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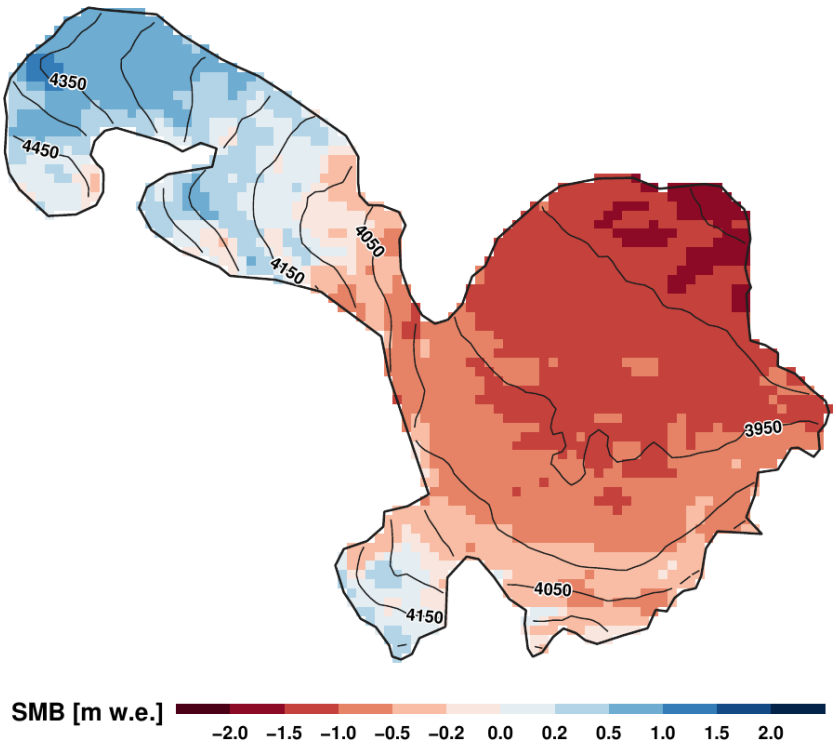
DMBSim v1.0

Tutorial 1: installation and simulation of single-year glacier mass balance



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1 Introduction

In this first tutorial we are going to install the model and then simulate the mass balance of Yakarcha glacier (Pamir-Alay) over one year (2020). We will proceed like this:

- Install the **required programs**
- Prepare the model **input files**
- Setup the model **parameters**
- **Run the model.**

2 Installation

We install the required programs in this order: first **R**, then **RStudio**, finally the **R packages** which are used by the model. If you have already installed some of the programs, you can skip the corresponding sections. To install everything, you need an internet connection and at least 2 GB of free disk space. **All steps below are required**, if any one of them goes wrong you should correct it or the model will not work properly.

- **Download and install R.** For the Windows operating system, download the installer from this page. For other operating systems, see the landing page. After download, open the installer and follow the instructions until installation is complete.
- **Download and install RStudio.** Go to this page and download the installer which corresponds to your operating system (usually Windows 10). Again, open the installer and proceed until RStudio is installed.
- To install the **required R packages** we use the program *install_packages.R*, which you can find inside *utils* in the model folder. Open file *install_packages.R* in RStudio and click on the *Source* button (Fig. 1) to run the program.

