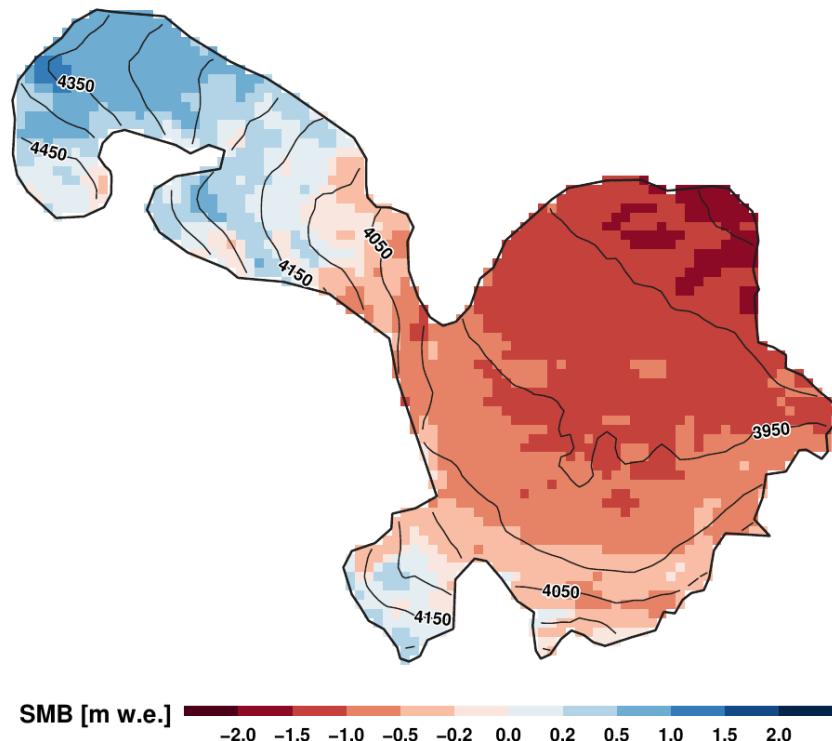


DMBSim v1.0

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**, then **RTools** (only if you use the Windows operating system), 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 of the most recent version 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.
- (Only if you use the Windows operating system) **Download and install RTools.** Go to [this page](#) and download the Rtools43 installer. Open the installer and proceed until RTools 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.

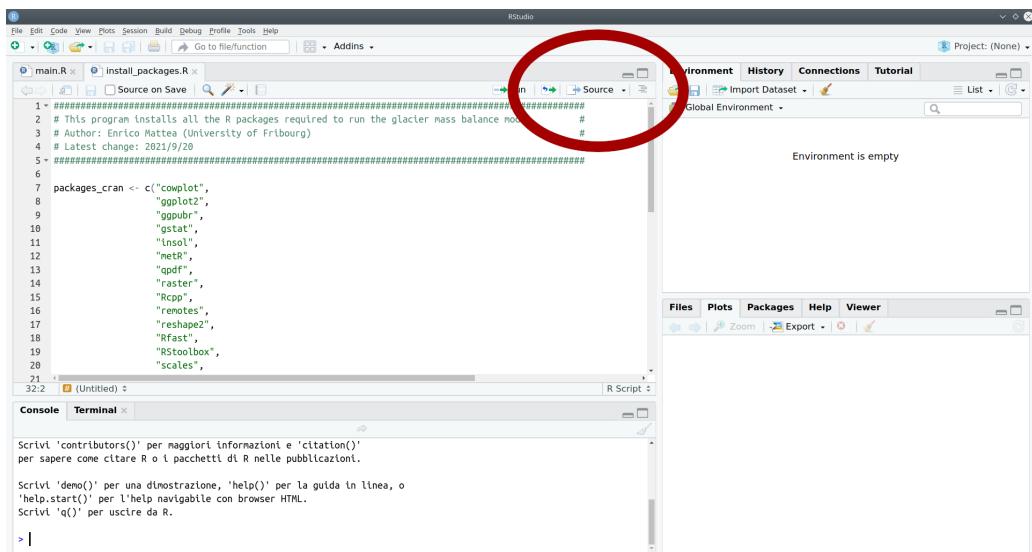


Figure 1: The Source button in RStudio.

