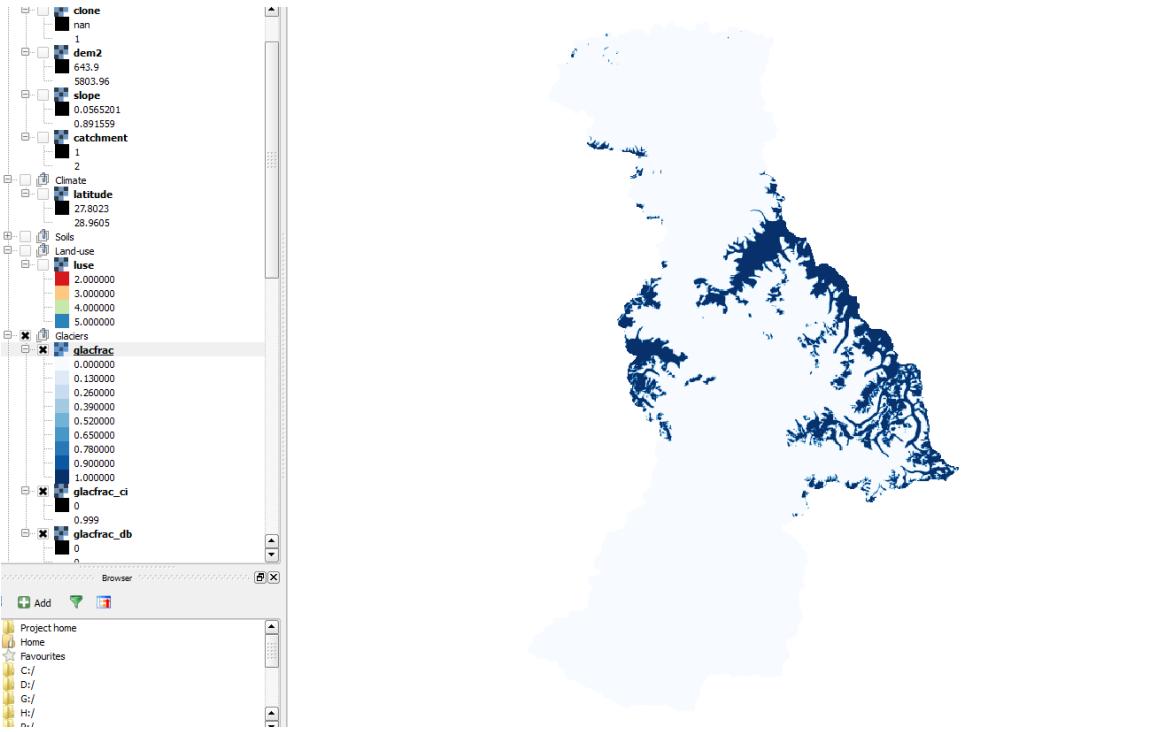


Figure 56: Example of glacier fraction map.

The glacier melt runoff factor (GlacF) differentiates between the amount of glacier melt that results in direct runoff and the amount of glacier melt that percolates to the groundwater. The default value is 0.90, and values range between zero and one. The user can opt to choose a spatially distributed value for GlacF, or to choose a single value that is applied homogeneously over the entire catchment.

4.9.2 Glacier degree-day-factors

The degree-day-factors for debris covered glaciers (DDFDG) and clean ice covered glaciers (DDFG) define the amount of glacier melt per day as a result of the average daily air temperature. Since different melting rates may apply to these two different types of glaciers, two parameters have to be set here.

The user can opt to choose a single value that results in a homogeneous degree-day-factor for the entire basin, or to choose a map with a spatially distributed degree-day-factor. The maps can be selected and added to the canvas by clicking the Select map button.

After completion of all the settings in the Glacier tab you may continue with the next tab: Snow

4.10 Snow

An overview of the snow tab is shown in Figure 57. A distinction has been made between snow storage settings and snow parameters that affect the melting of snow.

4.10.1 Snow storage

Within the snow storage section, the user needs to define the following three settings:

- SnowIni [mm]
- SnowWatStore [mm]
- SnowSC [-]



SnowIni defines for each cell the amount of initial snow storage. The user can either provide a single value that is applicable as homogeneous value to the entire basin, or provide a spatially distributed initial snow storage map. The map can be selected and added to the canvas by clicking the Select map button.

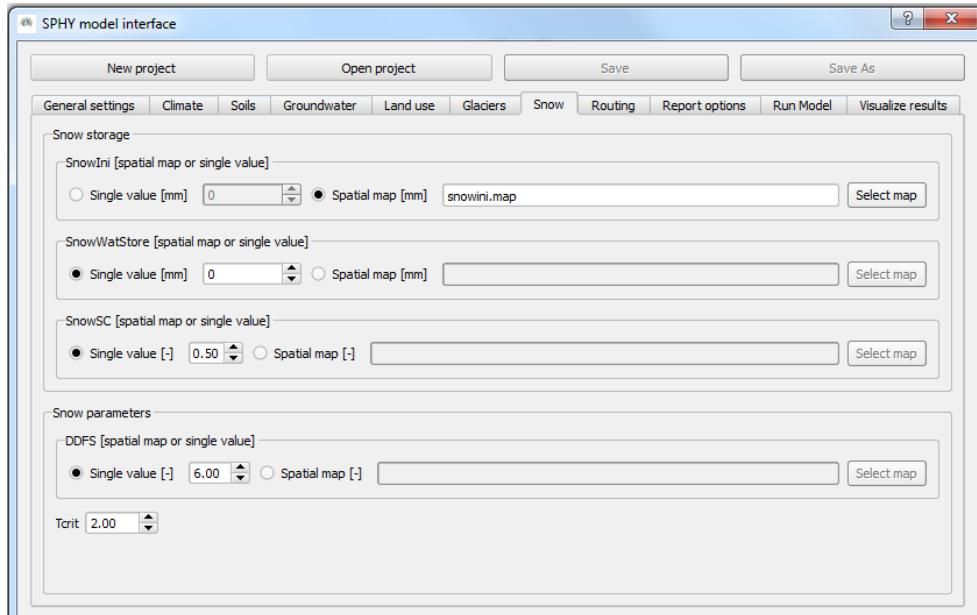


Figure 57: Overview of the Snow tab.

SnowWatStore defines for each cell the amount of melt water that is stored in the snow pack. This value can never be higher than the initial snow storage (SnowIni). The user can choose to either provide a single value for the entire basin, or to provide a spatially distributed SnowWatStore map. The map can be selected and added to the canvas by clicking the Select map button.

The maximum amount of melt water stored in SnowWatStore that can refreeze is defined by setting the SnowSC. Values for SnowSC range between zero and one, and the default value is set to 0.5. The user can opt to choose a single value that is homogeneous for the entire catchment, or to choose a spatially distributed SnowSC map. This map can be selected and added to the map canvas by clicking the Select map button.

4.10.2 Snow parameters

The final step in this section involves setting the snow parameters that affect melting and accumulation of snow:

- DDFS [mm degree⁻¹ day⁻¹]
- Tcrit [°C]

The degree-day-factor for snow (DDFS) defines the potential snow melt per day as a result of the average daily air temperature. The user can either select a spatially distributed DDFS map, or choose a single value that is applicable to the entire basin. The default value for DDFS is set to 6 mm degree⁻¹ day⁻¹.

The temperature threshold (Tcrit) defines if precipitation falls as snow or as rain. If the average daily air temperature is higher than Tcrit, then precipitation will fall as rain. Otherwise,



precipitation will fall as snow. Only a single value can be supplied here, and the default value for Tcrit is set to 2 °C.

After completion of all the settings in the Snow tab you may continue with the next tab: Routing.

4.11 Routing

Settings in the Routing tab affect the way streamflow routing is performed and how streamflow routing is reported as model output. An overview of the Routing tab is shown in Figure 58.

4.11.1 Recession coefficient and flow direction

The recession coefficient affects the velocity in which water is transported downstream through the delineated river network. Values for the recession coefficient range between zero and one, and the default value is set to 0.40. You can opt to choose either a spatially distributed recession coefficient map or single value that is applicable to the entire basin. A recession coefficient map can be selected and added to the map canvas by clicking the Select map button.

For the flow direction you need to select a map by clicking the Select map button. After selecting a flow direction map this map will be added to the map canvas. An example of a flow direction map is shown in Figure 59. A flow direction map needs to be prepared by the user, and is based on the DEM. The flow direction map contains for each cell a number that defines the direction of streamflow. The numbers and their corresponding directions are shown in Figure 60.

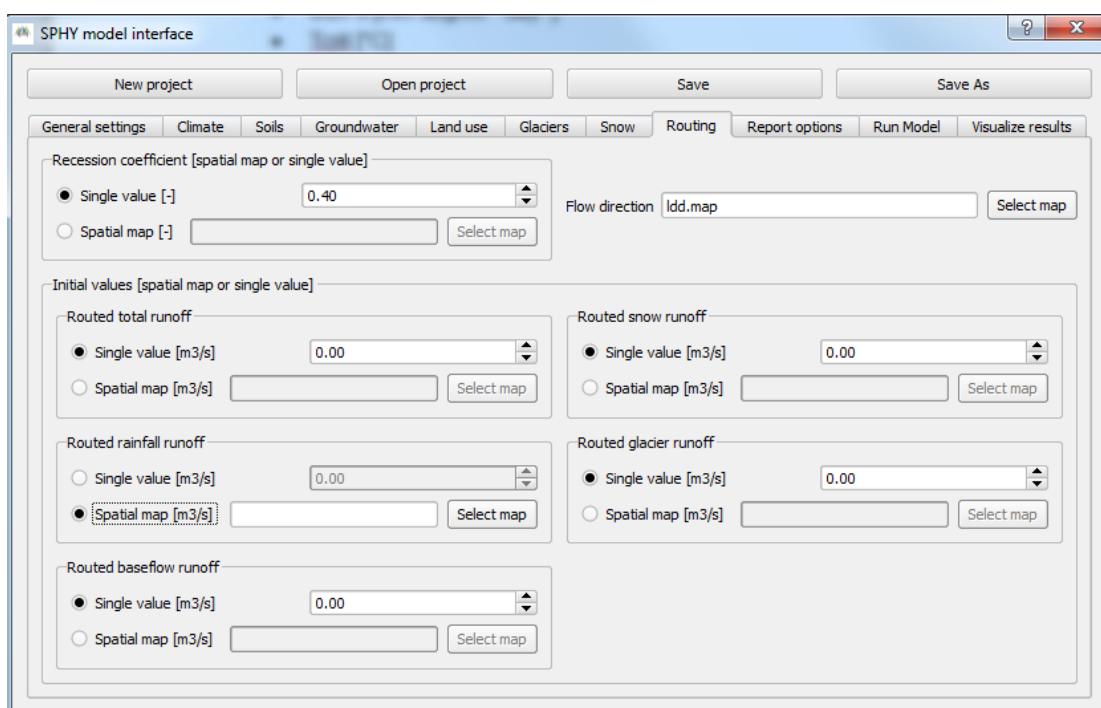


Figure 58: Overview of the routing tab.





Figure 59: Example of flow direction map.

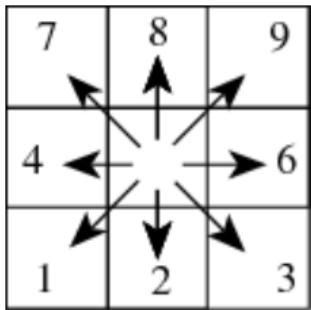


Figure 60: Values indicating the direction of flow in the flow direction map.

4.11.2 Initial values

The initial values that need to be set are:

- Routed total runoff [m^3/s]
- Routed rainfall runoff [m^3/s]
- Routed baseflow runoff [m^3/s]
- Routed snow runoff [m^3/s]
- Routed glacier runoff [m^3/s]

Routed total runoff is the sum of the individual routing components, which are the last four items shown above. The default values for all routing components are set to zero. However, it may be that you are interested in using results from a previous model as starting point for a new model



run. In that case you may provide the routed runoff of the last time-step of your previous model run as initial value for routed runoff of the current model run.

For each of the routed runoff components you may choose to either provide a single value that is applicable to the entire basin, or to provide a spatially distributed map with routed runoff. Maps are selected and added to the map canvas by clicking the Select map buttons.

Routing of the individual streamflow components (rainfall runoff, baseflow runoff, snow runoff, and glacier runoff) is more time-consuming than only routing the total runoff. If you are only interested in routing the total runoff, then it is possible to not compute the routing of the individual routing components. This can be achieved selecting the spatial map option for the routing component that you do not want to be calculated, and leave the corresponding field blank. This is also illustrated in Figure 58, where all routed runoff components will be calculated, except for the routed rainfall runoff.

After completion of all the settings in the Routing tab you are finished with setting all the model input maps and parameters. The next step involves setting the model output options in the Report options tab.

4.12 Report options

Figure 61 represents an overview of the Report options tab. Within this section of the GUI you need to specify for each variable if you want this to be reported as model output yes or no. The left side of this section shows a list with all the variables that can be reported as model output.