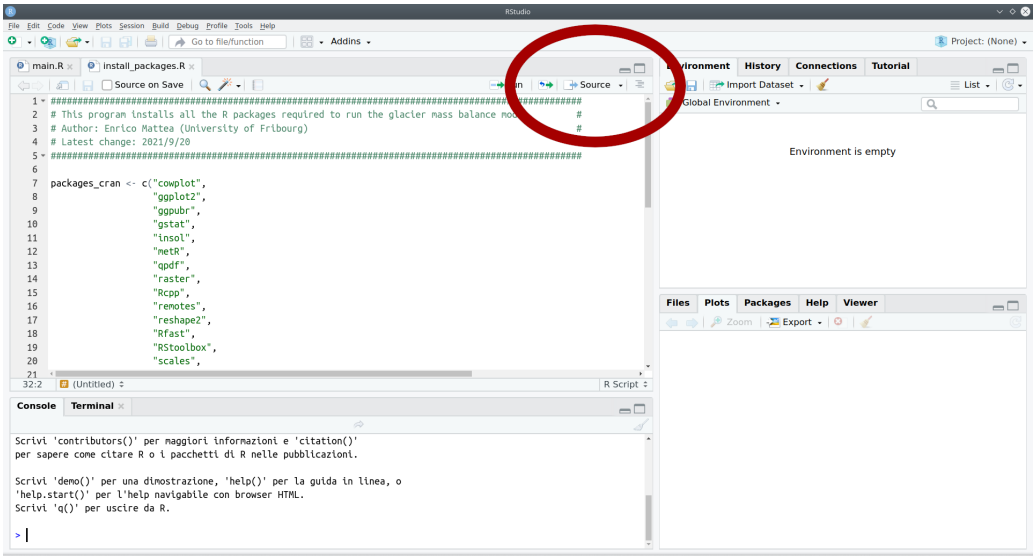

Figure 1: The Source button in RStudio.

- The program will download and install several packages **automatically**. After some time it will open a new window to install "Rtools": simply click "Next" and "Install" to proceed.
- When *install_packages.R* has finished (message **"All packages installed succesfully!"**), you should **close RStudio.**

3 Input files

3.1 Overview

For the mass balance model we have to provide some input data. It is **important to put the input data in the right place:** all the input data should go **inside the model folder,** in a folder called *input*. There **we create a sub-folder with the name of the glacier:** *input\yakarcha*. The name of the glacier should **not have any white spaces** (so for example we would use *batysh_sook* instead of *batysh sook*). Now we prepare the following input data for the model:

- a text file with the daily **meteorological series**
- a text file with the **mass balance measurements**
- a **glacier outline** in vector format (shapefile)
- an **elevation grid** (called "DHM": the full rectangle covering the glacier region, with no missing values)
- a grid of **surface type** (ice, firn, debris)
- 365 grids of **daily solar radiation.**

The first two (meteo and mass balance) are provided together with this tutorial, in folder *tutorial1_input\yakarcha*. To prepare **the last three** (elevation, surface type and radiation grids) we will use the program *make_input.R*, located in the model folder *utils*. This program will create and process the files **automatically.**

3.2 Meteorological series

The meteorological series goes into a simple text file, with 5 columns: **year, day of year (1-365), hour, temperature, precipitation** (Fig. 2). We call this meteo file *weather_yakarcha.dat* and we place it into a new folder: *input\yakarcha\weather*. The model works at **daily resolution**: "temperature" is the daily mean temperature, "precipitation" the total daily precipitation (in mm w.e., including solid and liquid), and the "hour" column has a constant value 12 for every day. As you can see in Fig. 2, **the meteo file can have a comment text** at the beginning, to explain what is inside. Later we can tell the model to ignore these comment lines.

Note: the meteo file must have **data for every day** which is modeled. The model always includes **the entire hydrological year** (1 October-30 September) in the simulation. The model also includes **the entire period measured** at the stakes. We want to model year 2020, with mass balance stakes visited on 14.8.2019 and again on 13.9.2020. Then we need at least meteo data for every day from 14.8.2019 to 30.9.2020. This is the meteo data which **must be present**, but in the meteo file there can also be (in addition) **the data of other days/years:** the model will select the right data automatically.

```
Yakarcha daily weather (virtual elevation 4000 m),
from ERA5 reanalysis (temperature corrected with lapse rate of -6.5 °C / km, precipitation untouched.
ERA original cell elevation: 2620.8 m
year doy hour t2m_mean precip
2018 1 12 -17.7185480651166 0
2018 2 12 -14.6076480374782 0
2018 3 12 -11.8609889460022 1.39179517586388
2018 4 12 -14.7327949901437 4.10392266821068
2018 5 12 -17.4879757612759 2.5714413503746
2018 6 12 -17.9348769901036 0.0203597889974231
2018 7 12 -17.43855001927 3.51552476618514
2018 8 12 -17.8744948028253 2.10866334646316
2018 9 12 -17.952224695118 0.197489953275004
2018 10 12 -17.7166002526239 0.27282117256547
2018 11 12 -17.6719831727096 2.55230314871702
```

Figure 2: The first lines of the meteo file.