- The program will download and install several packages **automatically**.
- When *install_packages.R* has finished (message "**All packages installed successfully!**"), 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 four** (outline, 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, or the model will refuse it. 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 correct data automatically.

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. **Note** that in (Fig. 3) some measurements (J8, J9 and J10) have a **special start date NA**: this is used for the summer snow pits and snow probes, where the "starting

```

1 Yakarcha daily weather (virtual elevation 4000 m),
2 from ERA5 reanalysis (temperature corrected with lapse rate of -6.5 °C / km, precipitation untouched.
3 ERA original cell elevation: 2620.8 m
4 year doy hour t2m mean precip
5 2018 1 12 -17.7185480651166 0
6 2018 2 12 -14.6076480374782 0
7 2018 3 12 -11.8609889460022 1.39179517586388
8 2018 4 12 -14.7327949901437 4.10392266821068
9 2018 5 12 -17.4879757612759 2.5714413503746
10 2018 6 12 -17.9348769901036 0.0203597889974231
11 2018 7 12 -17.43855001927 3.51552476618514
12 2018 8 12 -17.8744948028253 2.10866334646316
13 2018 9 12 -17.952224695118 0.197489953275004
14 2018 10 12 -17.7166002526239 0.27282117256547
15 2018 11 12 -17.6719831727096 2.55230314871702

```

Figure 2: The first lines of the meteo file.

"date" is usually not known (the measured change in this case is defined from the surface **at the end of the previous melting season**). Thus, for all measurements with start date NA **the model automatically sets the start date** at the end of the previous melting season.

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.

1	J1	14.8.2019	13.9.2020	462352.2	4315323	3861	-184.5	1
2	J2	14.8.2019	13.9.2020	462306.8	4315214	3897	-143.1	1
3	J3	14.8.2019	13.9.2020	462391.6	4315047	3924	-195.4	1
4	J4	14.8.2019	13.9.2020	462160.3	4314959	3939	-149.5	1
5	J5	14.8.2019	13.9.2020	461830.9	4314790	3989	-107.1	1
6	J6	14.8.2019	13.9.2020	461683.5	4315132	4049	-107.9	1
7	J7	14.8.2019	13.9.2020	461357.0	4315641	4227	-1.3	1
8	J8	NA	13.9.2020	461268.0	4315671	4260	50.5	1
9	J9	NA	13.9.2020	460968.0	4315752	4327	97.5	1
10	J10	NA	13.9.2020	460963.0	4315585	4387	110.5	1
11								

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 the 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).
- In the left column, we select **Data Sets** → **Sentinel** → **Sentinel-2**, then we click **Results** (Fig. 5).