The right side of this section shows the options for the model output settings, which are divided into:

- Map-series output
- Time-series output
- Report mm fluxes for basin averages



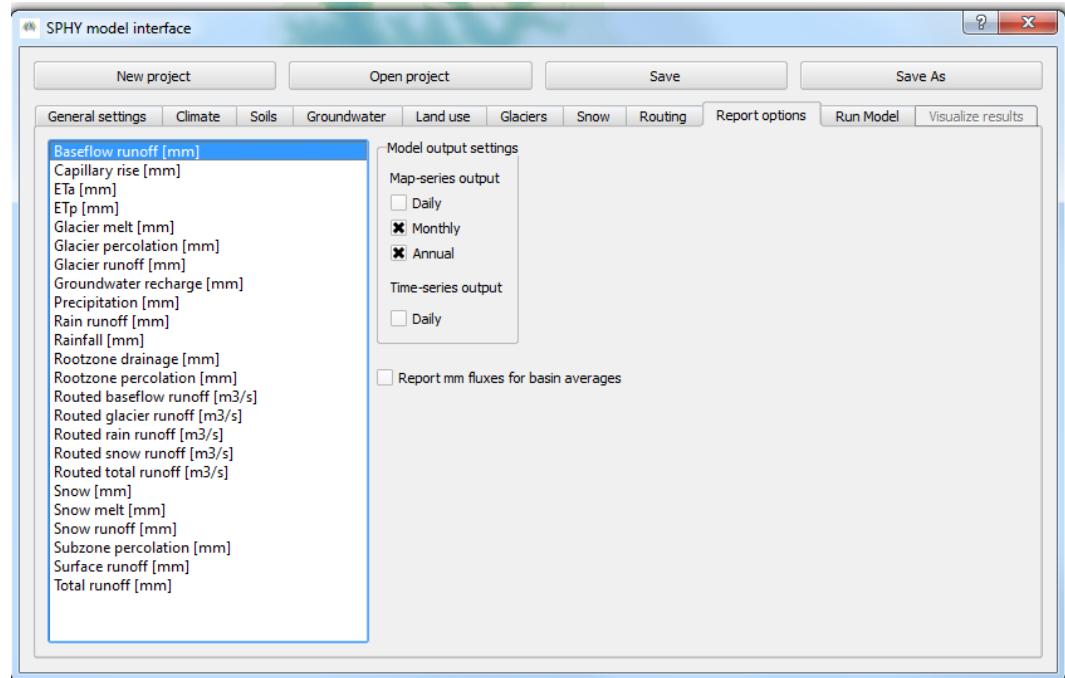


Figure 61: Overview of the Report options tab.

Under map-series output you can specify whether you want output maps to be reported on a daily, monthly, or annual basis. In the example above it can be seen that baseflow runoff is reported on both a monthly and annual basis.

Additionally, you may be interested in plotting time-series for certain variables on locations defined in the Stations map under Catchment settings. If this is required, then you need to check the Daily box under the Time-series output option.

Another interesting option is to report mm fluxes for basin averages. It is often more useful to analyze fluxes in mm than comparing fluxes in m^3/s . The “Report mm fluxes for basin averages” calculates for the areas upstream of your locations, which are defined in your Stations map, basin average fluxes in mm. This calculation will only be done for the in- and outgoing fluxes, which are: precipitation, actual evapotranspiration, glacier melt, routed snow runoff, routed rain runoff, routed glacier runoff, routed baseflow runoff, and routed total runoff.

After the reporting options have been set you can continue with the next tab: Run Model

4.13 Running the model

Figure 62 provides an overview of the Run Model tab. Before running the model you need to specify your environmental settings, which are setting the PATH of the PCRaster bin folder and selecting the python executable (python.exe).

The PCRaster bin PATH can be found under the PCRaster installation folder (see Section 4.2.3 from Terink et al. (2015a)). This folder can be selected by clicking the Select path button.

The python executable can be found under the Python installation folder (see Section 4.2.1 from Terink et al. (2015a)), and can be selected by clicking the Select python.exe button.



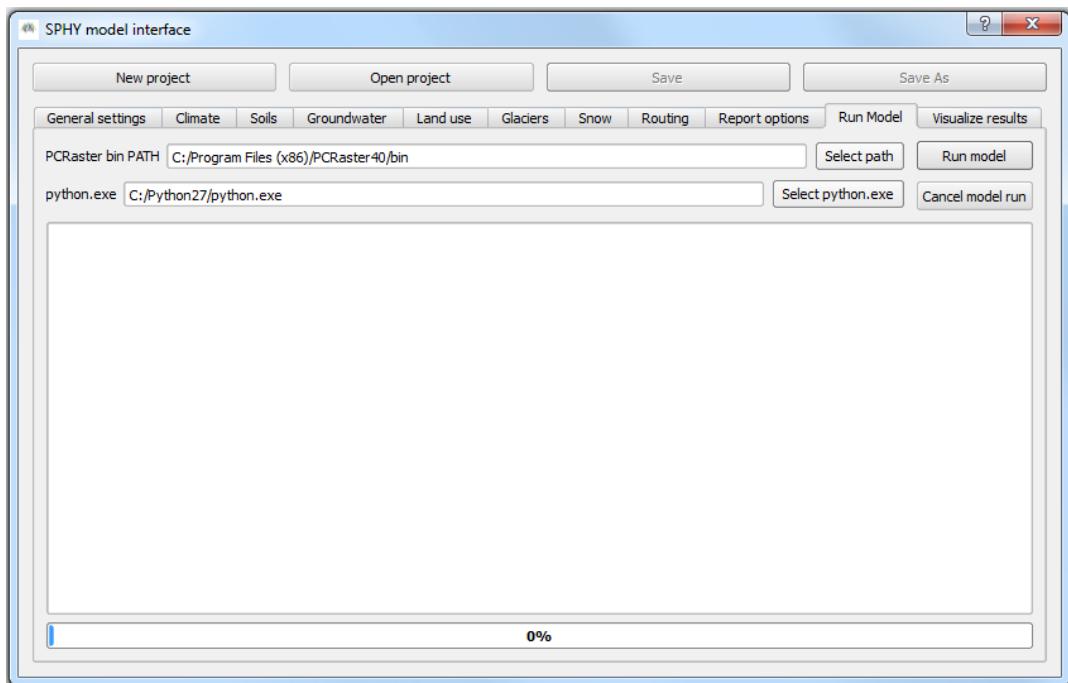


Figure 62: Overview or the Run Model tab.

After setting these environmental settings you can run the model by pressing the Run model button. During model execution the command line output will be reported in the log screen as is shown in Figure 63. Model run can be canceled anytime by pressing the Cancel model run button. If this is done, then previous model output will NOT be overwritten. Figure 64 shows an example of the log screen output of a cancelled model run.

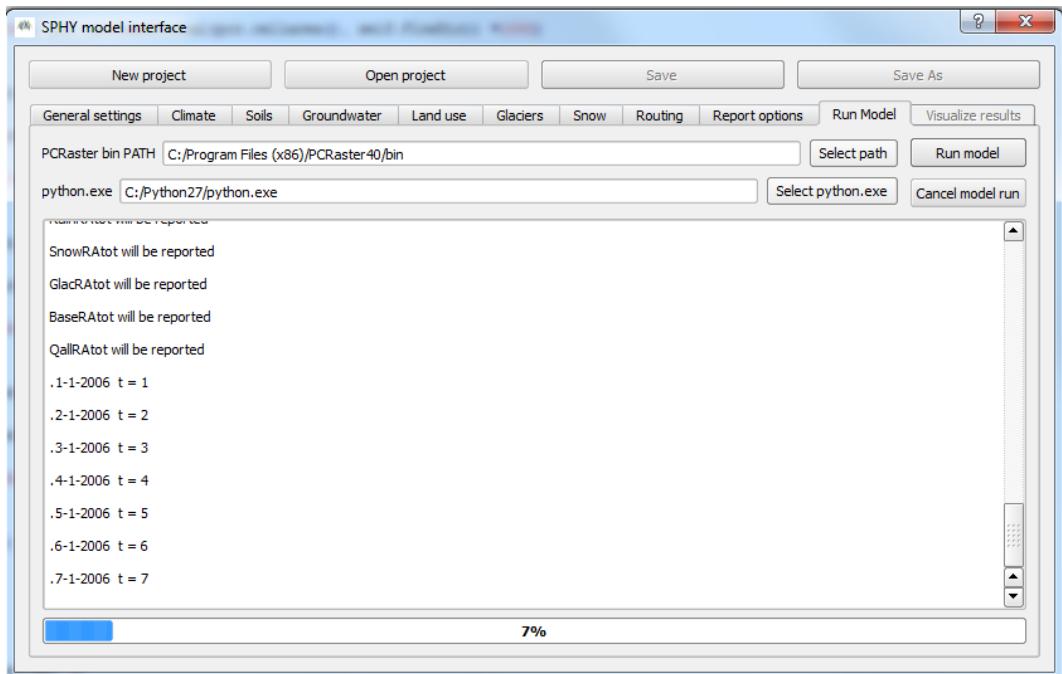


Figure 63: Example of log screen output during model run.



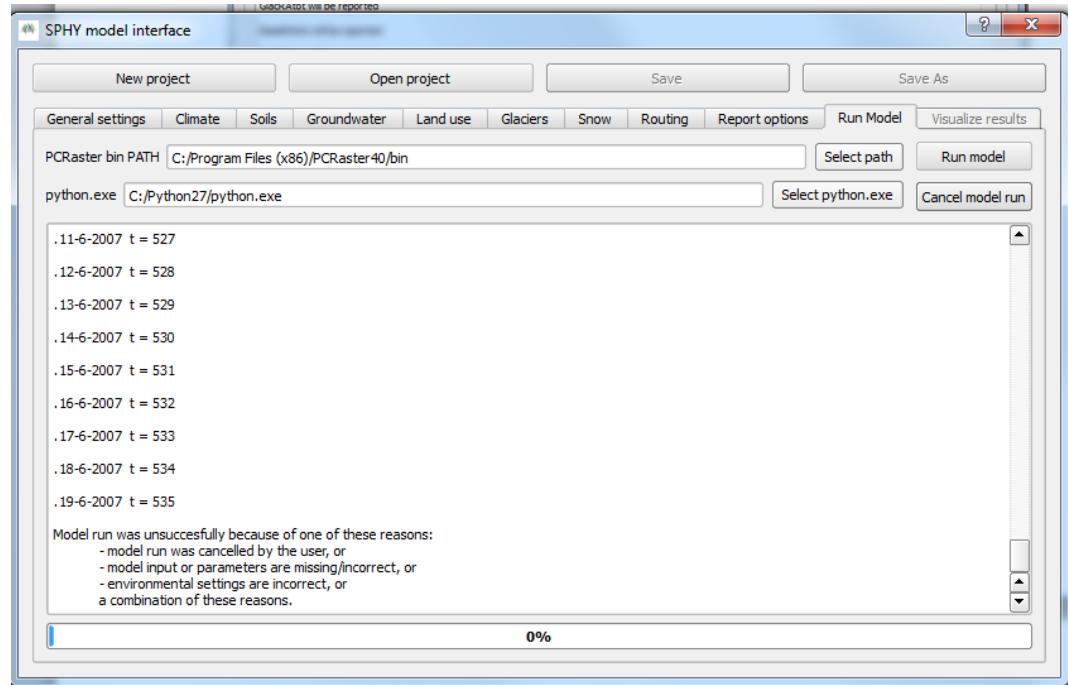


Figure 64: Example log screen output of cancelled model run.

If an error occurs after the Run model button has been clicked, then a screen similar to that of Figure 64 will be shown. In that case you need to check your model input/parameters, environmental settings, or a combination of these.

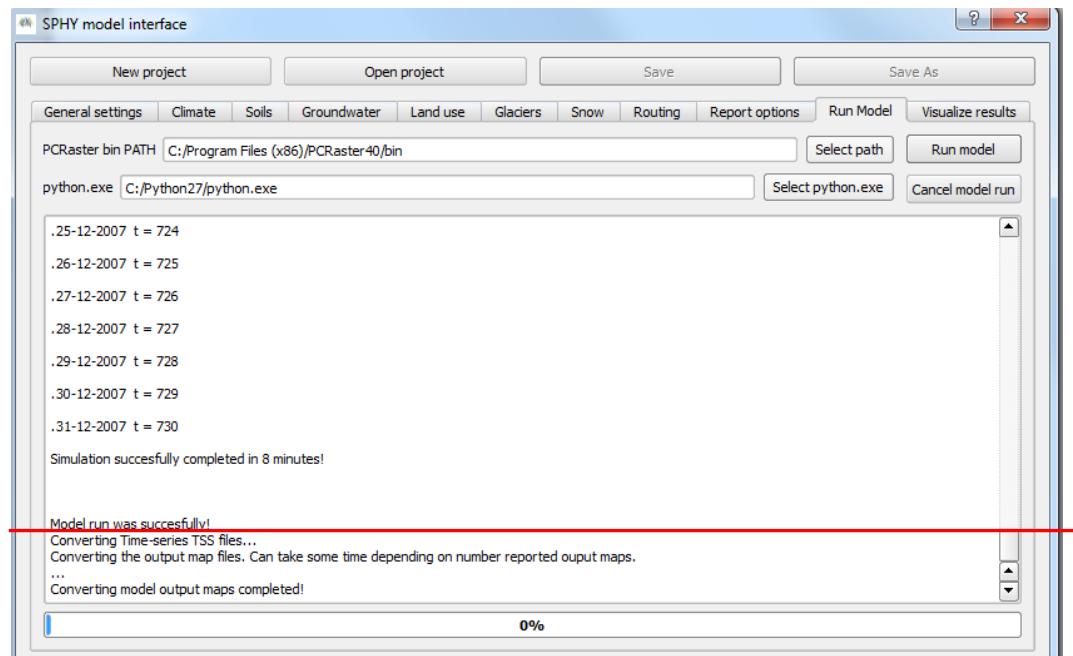


Figure 65: Example log screen output of successful model run.

