ICe volumE and Bedtopography Estimation from DEM (ICEBED)

ICEBED is a software tool that helps estimate a glacier's ice thickness, ice volume, and ice bed topography. This tool features a user-friendly GUI, enabling users to estimate the required outputs for one or multiple glaciers by following simple steps.

The ICEBED tool includes the GlabTop2_IITBversion ice thickness modelling approach (refer to Ramsankaran et al., 2018), an improved version of the GlabTop2 modelling approach (Frey et al., 2014). This semi-automated approach estimates a reliable shape factor for glaciers lacking field measurements. The differences between the GlabTop2_IITBversion and GlabTop2 models are shown below (as referenced in Pandit et al., 2020).

S. No.	Environment/Processes	Model versions	
		GlabTop2	GlabTop2_IITB
1.	Programming environment	IDL	Matlab 2015a
2.	Model input	DEM and glacier mask	DEM, slope, and glacier mask
3.	Random pixel selection	"randomu"-IDL in-build function	"randperm" -Matlab in-build function
4.	Calculation of mean slope	mb_cellgradient.pro -user function	BufferProcessing.m -user function
5.	IDW interpolation	Basic	IDW interpolation with added distance weighting exponent

To install this software, two files are required: the ICEBED.exe file and MATLAB Runtime software. You can access the MATLAB Runtime at https://in.mathworks.com/products/compiler/matlab-runtime.html and use MATLAB R2015a (8.5) based on the OS of your choice.

A window will appear once you select the .exe file (see below). Click Next and continue following the prompts.

The software will automatically check for MATLAB Runtime 2015a. If it is not present, you must install it manually by downloading it from the MATLAB website. Once installed, the software is ready for further use.

Steps to Estimate Ice Thickness Using the software tool ICEBED- ICe volumE and Bedtopography Estimation from DEM

1. **Required Inputs and formatting of Inputs for use:**

- DEM
- Mask
- Slope

Note:

All files must be in .asc format. Convert the tiff or jpeg images of DEM, MASK, and Slope files to .asc (ASCII) format first. These files should be in a single folder. If you use more than one glacier, then each glacier should have a separate folder containing the respective DEM, Slope and Mask.

- The input files must be clipped with the respective shapefile, keeping a buffer of 3 to 4 pixels or more outside the glacier boundary. All the files should be maintained to the same extent. The figure below (Figure 1) shows the three input files with similar rows and columns. If this is not correct, the software will show an error. Ensure that the NODATA values are assigned as -9999. It is important to note that the mask file must be a DEM of the glacier (not a slope-based mask file), and it should also maintain the same extent as DEM and SLOPE files, as shown in Figure 1.

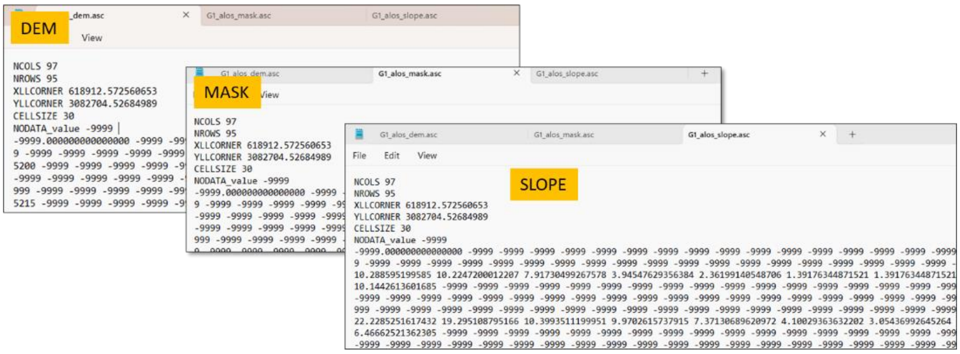


Figure 1: Illustration of the Input files in the .asc format

- Once the above verification is done, remove the header details appearing from 1st to 6th row (see Figure 2) in all three input files.

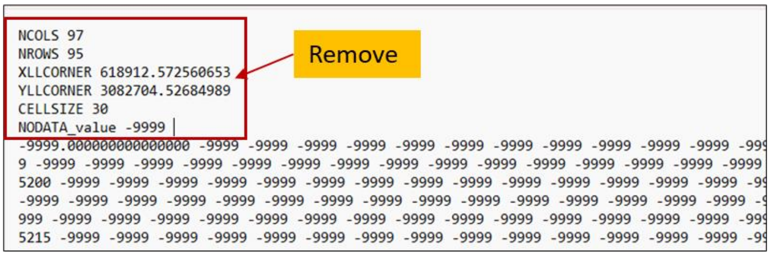


Figure 2: Details to be removed from the input files

Once the above process is done, the inputs are ready for estimating ice thickness.