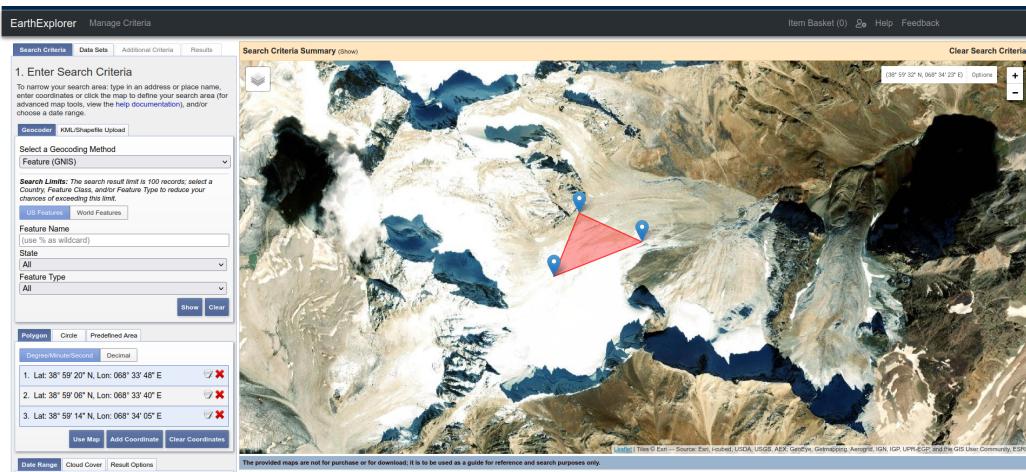


Figure 4: The EarthExplorer portal at Yakarcha glacier.

- 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 keep them ready since we will use them in the next steps.

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](#). A very useful download service for global DEMs is provided by the [OpenTopography](#) website. It is important to use a DEM with **no gaps/voids/NAs**, these will not work in the mass balance model.

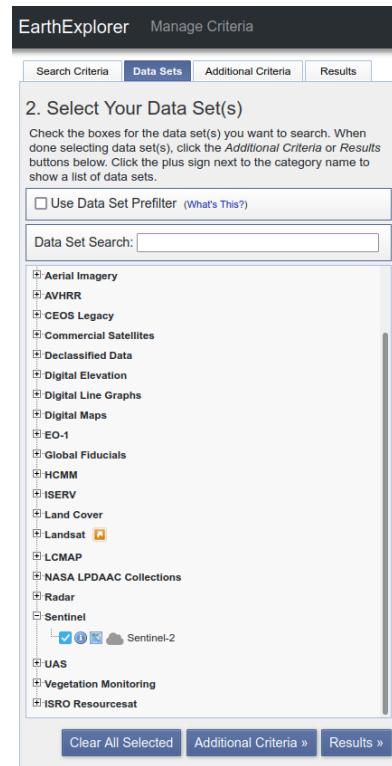


Figure 5: The EarthExplorer portal: selecting the Sentinel-2 dataset.