If your model run was successful, then a screen similar (without red line) to Figure 65 will be shown. The text "Model run was successfully!" indicates that model execution was successfully.

At this stage you still can click the Cancel model run to prevent previous model output to be overwritten. Otherwise the GUI continues with converting model output (part below red line) to a suitable output format. Converting the model output may take a long time, depending on the



length of the model simulation period and the settings in the Report options tab. The line with the three dots (...) indicates that the GUI is still working to convert the output.

After the line “Converting model output maps completed!” is shown, you can continue to the Visualize results tab in order to analyze model output.

4.14 Visualizing model output

If model execution has been completed successfully, then the Visualize results tab will become available. An overview of the Visualize results tab is shown in Figure 66. If no model run has been performed yet, or if nothing was reported in the Report options tab, then the list widgets in this tab will be completely empty.

A distinction has been made between time-series output (left list widget) and map-series output (three right list widgets). Map-series output has been split into three separate list widgets, being i) daily maps, ii) monthly maps, and iii) annual maps.

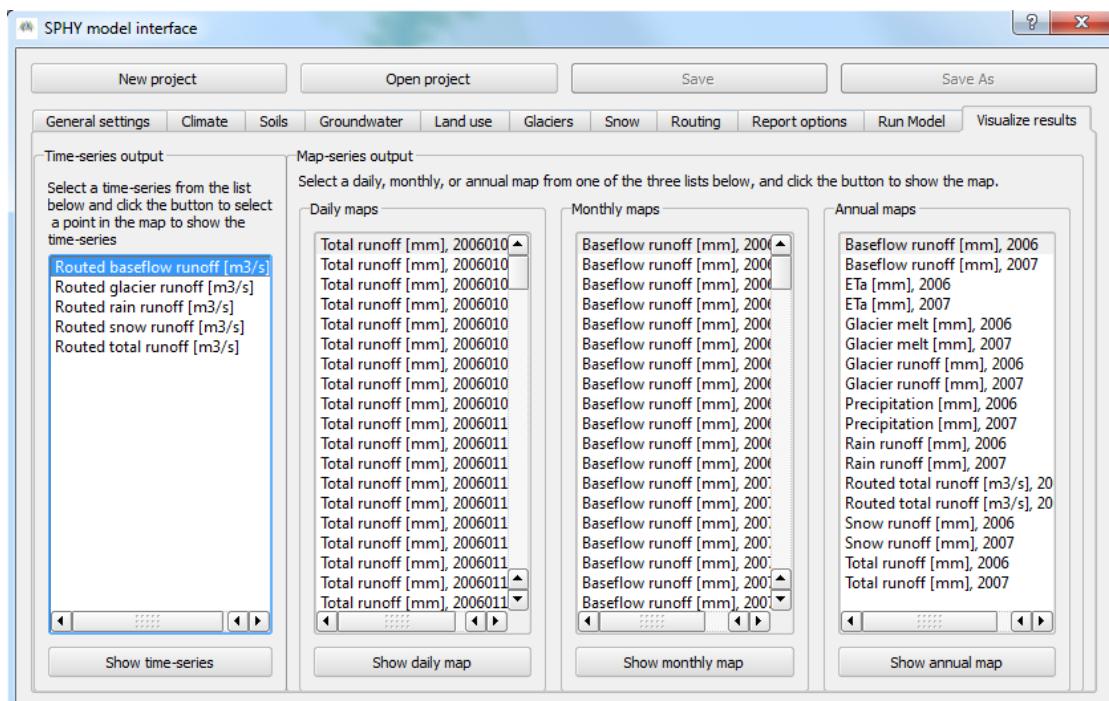


Figure 66: Overview of Visualize results tab.

4.14.1 Time-series output

Time-series plots can be shown for the locations that are defined in the Stations map in the General settings tab (Section 4.4.4). In order to show a time-series plot you need to:

1. Select the variable of interest from the list (in Figure 66 the “Routed baseflow runoff [m³/s]” is the selected variable).
2. Make sure that the Stations map layer (outlet) is selected in the map canvas (Figure 67).
3. Click the Show time-series button.
4. Finally, click on one of the points in the canvas that is part of your Stations map layer (Figure 68).



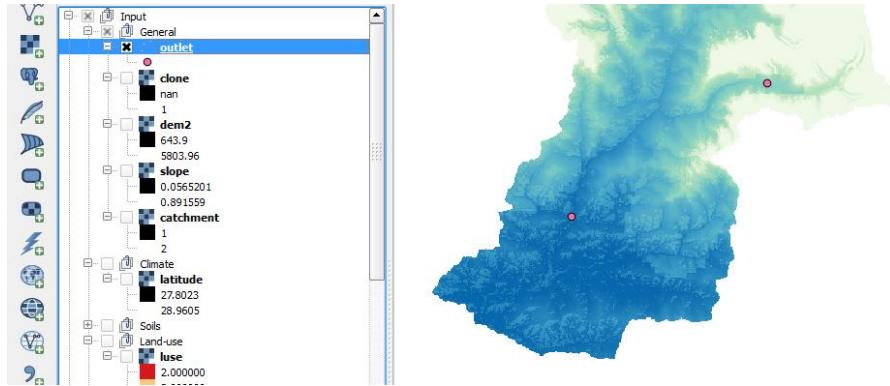


Figure 67: Setting the Stations map layer (outlet) as active layer.

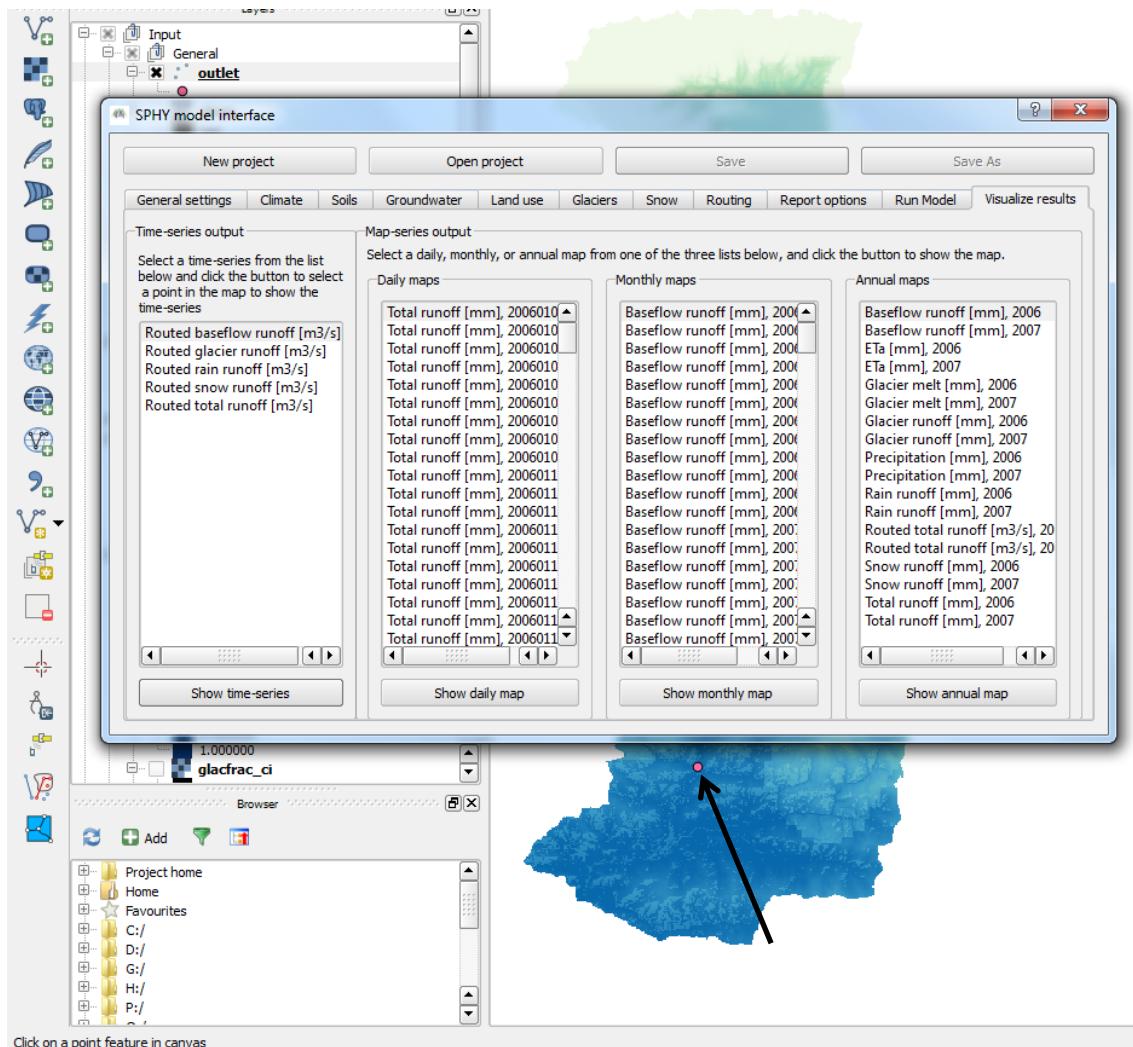


Figure 68: Click on a point feature in the canvas to show a time-series.

After completing step 4 a time-series plot will be shown (Figure 69). The buttons shown inside the red box allow you to zoom in and zoom out of your graph, pan through the graph, change axis and label settings, and save your graph to an image file.



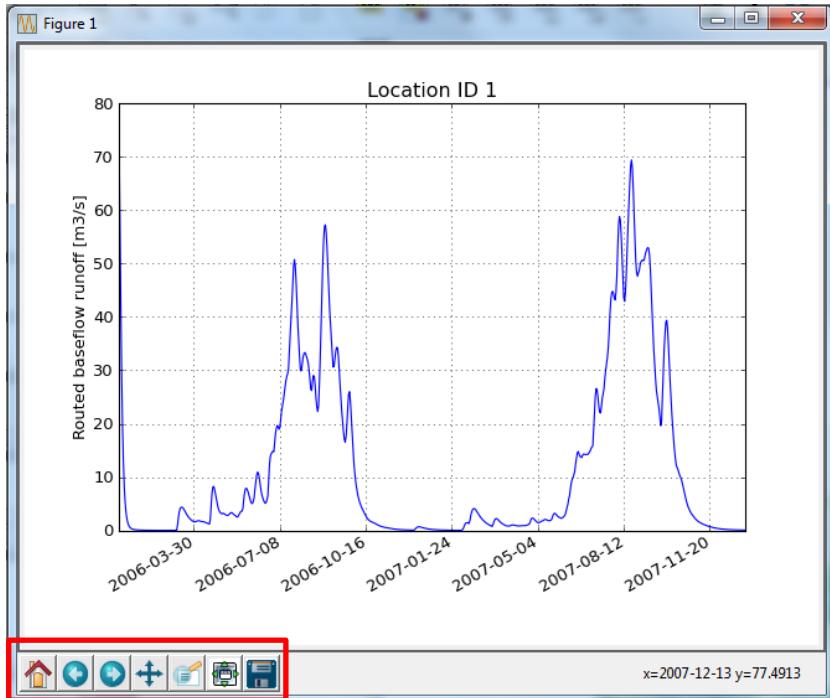


Figure 69: Example of time-series plot.

4.14.2 Map-series output

Showing map-series output is more straightforward than the plotting of time-series. An output map (daily, monthly, or annual) can be added to the canvas by selecting the map of interest from the list widget, and subsequently press the Show XXX map button at the bottom of the list widget, with XXX being daily, monthly, or annual.

Within the QGIS map canvas three layer groups are defined within the Output group layer, being:

- Daily
- Monthly
- Annual

The selected map output will be inserted as a new layer in one of these groups. If the layer name already existed in the group, then this layer will be overwritten with the new selected map layer. Figure 70 shows an example of adding an annual rainfall map to the map canvas. Since it is an annual map, it will be inserted inside the Output – Annual layer group.