2. Open the tool called as ICEBED- ICe volumE and Bedtopography Estimation from DEM, after installing the exe files. This tool follows the GlabTop2 IITB version which is the improved version of GlabTop2 model approach (Ramsankaran et al, 2018). The display will be shown as in Figure 3.

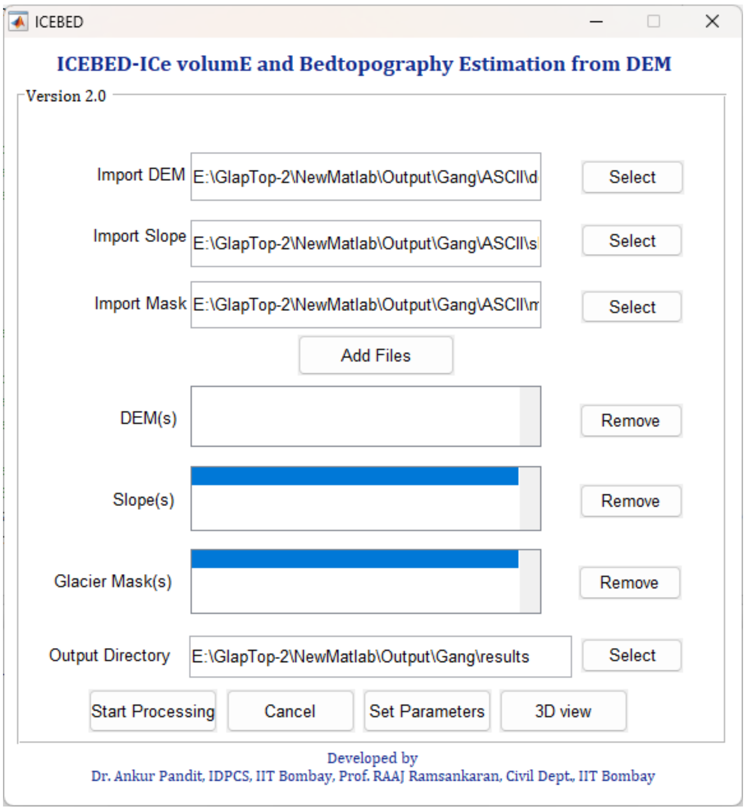


Figure 3: ICEBED tool with Graphical Use Interface (GUI).

After converting the input files, check the following:

a) In the "Import Data (DEM, Slope, and Mask)" section (see Figure 3), add all the appropriate inputs in the respective tabs.

i. Once you import the DEM, Slope, and Mask for a particular glacier (e.g., Hamtah), click the 'Add Files' button. This will add the inputs (i.e., DEM, Slope, and Mask) to the panel below.

ii. If you are interested in adding another glacier, simply import the DEM, Slope, and Mask as mentioned above and click the 'Add Files' button. This will add the inputs below the first glacier's (i.e., Hamtah Glacier) inputs.

iii. Repeat the same for multiple glaciers (see Figure 4). Depending on the processing power of your system, you can run the software for multiple glaciers. **Note:** Normally, 10-15 glaciers can be processed at once.