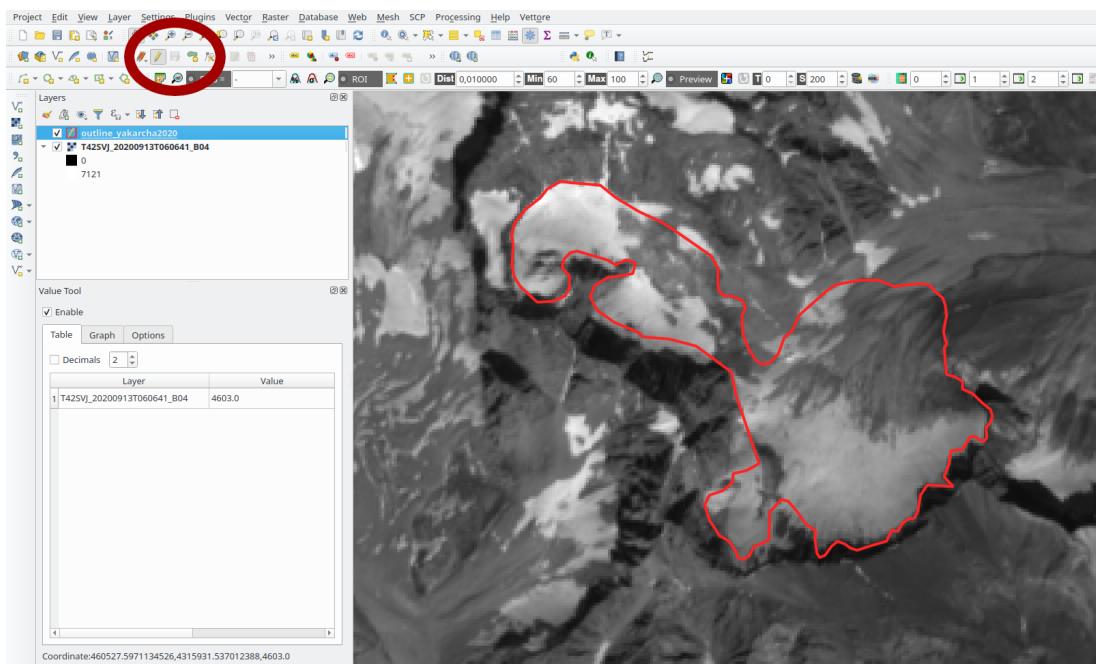


Figure 6: The glacier outline traced in QGIS over the Sentinel-2 image. The red circle shows the **Toggle Editing** and **Add Polygon Feature** buttons.

3.6 Program *make_input.R*

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

Note: it is **not needed to change the coordinate system** of any file: *make_input.R* will always **adjust** all coordinate systems **automatically**.

- 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*. The program can also use **multiple input DEM files** in case the glacier is divided across several tiles: if you provide more than one input DEM, they are merged together before processing.
- We click button **Choose input glacier shapefile** and we select the outline shapefile which we have created before: *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 leave empty the **grid cell size**, it is computed automatically. We can also force a specific cell size by writing a value (in meters).
- 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*\, *outline*\, *radiation*\ and *surftype*\. We **move** all these (the entire folder *utils\yakarcha*\) 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, folder *radiation*\ contains 365 radiation grids (the first one is called *dir00124.tif*), and the other folders have only 1 file each.

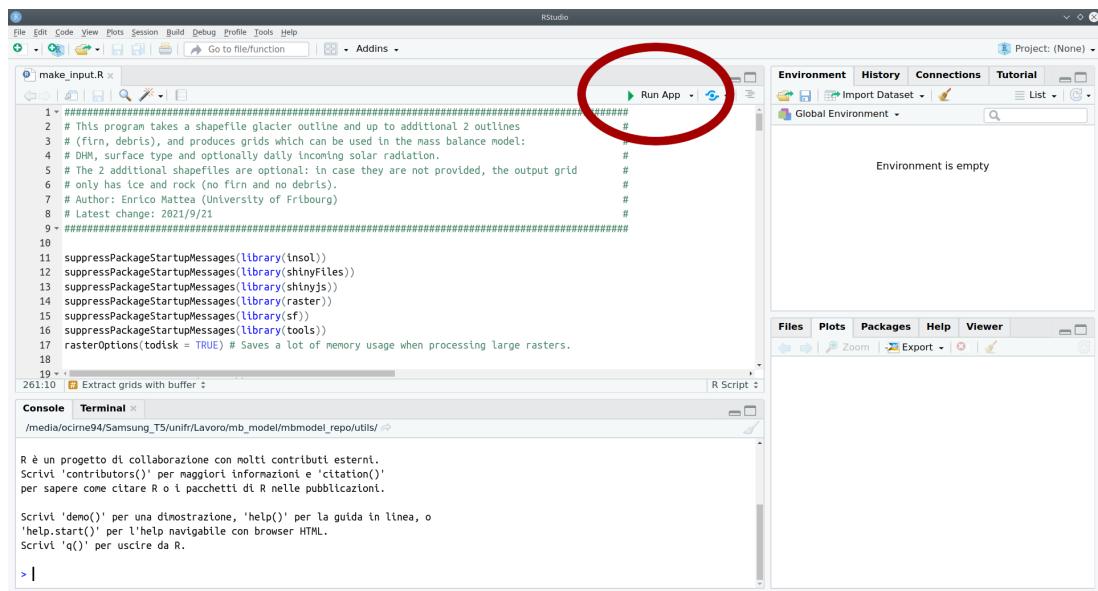


Figure 7: The **Run App** button in RStudio.