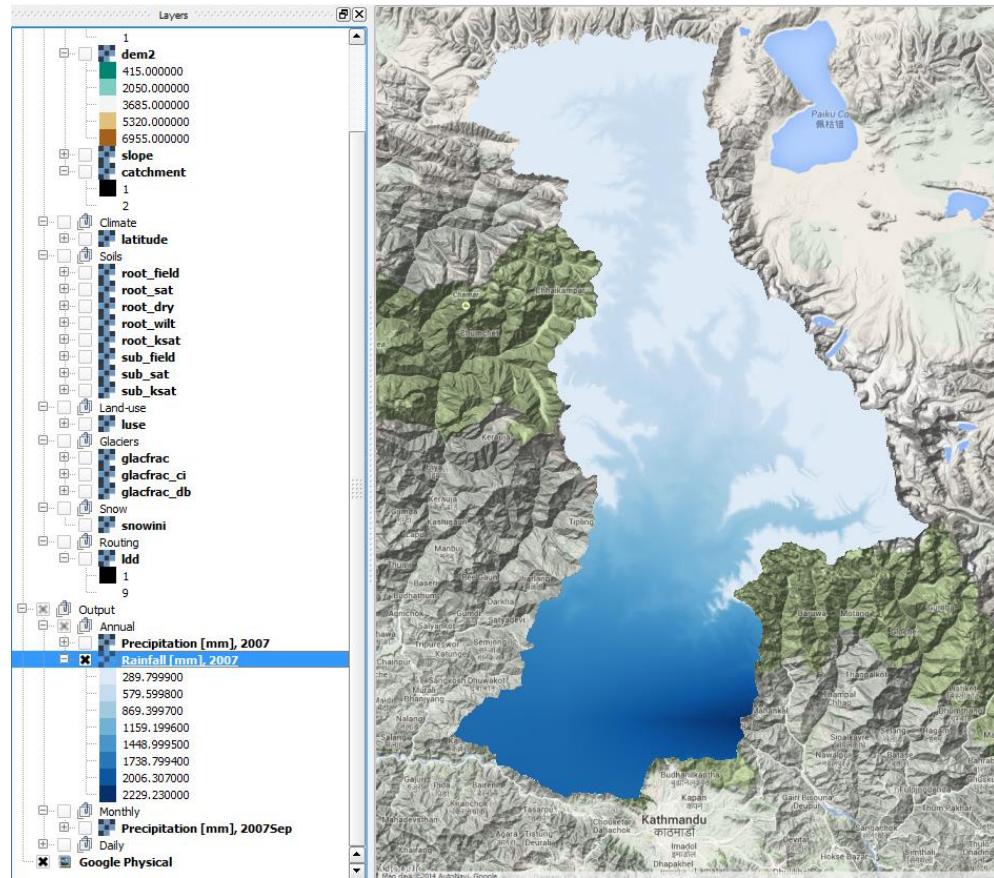


Figure 70: Example of annual rainfall map that has been added to the map canvas.



5 References

- De Boer, F. 2015. HiHydroSoil : A high resolution soil map of hydraulic properties, Wageningen, The Netherlands. FutureWater report 134.
- Defourny, P., C. Vancutsem, P. Bicheron, C. Brockmann, F. Nino, L. Schouten, and M. Leroy. 2007. GLOBCOVER : A 300 m global land cover product for 2005 using ENVISAT MERIS time series, in Proceedings of ISPRS Commission VII Mid-Term Symposium: Remote Sensing: from Pixels to Processes, Enschede (NL) 8-11 May 2006, pp. 8–11.
- Droogers, P., and R. G. Allen. 2002. Estimating reference evapotranspiration under inaccurate data conditions. *Irrig. Drain. Syst.*, 16, 33–45.
- Lehner, B., K. Verdin, and A. Jarvis. 2006. HydroSHEDS Technical Documentation Version 1.0
- Maussion, F., D. Scherer, T. Mölg, E. Collier, J. Curio, and R. Finkelnburg. 2014. Precipitation Seasonality and Variability over the Tibetan Plateau as Resolved by the High Asia Reanalysis. *J. Clim.*, 27(5), 1910–1927, doi:10.1175/JCLI-D-13-00282.1. Available from: <http://journals.ametsoc.org/doi/abs/10.1175/JCLI-D-13-00282.1>. (Accessed 7 November 2014).
- Pfeffer, W. T. et al. 2014. The Randolph Glacier Inventory: a globally complete inventory of glaciers. *J. Glaciol.*, 60(221), 537–552, doi:10.3189/2014JoG13J176. Available from: <http://www.igsoc.org/journal/60/221/j13J176.html>.
- Schneider, U., A. Becker, P. Finger, A. Meyer-Christoffer, M. Ziese, and B. Rudolf. 2013. GPCC's new land surface precipitation climatology based on quality-controlled in situ data and its role in quantifying the global water cycle. *Theor. Appl. Climatol.*, 26, doi:10.1007/s00704-013-0860-x. Available from: <http://link.springer.com/10.1007/s00704-013-0860-x> (Accessed 22 October 2013).
- Terink, W., A.F. Lutz, G.W.H. Simons, W.W. Immerzeel, P. Droogers. 2015. SPHY v2.0: Spatial Processes in HYdrology. *Geoscientific Model Development*, 8, 2009-2034, doi:10.5194/gmd-8-2009-2015.
- Terink, W., A.F. Lutz, W.W. Immerzeel. 2015a. SPHY v2.0: Spatial Processes in HYdrology. Model theory, installation, and data preparation. FutureWater report 142.
- Terink, W., A.F. Lutz, G.W.H. Simons. 2015b. SPHY: Spatial Processes in HYdrology. Case-studies for training. FutureWater report 144.
- Terink, W., P. Droogers, G.W.H. Simons. 2015c. Reservoir module in SPHY. Implemented in SPHY v2.1. FutureWater report 136.
- Weedon, G. P., G. Balsamo, N. Bellouin, S. Gomes, M. J. Best, and P. Viterbo. 2014. The WFDEI meteorological forcing data set: WATCH Forcing Data methodology applied to ERA-Interim reanalysis data. *Water Resour. Res.*, 7505–7514, doi:10.1002/2014WR015638.



Copyright

Redistribution and use of the SPHY model source code or its binary forms, with or without modification, are permitted provided that the following conditions are met:

1. Redistributions of source code must retain this copyright notice, this list of conditions and the following disclaimer.
2. Redistributions in binary form must reproduce the above copyright notice, this list of conditions and the following disclaimer in the documentation and/or other materials provided with the distribution.
3. Any changes, modifications, improvements and/or simplifications of the source code should be sent to FutureWater.
4. Any redistribution of source code or binary form should be reported to FutureWater.
5. Any application, publication and/or presentation of results generated by using the Software should be reported to FutureWater.

THIS SOFTWARE IS PROVIDED BY THE COPYRIGHT HOLDERS AND CONTRIBUTORS "AS IS" AND ANY EXPRESS OR IMPLIED WARRANTIES, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE ARE DISCLAIMED. IN NO EVENT SHALL THE COPYRIGHT OWNER OR CONTRIBUTORS BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO, PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE USE OF THIS SOFTWARE, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE.



Appendix 1: Input and Output

This appendix provides an overview of the input that is required by the SPHY model, and the output that can be reported by the SPHY model. It should be noted that the current version of the SPHY model GUI (version 1.0) does not support the interaction with all the input that can be specified in the SPHY model configuration file (*.cfg). This will be implemented in future versions of the GUI. Table 2 specifies the model input that can be specified in the current version of the SPHY model GUI. An overview of the output that can be reported by the model is shown in Table 3.

Table 2: Overview of SPHY model input.

Map or parameter name	Interface tab	Spatial map [SM], single value [SV], or table [TB]	For maps: Boolean [BO], Nominal [NO], Scalar [SC], Directional [DI]. For single value: Integer [IN] or Float [FL]	Units
Clone map	General settings	SM	BO	[·]
DEM map	General settings	SM	SC	[MASL]
Slope map	General settings	SM	SC	[·]
Sub-basins map	General settings	SM	NO	[·]
Stations map	General settings	SM	NO	[·]
Precipitation	Climate	SM	SC	[mm/d]
Avg. daily temperature	Climate	SM	SC	[°C]
Max. daily temperature	Climate	SM	SC	[°C]
Min. daily temperature	Climate	SM	SC	[°C]
Latitude zones	Climate	SM	SC	[latitude]
Solar constant	Climate	SV	FL	[MJ/m ² /min]
Field capacity	Soils	SV	SC	[mm/mm]
Saturated content	Soils	SV	SC	[mm/mm]
Permanent wilting point	Soils	SV	SC	[mm/mm]
Wilting point	Soils	SV	SC	[mm/mm]
Saturated hydraulic conductivity	Soils	SV	SC	[mm/d]
Rootlayer thickness	Soils	SM, SV	SC IN	[mm]
Sublayer thickness	Soils	SM, SV	SC IN	[mm]
Maximum capillary rise	Soils	SV	IN	[mm]
Groundwater layer thickness	Groundwater	SM, SV	SC IN	[mm]
Saturated groundwater content	Groundwater	SM, SV	SC IN	[mm]
Initial groundwater storage	Groundwater	SM, SV	SC IN	[mm]
Baseflow threshold	Groundwater	SM, SV	SC IN	[mm]
deltaGw	Groundwater	SM, SV	SC IN	[d]
alphaGw	Groundwater	SM, SV	SC FL	[·]
Land use map	Land use	SM	NO	[·]
Crop coefficients lookup table (see example Figure 54)	Land use	TB	FL	[·]
Initial glacier fraction	Glaciers	SM	SC	[·]



Clean ice glacier fraction	Glaciers	SM	SC	[·]
Debris covered glacier fraction	Glaciers	SM	SC	[·]
GlacF	Glaciers	SM, SV	SC FL	[·]
DDFDG	Glaciers	SM, SV	SC FL	[mm/°C/d]
DDFG	Glaciers	SM, SV	SC FL	[mm/°C/d]
SnowIni	Snow	SM, SV	SC IN	[mm]
SnowWatStore	Snow	SM, SV	SC IN	[mm]
SnowSC	Snow	SM, SV	SC FL	[·]
DDFS	Snow	SM, SV	SC FL	[mm/°C/d]
Tcrit	Snow	SV	FL	[°C]
Recession coefficient	Routing	SM, SV	SC FL	[·]
Flow direction (see example Figure 59 and Figure 60)	Routing	SM	DI	[·]
Routed total runoff	Routing	SM, SV	SC FL	[m³/s]
Routed rainfall runoff	Routing	SM, SV	SC FL	[m³/s]
Routed baseflow runoff	Routing	SM, SV	SC FL	[m³/s]
Routed snow runoff	Routing	SM, SV	SC FL	[m³/s]
Routed glacier runoff	Routing	SM, SV	SC FL	[m³/s]

Table 3: Overview of SPHY model output (Report options tab).

Output variable	Spatial map [SM] or time-series [TS]	Output frequency: daily [D], monthly [M], or annual [A]	Units	Option to report sub-basin average flux in mm: yes [Y] or no [N].
Baseflow runoff	SM, TS	D, M, A	mm	N
Capillary rise	SM, TS	D, M, A	mm	N
ETa	SM, TS	D, M, A	mm	Y
ETp	SM, TS	D, M, A	mm	N
Glacier melt	SM, TS	D, M, A	mm	Y
Glacier percolation	SM, TS	D, M, A	mm	N
Glacier runoff	SM, TS	D, M, A	mm	N
Groundwater recharge	SM, TS	D, M, A	mm	N
Precipitation	SM, TS	D, M, A	mm	Y
Rain runoff	SM, TS	D, M, A	mm	N
Rainfall	SM, TS	D, M, A	mm	N
Rootzone drainage	SM, TS	D, M, A	mm	N
Rootzone percolation	SM, TS	D, M, A	mm	N
Routed baseflow runoff	SM, TS	D, M, A	m³/s	Y
Routed glacier runoff	SM, TS	D, M, A	m³/s	Y
Routed rain runoff	SM, TS	D, M, A	m³/s	Y
Routed snow runoff	SM, TS	D, M, A	m³/s	Y
Routed total runoff	SM, TS	D, M, A	m³/s	Y
Snow	SM, TS	D, M, A	mm	N
Snow melt	SM, TS	D, M, A	mm	N



Snow runoff	SM, TS	D, M, A	mm	N
Subzone percolation	SM, TS	D, M, A	mm	N
Surface runoff	SM, TS	D, M, A	mm	N
Total runoff	SM, TS	D, M, A	mm	N



Appendix 2: Hindu Kush-Himalaya database

Download link:

[Hindu Kush-Himalaya database](#)

Database extent:

Xmin: 65.00

Xmax: 100.0

Ymin: 20.0

Ymax: 40.0

HydroSheds SRTM DEM

The included Digital Elevation Model (DEM) is the USGS HydroSheds hydrologically conditioned DEM (Lehner et al., 2006). The data is based on the SRTM DEM and public available through <http://hydrosheds.cr.usgs.gov>. The specific product included is “Hydrologically conditioned elevation”. This product is available divided in 5°x5° tiles. Parts of the tiles have been mosaicked to generate the DEM as in Figure 71.