3.3 Mass balance measurements

The mass balance measurements go into a simple text file, with 8 columns: **point name** (with no spaces), **start date, end date, X coordinate, Y coordinate, altitude, measured change at the stake, measured density** (Fig. 3). We call this file *mb_yakarcha.dat* and we place it into a new folder: *input\yakarcha\massbalance*. We are modeling the year 2020, so the "start date" is in summer 2019, the "end date" in summer 2020. The format is "day.month.year", such as 14.8.2019 for 14 August 2019. The X and Y coordinates should be in meters (UTM: for Yakarcha, we use UTM zone 42N, which is also called EPSG:32642). The **measured change at the stake** is **in centimeters**, > 0 for accumulation and < 0 for ablation. **Density** is in g cm^{-3} (water $= 1$, ice $= 0.9$). Our measurements at Yakarcha are already in centimeters water-equivalent (cm w.e.), so we use density $= 1$.

```
J1 14.8.2019 13.9.2020 462352.2 4315323 3861 -184.5 1
J2 14.8.2019 13.9.2020 462306.8 4315214 3897 -143.1 1
J3 14.8.2019 13.9.2020 462391.6 4315047 3924 -95.4 1
J4 14.8.2019 13.9.2020 462160.3 4314959 3939 -49.5 1
J5 14.8.2019 13.9.2020 461830.9 4314790 3989 -107.1 1
J6 14.8.2019 13.9.2020 461683.5 4315132 4049 -207.9 1
J7 14.8.2019 13.9.2020 461357.0 4315641 4227 -150.3 1
```

Figure 3: The file with the mass balance measurements.

3.4 Glacier outline

The glacier outline is a polygon which delimits the glacier surface (Fig. 6). To create the outline shapefile we draw it manually over a satellite image of the glacier, taken by Sentinel-2. We download the image from the EarthExplorer portal. To draw the outline we use the program QGIS, but you can also use ArcGIS or any other program you like. **Note:** if you already have a method to create the glacier outline shapefile, you can use it instead of these steps below.

- If you don't have an account on EarthExplorer, first create one here: https://ers.cr.usgs.gov/register.
- Login here: https://ers.cr.usgs.gov/login.
- Now go to the portal: https://earthexplorer.usgs.gov/.
- On the map, we move to the glacier (38° 59' North, 68° 34' East).
- We click three points to draw a triangle over the glacier (Fig. 4).

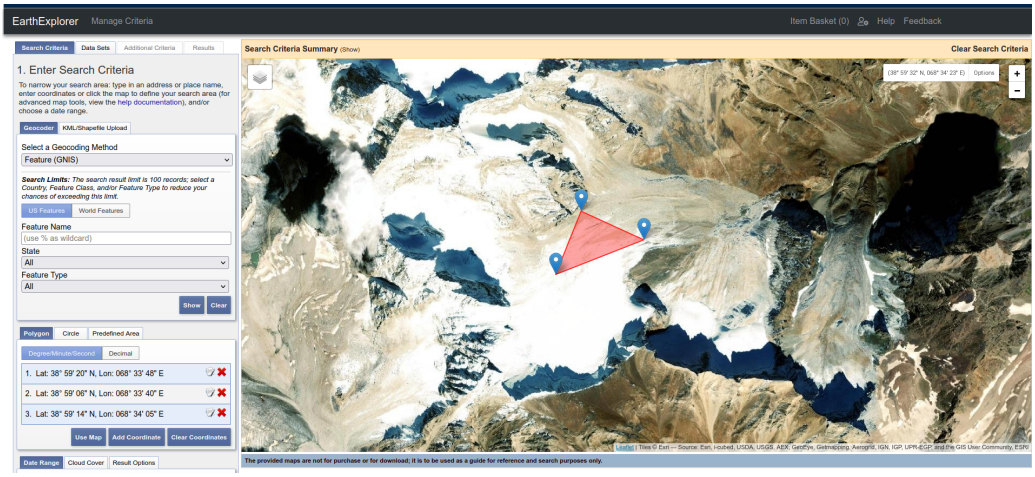

Figure 4: The EarthExplorer portal at Yakarcha glacier.