The screenshot shows a web-based application window titled 'http://127.0.0.1:3705'. It contains several input fields and status messages:

- Choose glacier name:** yakarcha
- Choose model year:** 2020
- Choose one or more input DEM files**
- Choose input glacier shapefile**
- Choose input firn shapefile (optional)**
- Choose input debris shapefile (optional)**
- Choose reference grid file (optional)**
- Choose margin size around the outline, in meters:** 100
- Choose grid cell size in meters (leave blank for automatic cell size):** (empty input field)
- Compute daily potential solar radiation (SLOW!):**
- Status messages:**
 - Glacier name selected.
 - Model year selected.
 - Input DEM file(s) selected.
 - Input outline file selected.
 - Input firn shapefile (optional) not yet selected.
 - Input debris shapefile (optional) not yet selected.
 - Input reference grid file (optional) not yet selected.
- RUN!** button

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

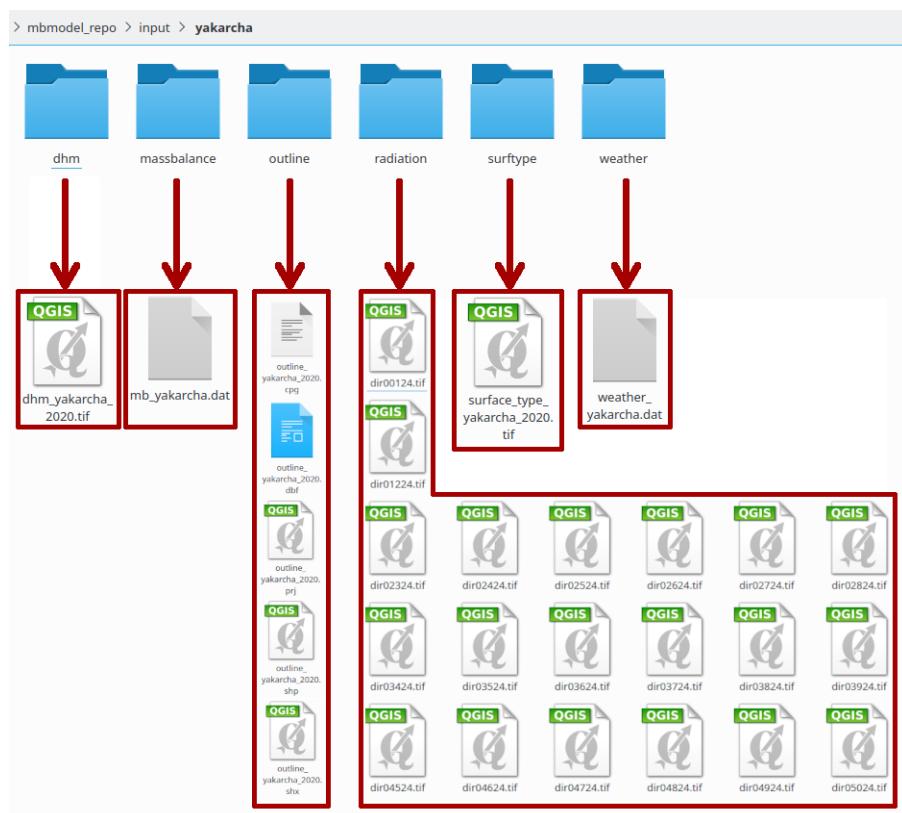


Figure 9: The folder `input\yakarcha\` after preparing all the input data.

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 <code>input\</code>
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 (Fig. 10). The full list of codes is here
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 that we want to simulate: 2020
last_year	2020	Last year that we want to simulate, we want to do just one year so it is again 2020