Data format and size	GeoTiff 2.35 GB			
Values	Elevation in meters above sea level			
Projection	Geographic (LAT/LON) WGS1984 (EPSG:4326)			
Spatial resolution	3 arc-second (~90 meter at the equator)			
Extent (dd):	xmin: 65.00	xmax: 100.00	ymin: 20.00	ymax: 40.00

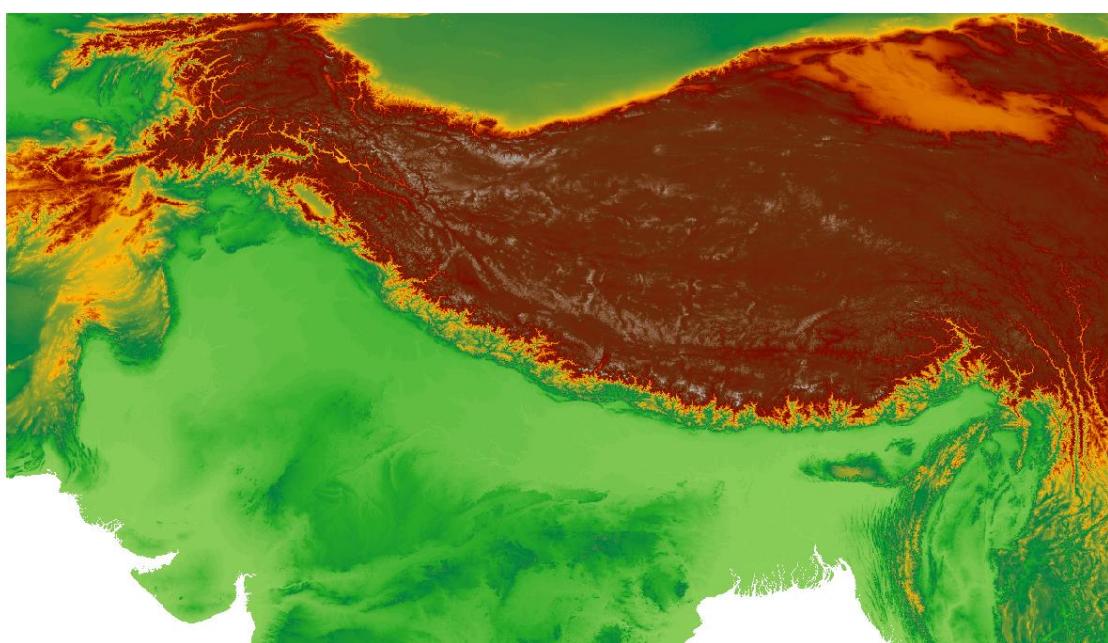


Figure 71: HydroSheds DEM included in the Hindu Kush-Himalaya database.



HydroSheds streams

HydroSheds has also stream lines available as derived from the hydrologically corrected DEM. The data is available as lines shapefile. The data is derived from the 15 arc seconds DEM.

Data format and size	Shapefile 40 MB			
Values	Line elements with ID and number of upstream cells			
Projection	Geographic (LAT/LON) WGS1984 (EPSG:4326)			
Extent (dd):	xmin: 65.00	xmax: 100.00	ymin: 20.00	ymax: 40.00

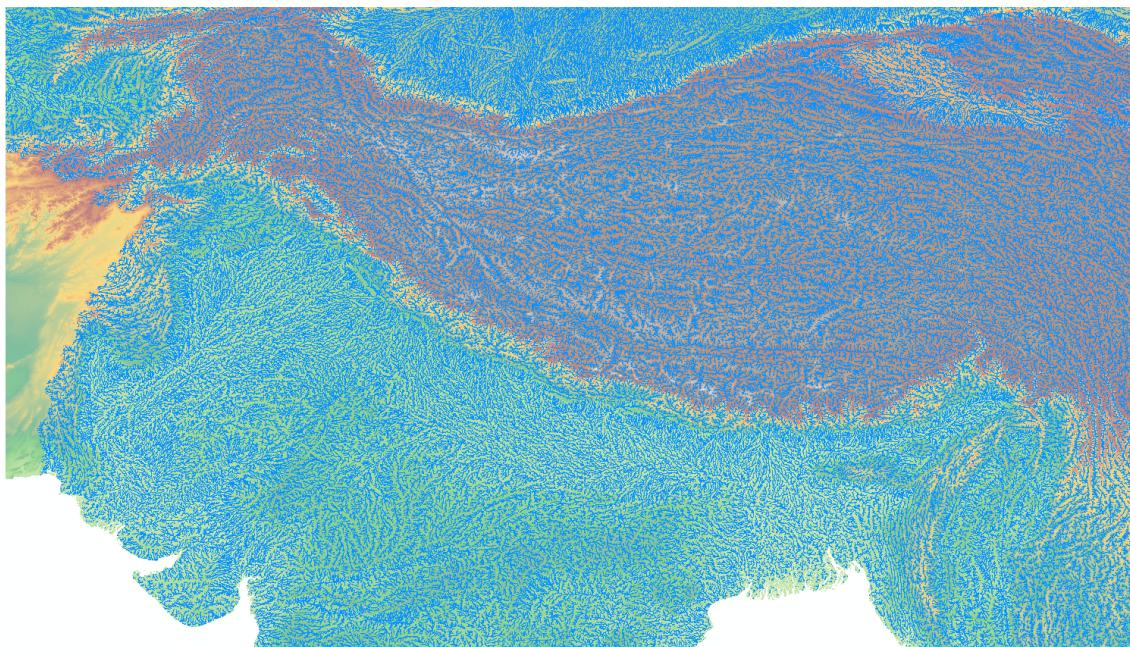


Figure 72: HydroSheds streams included in the Hindu Kush-Himalaya database.

Randolph Glacier Inventory (RGI v4.0)

The Randolph Glacier inventory (Pfeffer et al., 2014) is considered the most complete global glacier outlines inventory. The inventory is available online through GLIMS:

http://www.glims.org/RGI/rgi_dl.html. Version 4.0 was released in December 2014. The outlines for three regions are included in the dataset: Central Asia, South Asia West, South Asia East (Figure 73). These regions were available as separate shapefiles which have been merged into one shapefile.

Data format and size	Shapefile 120 MB			
Values	Glacier outlines as polygons and glacier properties in attribute table			
Projection	Geographic (LAT/LON) WGS1984 (EPSG:4326)			



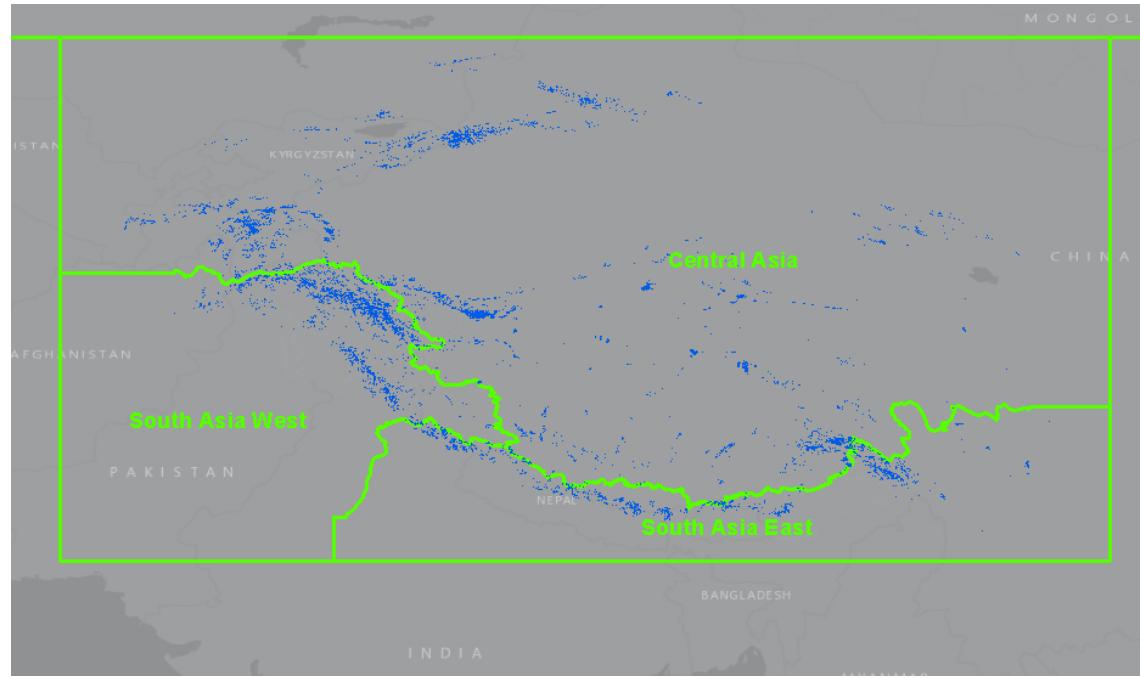


Figure 73: Randolph Glacier Inventory 4.0 glacier outlines (blue) included in Hindu Kush-Himalaya database. RGI regions are indicated by green polygons.

GlobCover Land use data

GlobCover (Defourny et al., 2007) is an ESA initiative which began in 2005 in partnership with JRC, EEA, FAO, UNEP, GOFC-GOLD and IGBP. The aim of the project was to develop a service capable of delivering global composites and land cover maps using as input observations from the 300m MERIS sensor on board the ENVISAT satellite mission. ESA makes available the land cover maps, which cover 2 periods: December 2004 - June 2006 and January - December 2009. The latter is included in the dataset. A quick scan comparing different available public domain global land use datasets shows that GlobCover is the most reliable at the moment.

Data format and size	GeoTiff 86.5 MB			
Values	Land use classes (categorical as integer values)			
Projection	Geographic (LAT/LON) WGS1984 (EPSG:4326)			
Spatial resolution	300 meter			
Extent (dd):	xmin: 65.00	xmax: 100.00	ymin: 20.00	ymax: 40.00



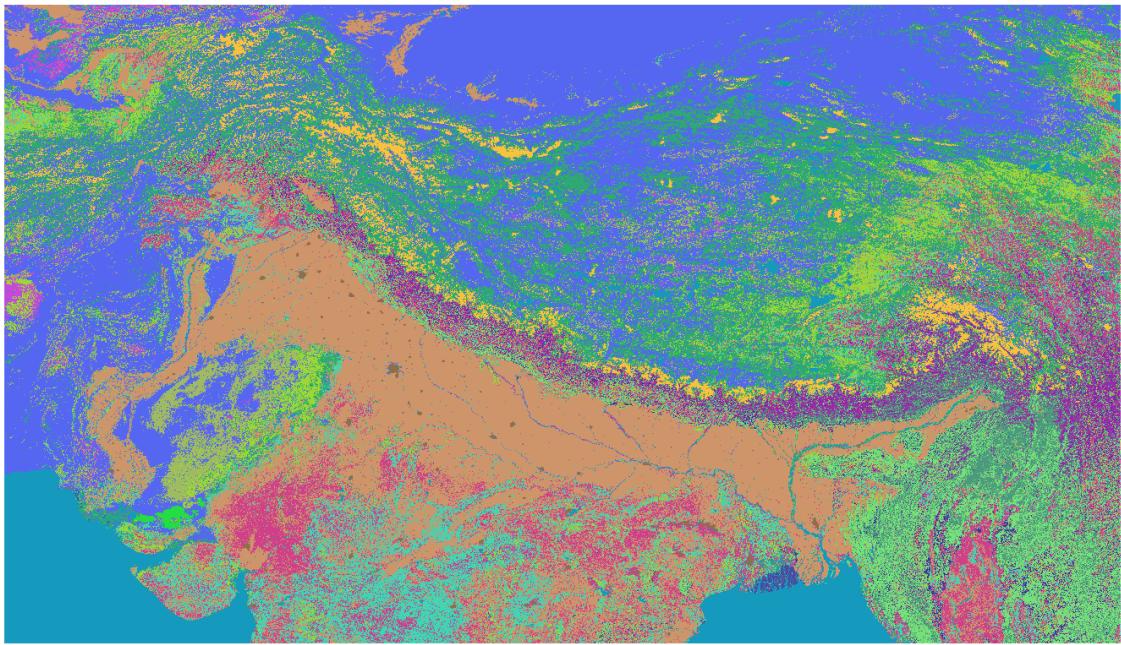


Figure 74: GlobCover domain included in the Hindu Kush-Himalaya database.

HiHydroSoil

FutureWater has developed a new global soil product containing quantitative hydrological properties, as required by most hydrological models, including SPHY (Terink et al., 2015a). This global physical soil properties product (HiHydroSoil) is based on the SoilGrids1km database. The Harmonized World Soil Database (HWSD) is used to fill missing data in the SoilGrids1km. Pedotransfer functions are used to estimate physical soil properties from soil type. A detailed description of the HiHydroSoil product can be found in de Boer (2015).

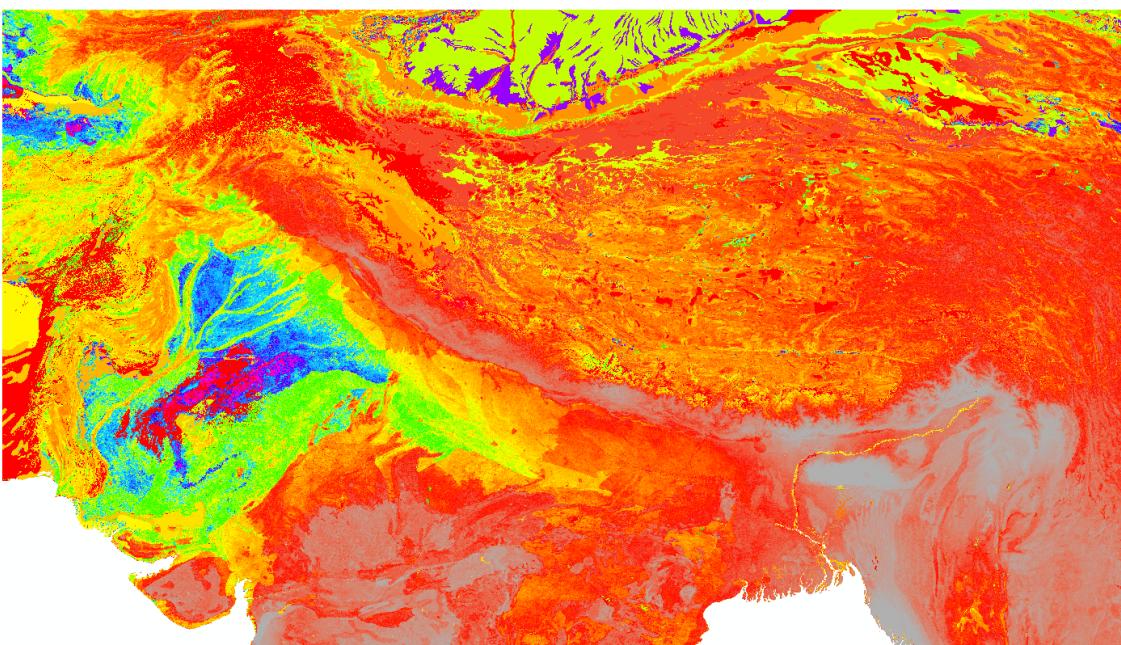


Figure 75: HiHydroSoil saturated conductivity of the topsoil layer in the Hindu Kush-Himalaya database.