- In the left column, we select **Data Sets** → **Sentinel** → **Sentinel-2**, then we click **Results** (Fig. 5).
- In the left column a list of images appears, on many pages. We choose the one called *L1C_T42SVJ_A027301_20200913T060752*, with "Acquisition Date" 2020/09/13, and we download the "L1C Tile in JPEG2000 format".
- We extract the zip file and we open in QGIS the file located under GRANULE → *L1C_T42SVJ_A027301_20200913T060752* → *IMG_DATA* → *T42SVJ_20200913T060641_B04.jp2*.
- In QGIS we move to the glacier and we click on **Layer** → **Create Layer** → **New Shapefile Layer**, geometry type **Polygon**, file name *outline_yakarcha_2020.shp*, coordinates system **EPSG:32642**.
- Then we manually trace the glacier outline: we click on **Toggle Editing** and **Add Polygon Feature**, then we draw the polygon following the glacier outline (Fig. 6).
- Finally we click again on **Toggle Editing** and we save the changes.

The shapefile is made of 5 separate files, which end with .shp, .shx, .dbf, .prj and .cpg. We move all of them to a folder called *input\yakarcha\outline*.

3.5 DEM

The glacier topography is defined by a DEM file. We download this file from EarthExplorer: the procedure is the same as for the Sentinel-2 image (see above), but the file is located under **Data Sets** → **NASA LPDAAC collections** → **ASTER collections** → **Aster Global DEM V3** (don't forget to **remove** the previous Data Sets **(Sentinel** → **Sentinel-2)** before clicking on **Results**). When you try to download the DEM, EarthExplorer can ask you to do a login: in this case you can register here. We download the GeoTIFF format and extract the .zip archive. The important file is *ASTGTMV003_N38E068_dem.tif*, for the moment we leave it where it is: we will use it in the next step.

Note: if you want to use a different DEM, you can have a look at this excellent list. It is important to use a DEM with **no gaps/voids/NAs**, these will not work in the mass balance model.

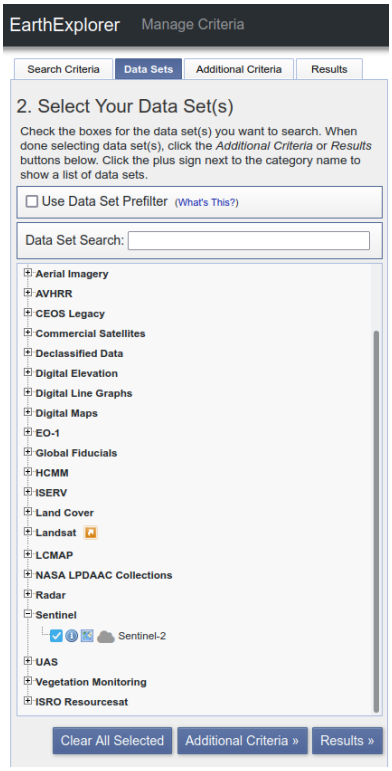

Figure 5: The EarthExplorer portal: selecting the Sentinel-2 dataset.