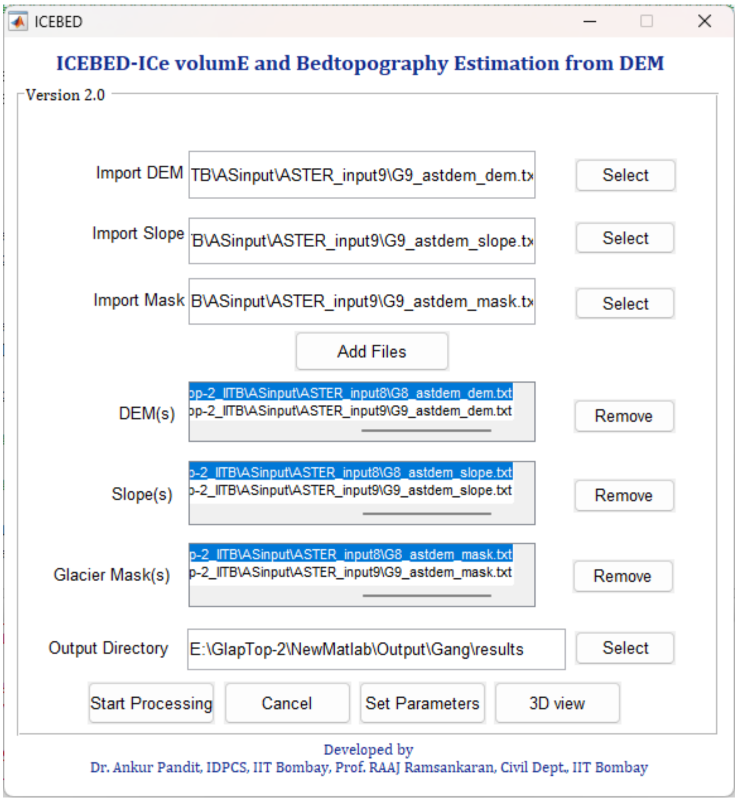


Figure 4: Illustration of adding more than one glacier in the input panels, i.e. panels below the 'Add Files' button.

b) Once all the necessary inputs are added, select the 'Add Files' button, and all the files will be added in the respective sections.

c) Next, select the 'Set Parameters' section to set the input parameters.

d) The list of parameters will be displayed as shown in Figure 4. Here, only one input, i.e., ice density, needs to be supplied based on your evaluation. This parameter usually varies from 850 to 917 kg/m^3.

Keep the remaining parameters (as shown in Figure 5) as they are. Assign the pixel size based on the spatial resolution of the input DEM and Slope. Its unit is in meters. By default, it is set to '30m'. However, the pixel value can be changed accordingly based on your needs and requirements.

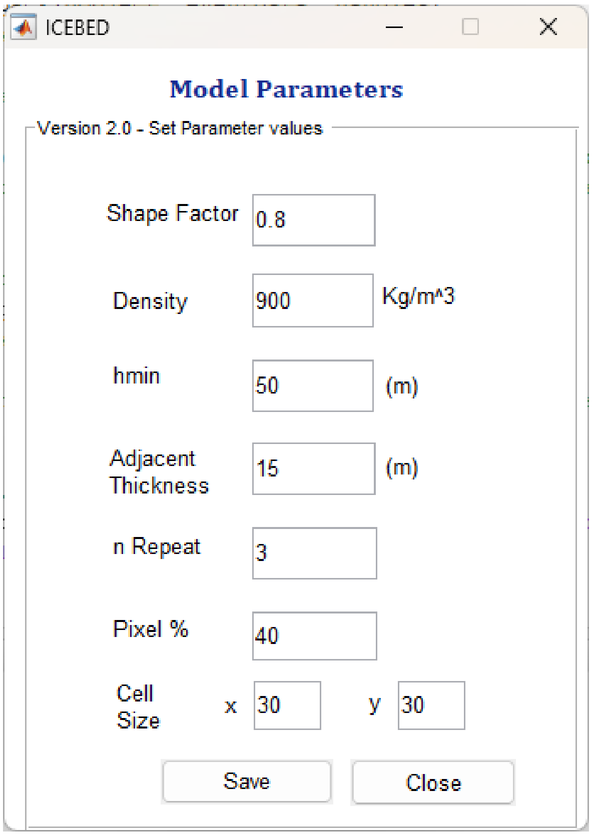


Figure 5: Set Parameters block in the De_GlaThiEs tool.

e) Provide the desired output folder location once the parameters are set. **Note:** It is recommended not to use the input folder location.

f) Now that all the inputs and settings are complete select the 'Start Processing' button. The tool will automatically run and display the ice thickness results as an image. Once the process is over, a new popup will appear, indicating that the process is completed.

g) Now we have the output results for a glacier, which has a total of 32 folders,

31 folders beginning with 'GlaThiEs_folder-name_date_time' (refer to Figure 6 in violet box) contain the ice thickness calculated for each shape factor value, corresponding bed topography estimates, metadata files, etc. (refer to Figure 7). Refer to the 'MetaDataFile' to know the inputs used and other details like shape factor value, mean ice thickness, and glacier volume (refer to Figure 8).