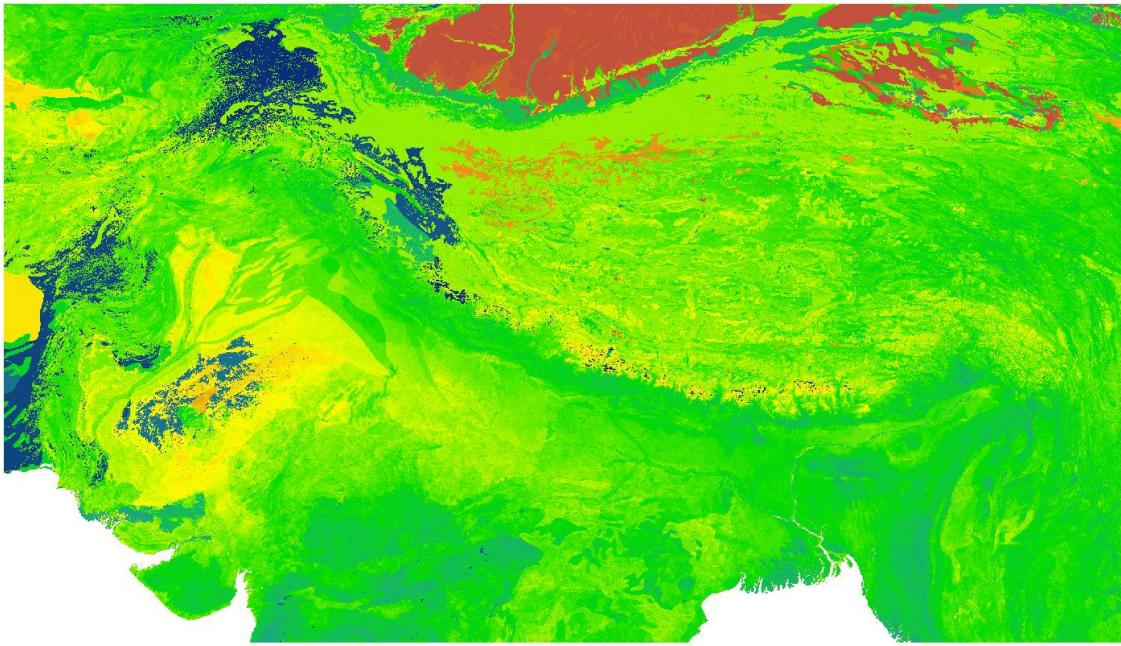


Figure 76: HiHydroSoil field capacity of the topsoil layer in the Hindu Kush-Himalaya database.

Data format and size	8 x GeoTiff 39 MB		
Values	Top Soil Saturated water content (WCSat (mm/mm)) Field capacity (pF2 (mm/mm)) Wilting point (pF3 (mm/mm)) Permanent wilting point (pF4.2 (mm/mm)) Saturated conductivity (Ksat (mm/day))	Sub Soil Saturated water content (WCSat, mm/mm) Field capacity (pF2 (mm/mm)) Saturated conductivity (Ksat (mm/day))	
Projection	Geographic (LAT/LON) WGS1984 (EPSG:4326)		
Spatial resolution	0.0083° (~800m)		
Extent (dd):	xmin: 65.00	xmax: 100.00	ymin: 20.00 ymax: 40.00

Latitude

SPHY requires each grid cell's latitude for the calculation of the reference evapotranspiration using the Modified-Hargreaves equation (Droogers and Allen, 2002). The latitude is derived for a $0.01^\circ \times 0.01^\circ$ grid covering the dataset domain.

Data format and size	GeoTiff 56 MB		
Values	Latitude values (LAT) in decimal degrees		
Projection	Geographic (LAT/LON) WGS1984 (EPSG:4326)		
Spatial resolution	0.01° (~1000m at the equator)		
Extent (dd):	xmin: 65.00	xmax: 100.00	ymin: 20.00 ymax: 40.00



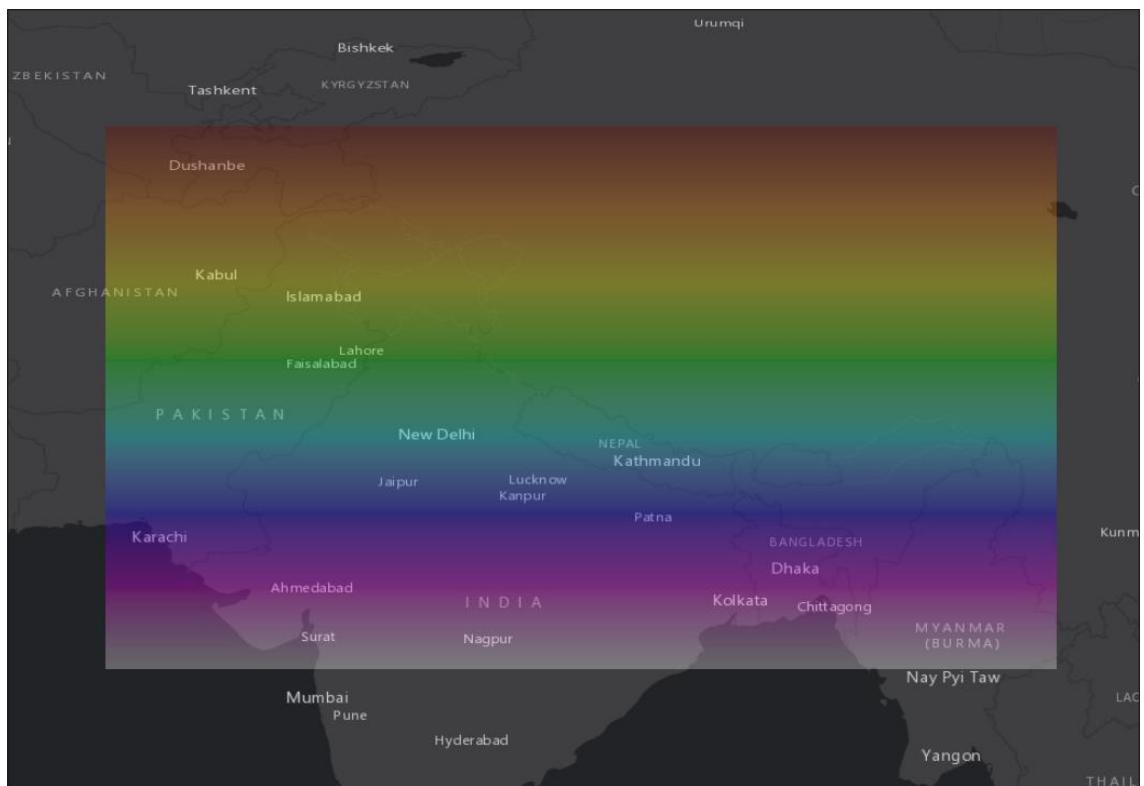


Figure 77: Latitude values for the Hindu Kush-Himalaya database.

Watch Forcing Data ERA-INTERIM (WFDEI)

The WFDEI dataset (Weedon et al., 2014) is clipped for the domain covering the Hindu Kush-Himalaya region, including the downstream basins of Indus, Ganges and Brahmaputra. The data only covers grid cells classified as land, grid cells located in the sea are not included. Initially the Refined High Asia Reanalysis (HAR, (Maussion et al., 2014)) was selected. However, this dataset misses the western part of the upper Indus basins and was therefore considered not to be useful to be included in this dataset. Experiences from ICIMOD's HI-AWARE and Upper Indus basin project showed that the Watch Forcing ERA Interim dataset (WFDEI, (Weedon et al., 2014)), with precipitation data corrected using the GPCC dataset (Schneider et al., 2013) seems to be the most suitable large-scale dataset available.

Average Near surface air temperature at 2 m at time stamp

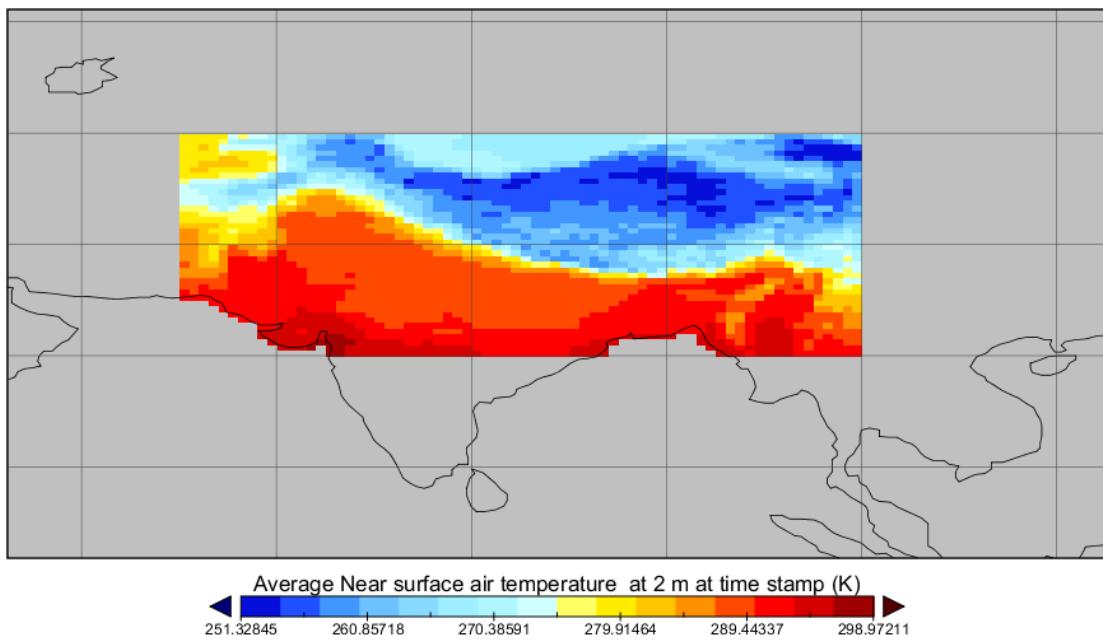


Figure 78: Average air temperature grid from WFDEI for the Hindu Kush-Himalaya database.

Daily mean air temperature:

Data format and size	NetCDF (1 file per month) 118 MB			
Values	Daily mean air temperature (Kelvin)			
Projection	Geographic (LAT/LON) WGS1984 (EPSG:4326)			
Spatial resolution	0.5°			
Extent (dd):	xmin: 65.00	xmax: 100.00	ymin: 20.00	ymax: 40.00
Time step	Daily			
Period covered	1 January 1981 – 31 December 2010			

Daily maximum air temperature:

Data format and size	NetCDF (1 file per month) 118 MB			
Values	Daily maximum air temperature (Kelvin)			
Projection	Geographic (LAT/LON) WGS1984 (EPSG:4326)			
Spatial resolution	0.5°			
Extent (dd):	xmin: 65.00	xmax: 100.00	ymin: 20.00	ymax: 40.00
Time step	Daily (calculated as maximum from 3-hourly data)			
Period covered	1 January 1981 – 31 December 2010			

Daily minimum air temperature:

Data format and size	NetCDF (1 file per month) 118 MB			



Values	Daily minimum air temperature (Kelvin)			
Projection	Geographic (LAT/LON) WGS1984 (EPSG:4326)			
Spatial resolution	0.5°			
Extent (dd):	xmin: 65.00	xmax: 100.00	ymin: 20.00	ymax: 40.00
Time step	Daily (calculated as minimum from 3-hourly data)			
Period covered	1 January 1981 – 31 December 2010			

Daily precipitation:

Data format and size	NetCDF (1 file per month) 118 MB			
Values	Precipitation rate ($\text{kg m}^{-2} \text{s}^{-1}$)			
Projection	Geographic (LAT/LON) WGS1984 (EPSG:4326)			
Spatial resolution	0.5°			
Extent (dd):	xmin: 65.00	xmax: 100.00	ymin: 20.00	ymax: 40.00
Time step	Daily (calculated as sum of rain and snow)			
Period covered	1 January 1981 – 31 December 2010			



Appendix 3: Southeast Africa database

Download link:

[Southeast Africa database](#)

Database extent:

Xmin: 17.7519

Xmax: 41.4365

Ymin: -27.9968

Ymax: -7.7807

HydroSheds SRTM DEM

The included Digital Elevation Model (DEM) is the USGS HydroSheds hydrologically conditioned DEM (Lehner et al., 2006). The data is based on the SRTM DEM and public available through <http://hydrosheds.cr.usgs.gov>. The specific product included is the hydrologically conditioned elevation at a spatial resolution of 3 arc-seconds.