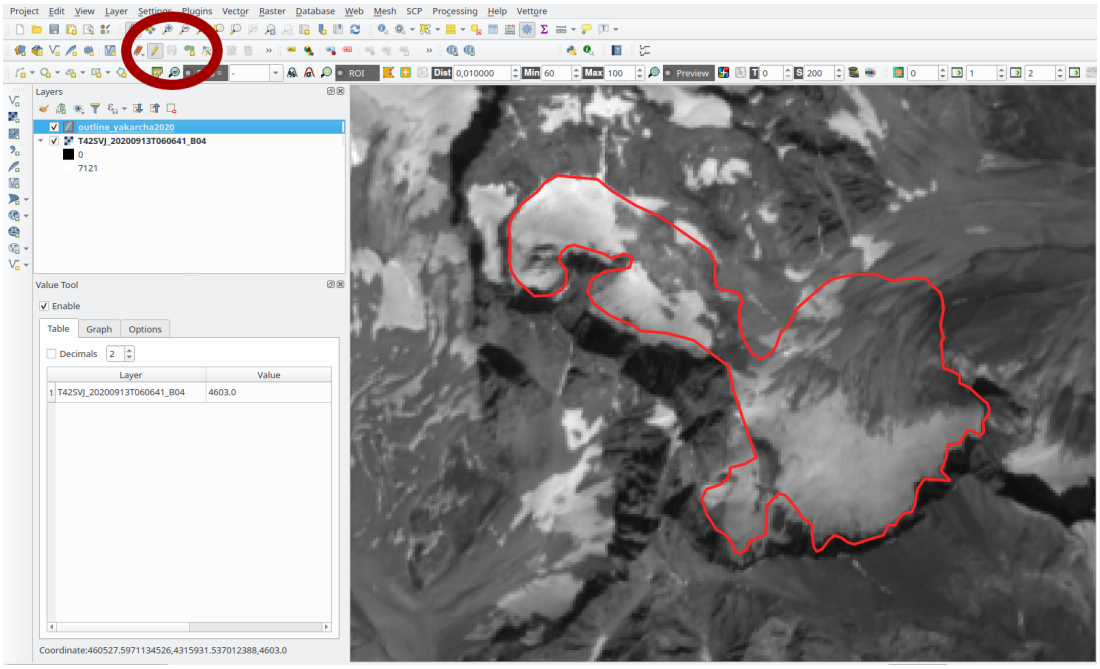

Figure 6: The glacier outline traced in QGIS over the Sentinel-2 image. The red circle shows the **Toggle Editing** and **Add Polygon Feature** buttons.

3.6 Program *make_input.R*

We use program *make_input.R* to prepare the input files which are still missing.

- First we open with RStudio the file *make_input.R* (inside folder *utils*\).
- We click on **Run App** (Fig. 7).
- A new window opens: **Mass balance model assistant**.
- We enter the **glacier name**. This is the same as the folder where we are putting the input files: *yakarcha*.
- We enter the **modeled year**: 2020.
- We click button **Choose one or more input DEM files** and we select the file which we have just downloaded: *ASTGTMV003_N38E068_dem.tif*.
- We click button **Choose input glacier shapefile** and we select the outline shapefile which we have created before: *input**outline**outline_yakarcha_2020.shp*.
- We don't touch the other buttons, in the text field we **choose a margin size** of 100 m around the outline.
- We select **Compute daily potential solar radiation**.
- Finally we click on button **RUN!** (Fig. 8).
- The program is now working, it can take a few minutes. You can **follow the progress in the big window of RStudio**.
- When the program has finished (notification **Processing finished**), inside the *utils*\ folder there is a new folder, called *yakarcha*\. This contains folders *dhm*\, *radiation*\ and *surftype*\. We move these to the folder *input**yakarcha*\.
- **In the end the input folder looks like Fig. 9:** under *input**yakarcha*\ there are 6 folders (*dhm*\, *massbalance*\, *outline*\, *radiation*\, *surftype*\ and *weather*\). Folder *outline*\ contains the shapefile (5 files), folder *radiation*\ contains 365 radiation grids (the first one is called *dir00124.tif*), and the other folders have only 1 file each.