One folder named 'Avg_Thickness' (refer to Figure 6 in red box) contains the mean ice thickness of all 31 ice thickness estimates

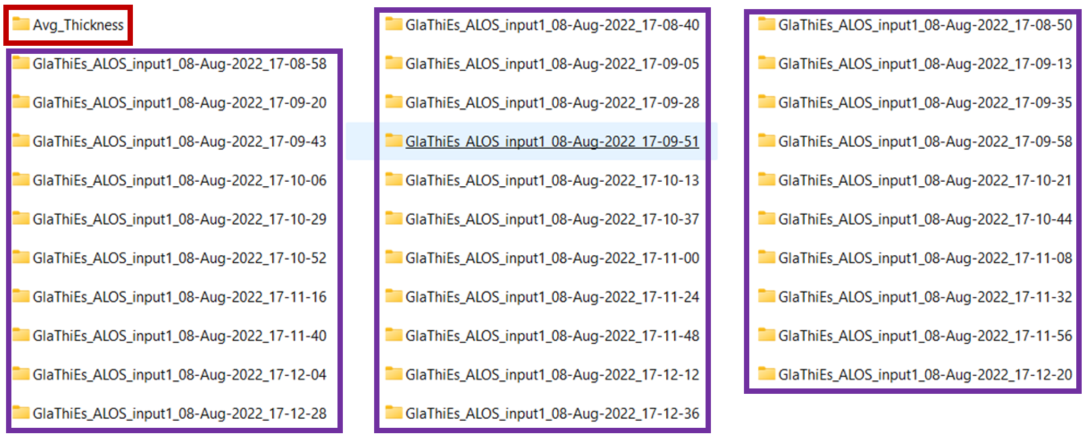


Figure 6: Snapshot of the output folders by ICEBED tool after the end of processing.

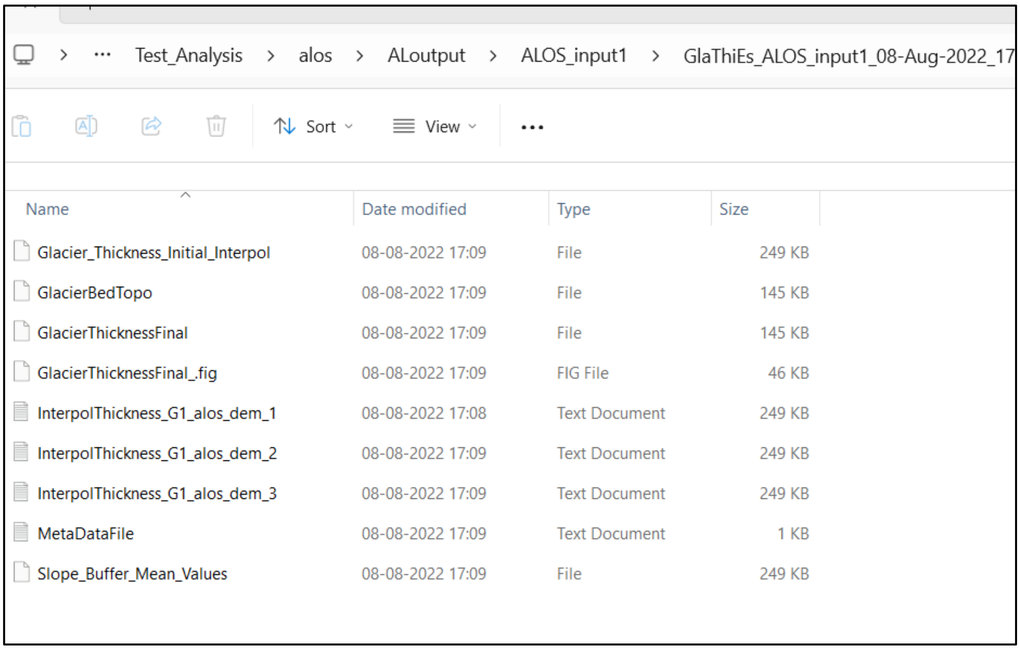
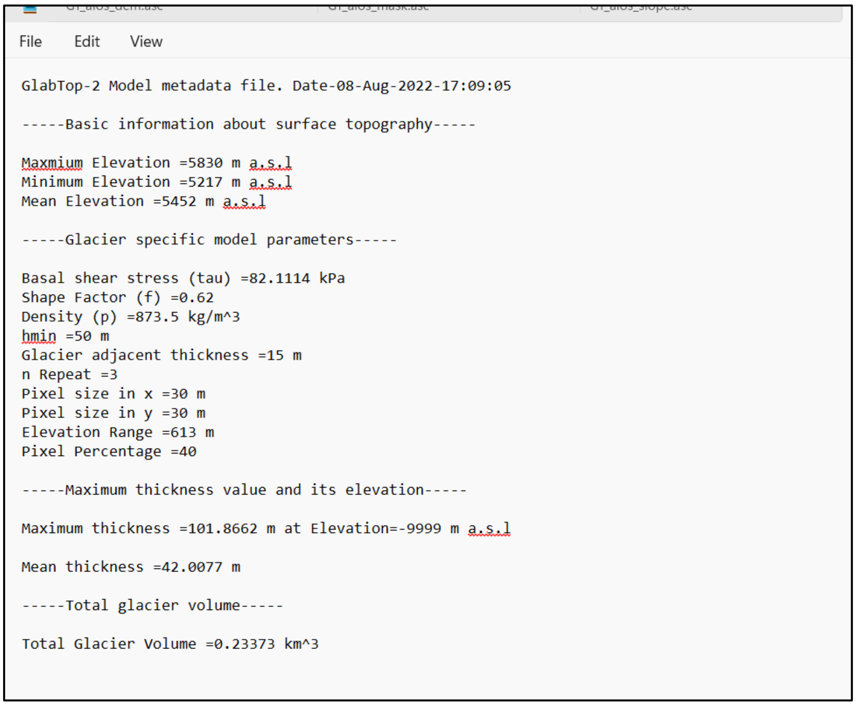