Data format and size	GeoTiff 13.1 MB			
Values	Elevation in meters above sea level			
Projection	Geographic (LAT/LON) WGS1984 (EPSG:4326)			
Spatial resolution	3 arc-second (~90 meter at the equator)			
Extent (dd):	xmin: 17.7519	xmax: 41.4365	ymin: -27.9968	ymax: -7.7807





Figure 79: HydroSheds DEM included in the Southeast Africa database.

HydroSheds streams

HydroSheds has also stream lines available as derived from the hydrologically corrected DEM. The data is available as lines shapefile. The data is derived from the 15 arc-seconds DEM.

Data format and size	Shapefile 15 MB			
Values	Line elements with ID and number of upstream cells			
Projection	Geographic (LAT/LON) WGS1984 (EPSG:4326)			
Extent (dd):	xmin: 17.7519	xmax: 40.8292	ymin: -27.9968	ymax: -7.7807



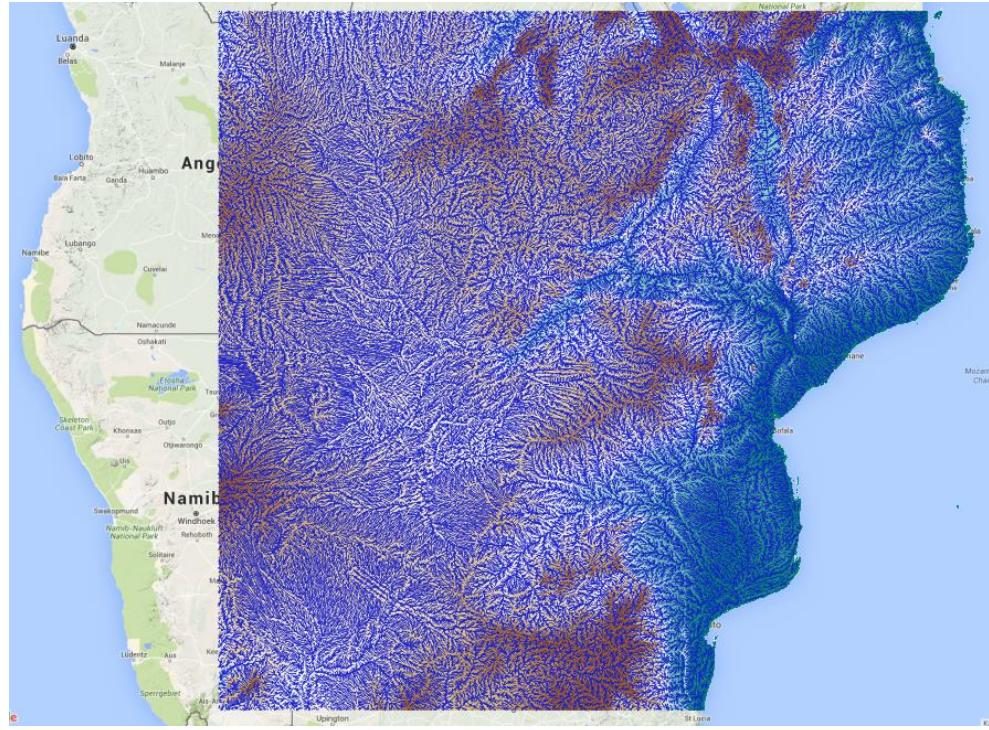


Figure 80: HydroSheds streams included in Southeast Africa database.

HydroSheds basins

HydroSheds also has river basins available, which is derived from the hydrologically corrected DEM. This data is available as polygon shapefile, and is derived from the 15 arc-seconds DEM. The basins included in the Southeast Africa database are shown in Figure 81.

Data format and size	Shapefile 2.5 MB			
Values	Polygon elements with ID and basin area in km ²			
Projection	Geographic (LAT/LON) WGS1984 (EPSG:4326)			
Extent (dd):	xmin: 17.7519	xmax: 40.8417	ymin: -27.9968	ymax: -7.7807



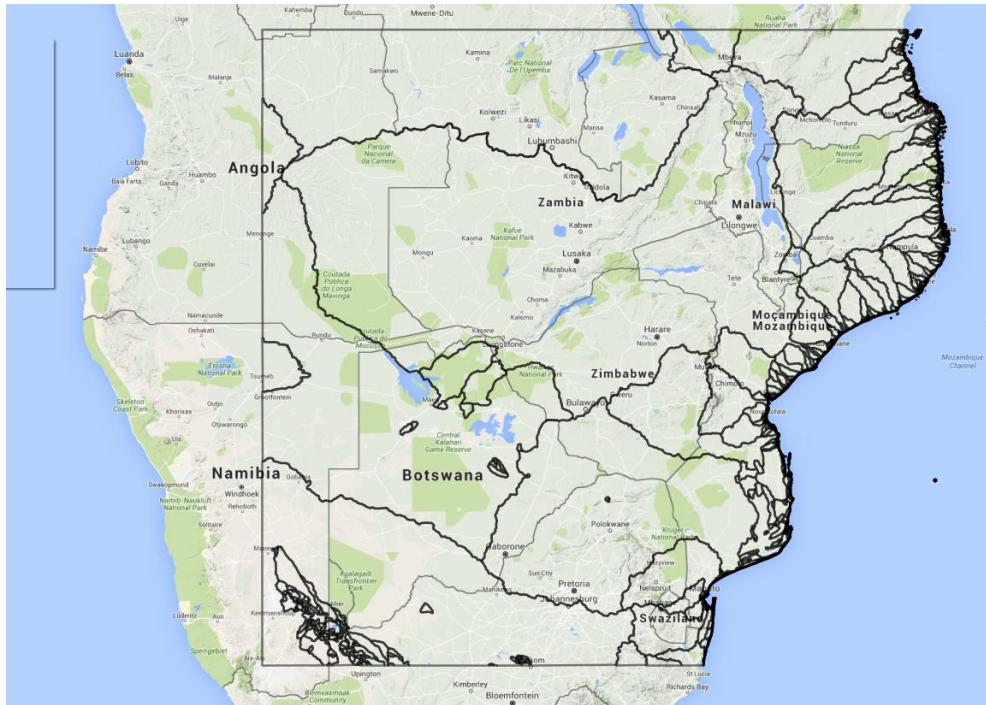


Figure 81: River basins shapefile included in the Southeast Africa database.

GlobCover Land use data

GlobCover (Defourny et al., 2007) is an ESA initiative which began in 2005 in partnership with JRC, EEA, FAO, UNEP, GOFC-GOLD and IGBP. The aim of the project was to develop a service capable of delivering global composites and land cover maps using as input observations from the 300m MERIS sensor on board the ENVISAT satellite mission. ESA makes available the land cover maps, which cover 2 periods: December 2004 - June 2006 and January - December 2009. The latter is included in the dataset. A quick scan comparing different available public domain global land use datasets shows that GlobCover is the most reliable at the moment.

Data format and size	GeoTiff 7 MB			
Values	Land use classes (categorical as integer values)			
Projection	Geographic (LAT/LON) WGS1984 (EPSG:4326)			
Spatial resolution	30 arc-second (~900 meter at the equator)			
Extent (dd):	xmin: 17.7519	xmax: 41.4365	ymin: -27.9968	ymax: -7.7807



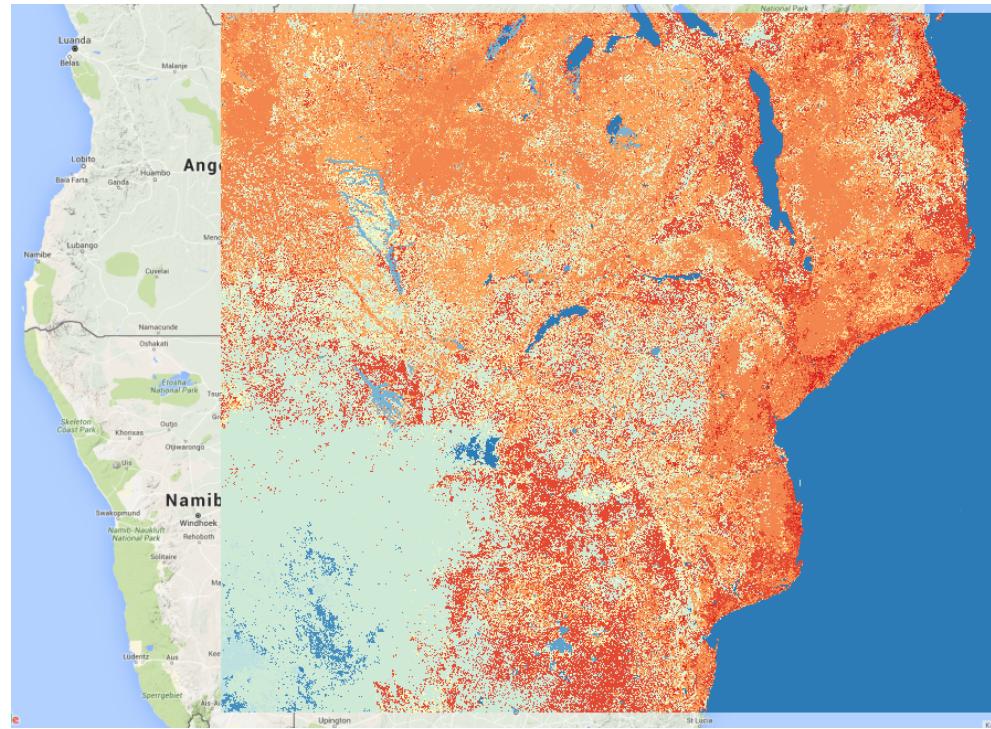


Figure 82: GlobCover domain included in the Southeast Africa database.

HiHydroSoil

FutureWater has developed a new global soil product containing quantitative hydrological properties, as required by most hydrological models, including SPHY (Terink et al., 2015a). This global physical soil properties product (HiHydroSoil) is based on the SoilGrids1km database. The Harmonized World Soil Database (HWSD) is used to fill missing data in the SoilGrids1km. Pedotransfer functions are used to estimate physical soil properties from soil type. A detailed description of the HiHydroSoil product can be found in de Boer (2015).



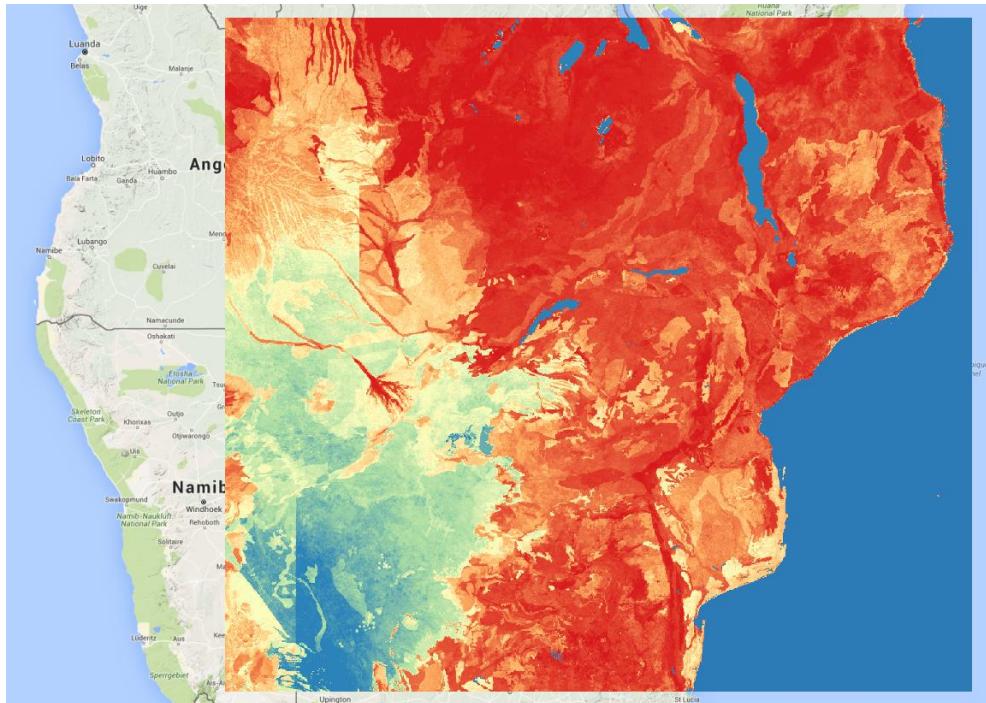


Figure 83: HiHydroSoil saturated conductivity of the topsoil layer in the Southeast Africa database.