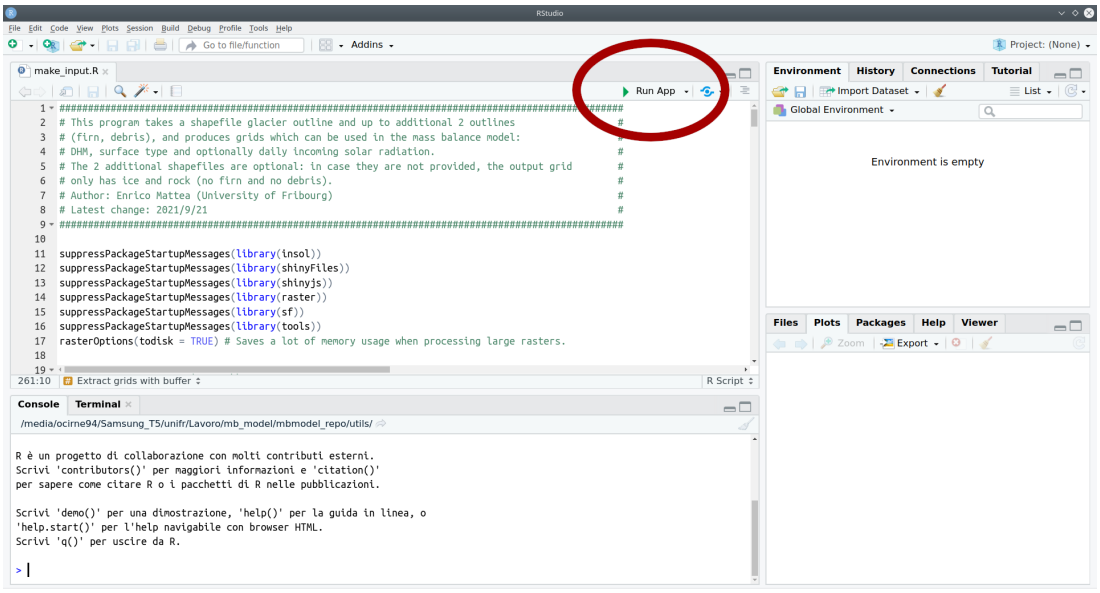

Figure 7: The **Run App** button in RStudio.

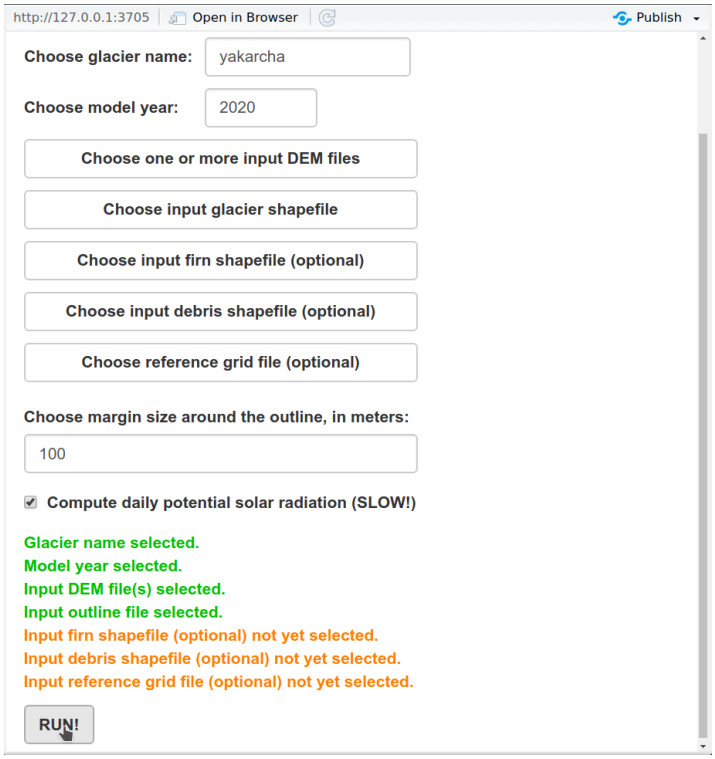

Figure 8: The *make_input.R* window after selecting the data, ready to click on **RUN!**