Figure 7: Snapshot of the folder showing the results present in each folder. It has Glacier ice thickness and bed topography



```
File    Edit    View

GlabTop-2 Model metadata file. Date-08-Aug-2022-17:09:05

-----Basic information about surface topography-----

Maxmium Elevation =5830 m a.s.l
Minimum Elevation =5217 m a.s.l
Mean Elevation =5452 m a.s.l

-----Glacier specific model parameters-----

Basal shear stress (tau) =82.1114 kPa
Shape Factor (f) =0.62
Density (p) =873.5 kg/m^3
hmin =50 m
Glacier adjacent thickness =15 m
n Repeat =3
Pixel size in x =30 m
Pixel size in y =30 m
Elevation Range =613 m
Pixel Percentage =40

-----Maximum thickness value and its elevation-----

Maximum thickness =101.8662 m at Elevation=-9999 m a.s.l

Mean thickness =42.0077 m

-----Total glacier volume-----

Total Glacier Volume =0.23373 km^3
```

Figure 8: Illustration of MetaDataFile details available in each output folder (excluding Avg_Thickness folder)

h) Following Ramsankaran et al. (2018), to obtain an optimized shape factor-based ice thickness estimates two inputs are required:

- **Mean ice thickness**, which can be found in the 'Avg_Thickness' folder.
- **Glacier cross-sections**:
    - Glacier cross-sections must be available at every 100 m elevation interval. These can be manually digitized or obtained from existing datasets. Shapefile-format cross-sections are available from the Open Global Glacier Model (OGGM) at the link Index of /~oggm/gdirs/oggm_v1.6/L1-L2_files/centerlines/RGI62/b_010/L2 (accessed on 10 01 2025).

Refer toEquation 3 given in Ramsankaran et al. (2018), which outlines calculating the optimised shape factor using the above two inputs. Once the optimized shape factor is determined—e.g. if the calculated value for a glacier is 0.68—the corresponding ice thickness estimate should be selected from the output file folder. In the output file, the folders arranged in a sequential order, starting from the **Avg_Thickness** folder, followed by folders containing ice thickness estimates for shape factor values **0.6, 0.61,** and so on, up to **0.9**.

If an optimized shape factor-based ice thickness estimate is not required, a commonly used shape factor value of **0.8** can be chosen instead. In this case, step 'h' is not necessary, and the ice thickness estimate can be directly selected from the corresponding folder.

For a detailed explanation of the entire process, refer to **Section 5.3: GlabTop2 Algorithm Implementation** in Ramsankaran et al. (2018).

Converting the Generated Output File to TIFF Format

1. **Prepare the File in ASCII Format:**
    - Once the final outputs (*GlacierThicknessFinal* or *GlacierBedTopo*, refer to Figure 7) are generated, open the file.
    - Add back the removed header details to the file and save it in .asc (ASCII) format.
    - **Note:** Ensure that the first six rows match the format of the input file (refer to Figure 2). Incorrect placement may cause errors.
2. **Define the Projection:**
    - After restoring the header, assign the same spatial projection as the input dataset.
    - Projection can be defined using any GIS software (e.g., QGIS, ArcGIS) or through programming in **Python, MATLAB, or R**.
3. **Convert to TIFF Format:**
    - Once the projection is set, the file can be saved in **TIFF (.tif)** format using GIS software or code-based conversion methods.

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Credits: Developed by **Dr. Ankur Pandit** and updated by **Mr. P J Navin Kumar**

Hydro Remote Sensing Applications (H-RSA) Group, Indian Institute of Technology (IIT) Bombay

For Clarification and Feedback, contact Prof. RAAJ Ramsankaran, IIT Bombay

Email: ramsankaran@civil.iitb.ac.in