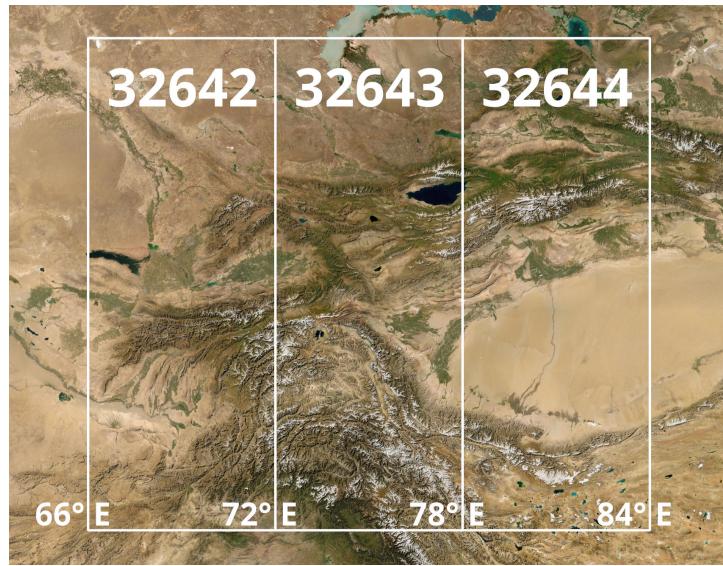


Figure 10: The **EPSG codes** of UTM zones in Central Asia, with their respective longitude borders.

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). While the model is running, we can see the progress in the **RStudio console** (Fig. 11). In the console the model will show in real time the result of the simulation, as well as **any error messages**. All messages are also written into a **log file** (under *logs*!).

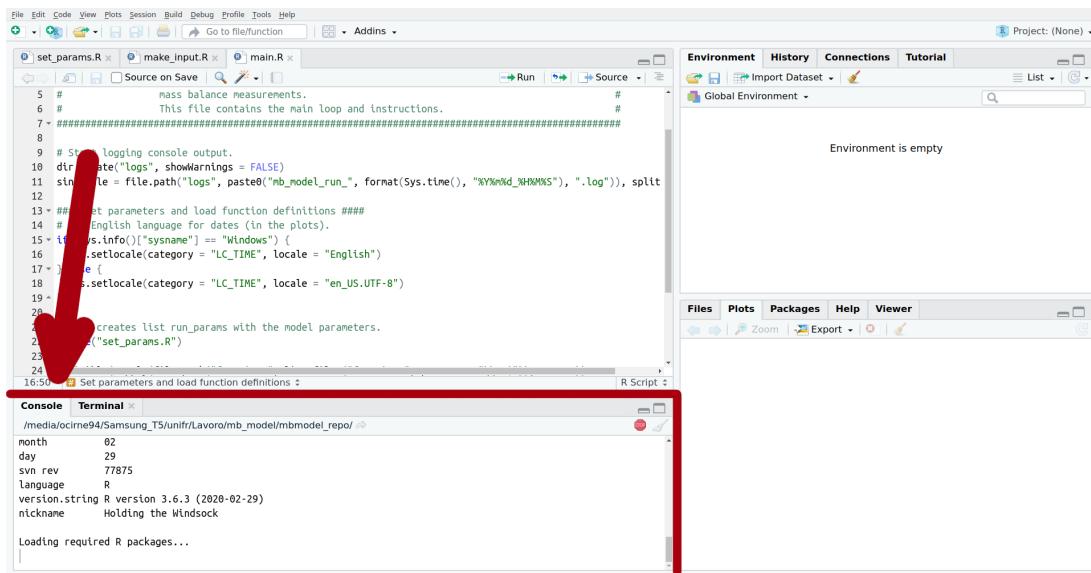


Figure 11: The **RStudio console** with the information messages written by the model.

6 Output files

The **model output** is written to a folder called *output\yakarcha*. The following **detailed results** are provided 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 (contour-line method). 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 and rainfall amounts, which can be compared to runoff measurements.
- Altitudinal profiles of the mass balance, also compared to the stake measurements
- Daily time series of mass balance at the stakes.

The **mass balance maps** are also written to individual GeoTiff files (example: *mb_annual_hydro_2020.tif*), which can be used in QGIS or ArcGIS. The other values - including **daily and total melt, accumulation, mass balance and rainfall** - are written to plain-text CSV 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*.