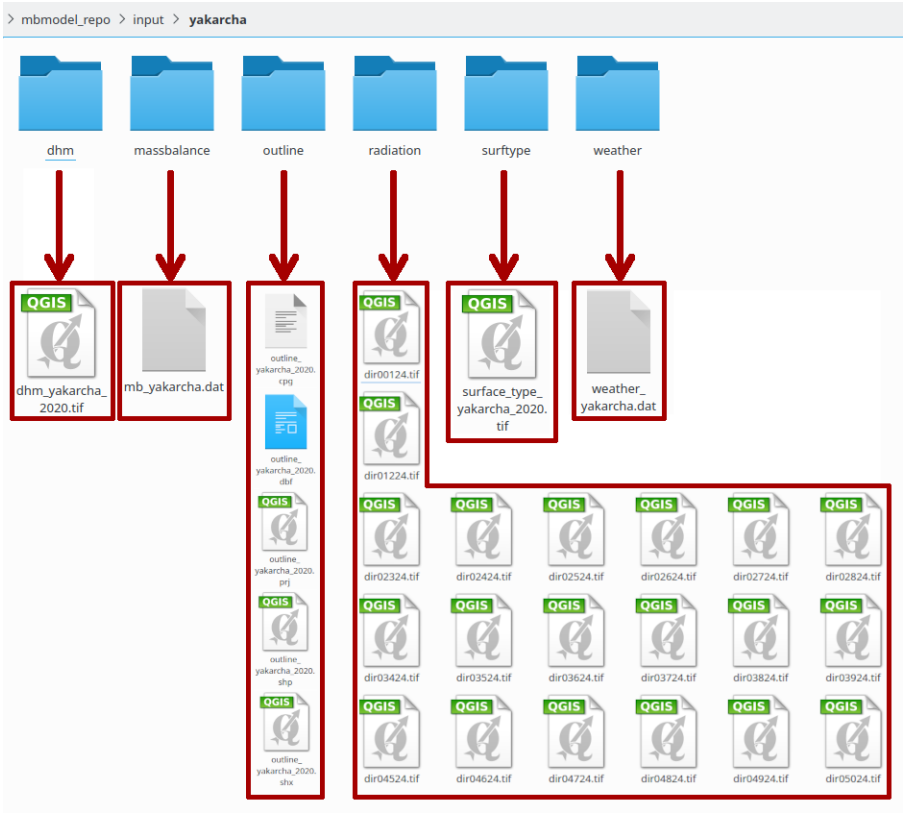

Figure 9: The folder *input\yakarcha* after preparing all the input data.

4 Model parameters

The model parameters are set in a file called *set_params.R*, in the model folder. We **open this file in RStudio,** and we set the parameters as shown in Table 1. There are many other parameters which can be set, but in this first simulation we only set the most important ones. When we change the parameters it is **important to keep the same format:** the **quotes** ("") and the **commas** (,) should **remain the same,** or the model will not work.

Table 1: model parameters which we change in this tutorial

Parameter name	**Value**	**Explanation**
name_glacier	"yakarcha"	Glacier name, it is the **same as the folder** under *input*\
filename_weather	"weather_yakarcha.dat"	Name of the meteo file, which we set in section 3.2
file_weather_nskip	4	Number of lines to skip in the meteo file, there are 4 lines which are not data (Fig. 2)
grids_crs	32642	EPSG code of the coordinates system, 32642 is UTM zone 42N. The list of codes is here
filename_outline_prefix	"outline_yakarcha"	First part of the outline file name, **before the year**. We called the file "outline_yakarcha2020.shp" in section 3.4 above, so the part before the year is "outline_yakarcha"
filename_outline_suffix	""	Last part of the outline file name, **after the year but before the .shp**: there is nothing, so we leave an empty string ("")
filename_massbalance_annual	"mb_yakarcha.dat"	Name of the **file with the annual mass balance measurements,** which we set in section 3.3
filename_massbalance_winter	""	Name of the file with the winter mass balance measurements. We don't have this so we leave it empty ("")
weather_aws_elevation	4000	Altitude of the meteo data. The Yakarcha file refers to an altitude of 4000 m
first_year	2020	First year which we want to simulate: 2020
last_year	2020	Last year which we want to simulate, we want to do just one year so it is again 2020

5 Running the model

After setting the parameters, we can run the model very simply: we just open in RStudio the file *main.R* and we click on *Source* (Fig. 1).

6 Output files

The model output is written to a folder called *output_yakarcha*. The **detailed results** are in file *massbalance_2020.pdf*, under *output\yakarcha\annual_results*:

- Mass balance map over the hydrological year (from 1 October 2019 to 30 September 2020).
- Mass balance map over the measurement period (14 August 2019 to 13 September 2020).
- Mass balance map over the annual measurement period, with a **local correction of the model result** based on the stakes. This is called **"Measurement period (annual, corrected)"**.
- Mass balance map over the winter period (1 October 2019 to 30 April 2020).
- Input meteorological series (temperature and precipitation).
- Daily time series of the cumulative **mass balance over the entire glacier**, also with the separate components of melt and accumulation.
- Daily melt amounts.
- Altitudinal profile of the mass balance
- Daily time series of the cumulative mass balance at the stakes.

The **mass balance maps** are also written to individual .tif files (example: *mb_annual_hydro_2020.tif*), which you can open in QGIS or ArcGIS. The other values are written to plain-text files (example: *mb_daily_series_glacier_2020.csv*).

The model also makes a summary of the results into two **overview files**: *output_yakarcha_overview.pdf* and *output_yakarcha_overview_areaplot.pdf*.