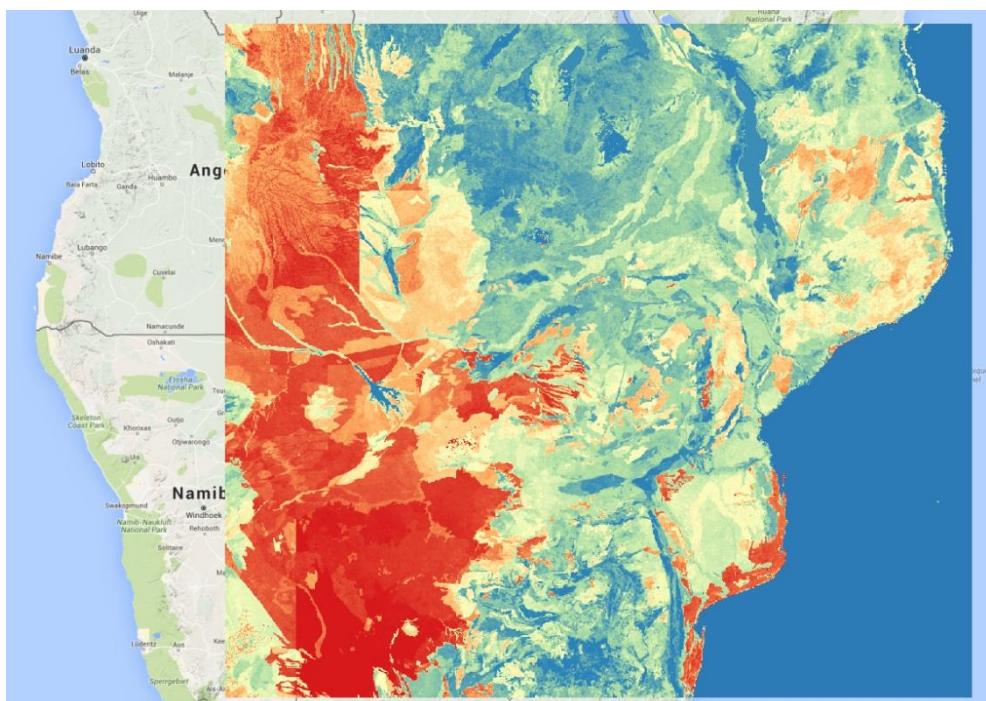


Figure 84: HiHydroSoil field capacity of the topsoil layer in the Southeast Africa database.

Data format and size	8 x GeoTiff 28 MB	
Values	Top Soil Saturated water content (WCSat (mm/mm)) Field capacity (pF2 (mm/mm))	Sub Soil Saturated water content (WCSat, mm/mm) Field capacity (pF2 (mm/mm))



	Wilting point (pF3 (mm/mm)) Permanent wilting point (pF4.2 (mm/mm)) Saturated conductivity (Ksat (mm/day))	Saturated conductivity (Ksat (mm/day))		
Projection	Geographic (LAT/LON) WGS1984 (EPSG:4326)			
Spatial resolution	0.0083° (~800m)			
Extent (dd):	xmin: 17.7519	xmax: 41.4365	ymin: -27.9968	ymax: -7.7807

Latitude

SPHY requires each grid cell's latitude for the calculation of the reference evapotranspiration using the Modified-Hargreaves equation (Droogers and Allen, 2002). The latitude is derived for a 0.00833° x 0.00833° grid covering the dataset domain.

Data format and size	GeoTiff 29 MB			
Values	Latitude values (LAT) in decimal degrees			
Projection	Geographic (LAT/LON) WGS1984 (EPSG:4326)			
Spatial resolution	0.00833° (~1000m at the equator)			
Extent (dd):	xmin: 17.7519	xmax: 41.4365	ymin: -27.9968	ymax: -7.7807

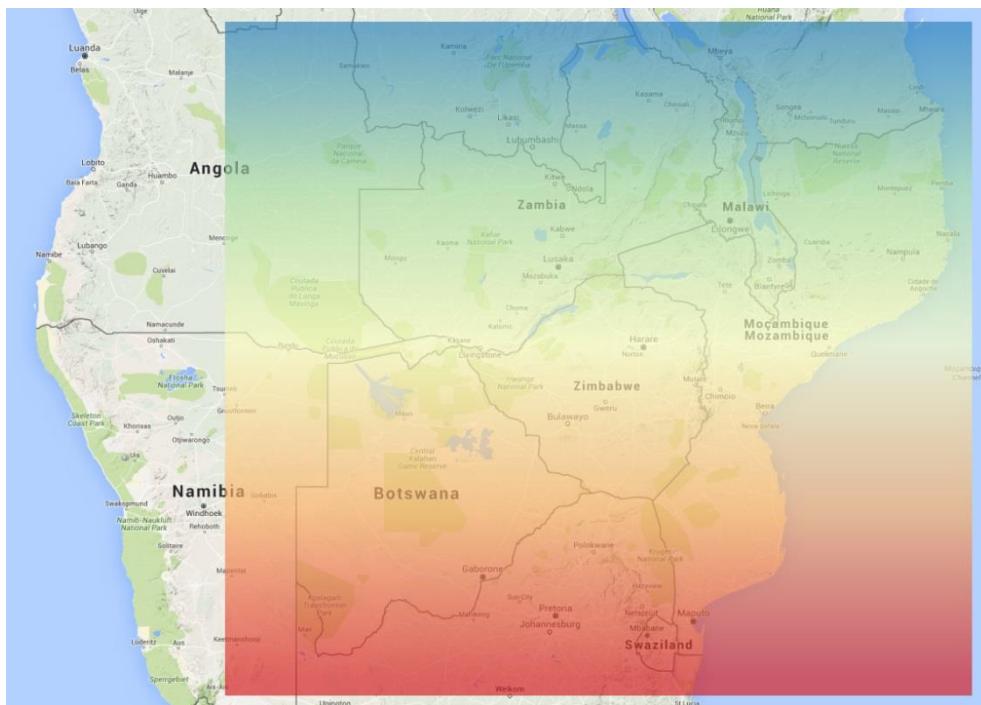


Figure 85: Latitude values for the Southeast Africa database.

FEWS RFE2.0 precipitation



Beginning January 1, 2001 RFE 2.0¹⁰ replaced RFE 1.0 as the operational CPC Africa rainfall algorithm. Along with a dramatically reduced processing time, the new algorithm gives increased accuracy and enhanced code portability. The output domain is 20W-55E, 40S-40N with a 0.1 degree resolution and daily temporal resolution, and each day's time scale is 6Z-6Z. More information about this dataset can be found at <http://www.cpc.noaa.gov/products/fews/data.html>. This dataset has been included in the Southeast Africa database for the extent as shown in the table below.

Data format and size	GeoTiff (1 file per day) 0.5 MB			
Values	Precipitation rate (mm/day)			
Projection	Geographic (LAT/LON) WGS1984 (EPSG:4326)			
Spatial resolution	0.1°			
Extent (dd):	xmin: 17.75	xmax: 41.45	ymin: -27.95	ymax: -7.75
Time step	Daily			
Period covered	1 January 2001 – 31 December 2010			

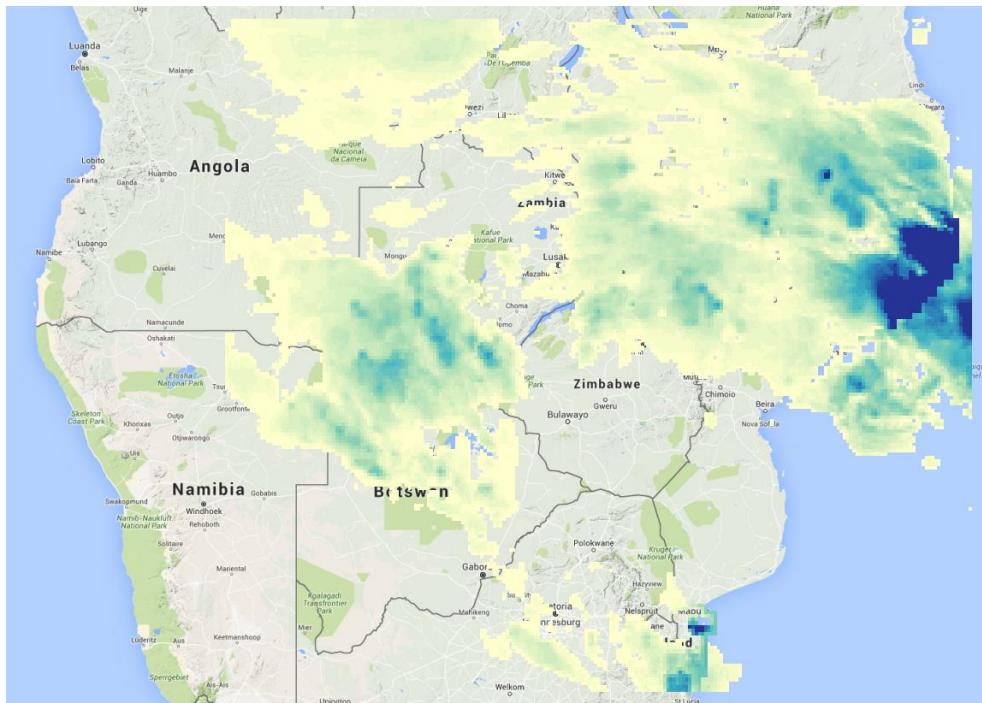


Figure 86: Daily precipitation grid from FEWS RFE2.0 for the Southeast Africa database.

GSOD temperature

The Global Surface Summary of the Day (GSOD¹¹) is derived from The Integrated Surface Hourly (ISH) dataset and provides precipitation and temperature data for more than 9000 stations worldwide. The ISH dataset includes global data obtained from the USAF Climatology Center, located in the Federal Climate Complex with NCDC.

¹⁰ http://www.cpc.noaa.gov/products/fews/RFE2.0_tech.pdf

¹¹ <https://data.noaa.gov/dataset/global-surface-summary-of-the-day-gsod>



For the Southeast Africa database, temperature data (average, maximum, and minimum daily air temperature) from 258 stations has been extracted (Figure 87). This station data has been interpolated to a zero MASL elevation plane, using inverse distance interpolation and a temperature lapse rate of -0.0065 degree/meter. The SPHY preprocessor GUI will interpolate the temperature data to the correct elevation level using the same temperature lapse rate and the HydroSHEDS DEM (Figure 79) for the extent of the area that will be selected in the GUI. The tables below show the properties for the interpolated GSOD temperature data.

Daily mean air temperature at zero MASL elevation plane:

Data format and size	GeoTiff (1 file per day) 0.2 MB			
Values	Daily mean air temperature (degrees Celsius)			
Projection	Geographic (LAT/LON) WGS1984 (EPSG:4326)			
Spatial resolution	0.1°			
Extent (dd):	xmin: 17.75	xmax: 41.45	ymin: -27.95	ymax: -7.75
Time step	Daily			
Period covered	1 January 2001 – 31 December 2010			

Daily maximum air temperature at zero MASL elevation plane:

Data format and size	GeoTiff (1 file per day) 0.2 MB			
Values	Daily maximum air temperature (degrees Celsius)			
Projection	Geographic (LAT/LON) WGS1984 (EPSG:4326)			
Spatial resolution	0.1°			
Extent (dd):	xmin: 17.75	xmax: 41.45	ymin: -27.95	ymax: -7.75
Time step	Daily			
Period covered	1 January 2001 – 31 December 2010			

Daily minimum air temperature at zero MASL elevation plane:

Data format and size	GeoTiff (1 file per day) 0.2 MB			
Values	Daily minimum air temperature (degrees Celsius)			
Projection	Geographic (LAT/LON) WGS1984 (EPSG:4326)			
Spatial resolution	0.1°			
Extent (dd):	xmin: 17.75	xmax: 41.45	ymin: -27.95	ymax: -7.75
Time step	Daily			
Period covered	1 January 2001 – 31 December 2010			



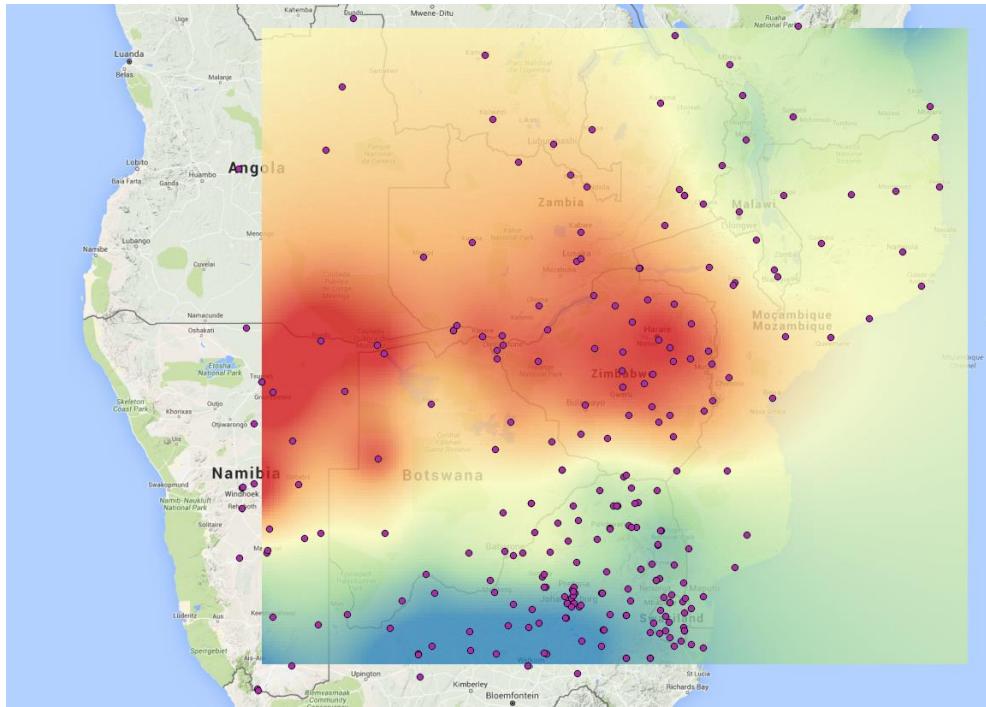


Figure 87: Daily air temperature grid from GSOD for the Southeast Africa database, interpolated at a zero MSL elevation plane, using a lapse rate of -0.0065 degree/meter.

