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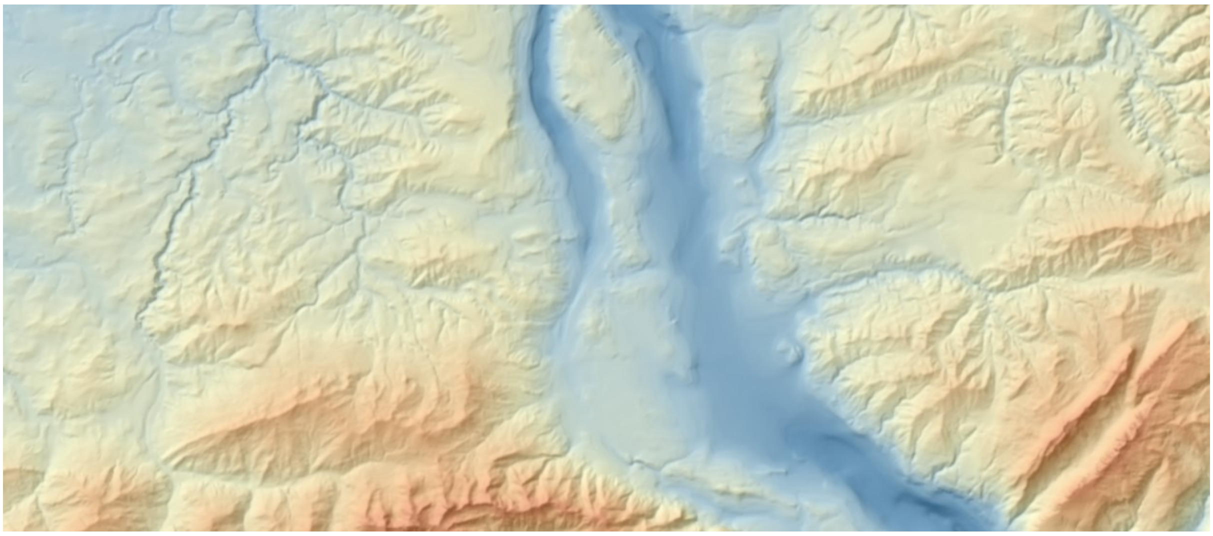
swissBEDROCK
Model description



**This model description is valid for the following releases:*

Release 1

Contents

Introduction

The boundary between solid rock and unconsolidated deposits is crucial across various disciplines. This transition marks a major change in most physical and chemical properties at depth. Factors such as strength, lithology, conductivity, porosity, and permeability change at this interface. Understanding its depth beneath the topographic surface is essential for assessing groundwater resources, evaluating potential water contamination risks and predicting natural hazards such as landslides and mudslides.
The swissBEDROCK dataset offers comprehensive national-level information on Switzerland's bedrock interface. It provides data with a resolution of 10 x 10 meters. In addition to the Bedrock Elevation Model (BEM), it includes information on the Thickness Model of Unconsolidated Deposits (TMUD), details on uncertainty, versions, version authors and changes with regard to previous versions.
swissBEDROCK consists of model components provided by external sources or third parties as well as model components produced by the Federal Office of Topography. These components are clearly attributed to their respective authors for further details. swissBEDROCK also features a versioning system, ensuring transparency and traceability over time. For each cell in the dataset, previous values are retained and change values are given, enhancing the ability to track modifications and updates accurately. This comprehensive approach enables users to access reliable and detailed geological information essential for various applications throughout Switzerland.
Maintenance is achieved with automated processes within a defined area/perimeter. Within this perimeter, the model is either replaced with a third-party model (**Regional Replace**), or it is readjusted within the perimeter according to new borehole data and GeoCover information (**Regional Update**).

Dataset structure

swissBEDROCK comprises a multi-band raster tile set. Each tile consists of a raster with cells measuring 10 x 10 meters and constituting 11 bands, which provide the information per cell given in Table 1. The dataset is available for download as a COG TIFF. The coordinate system of the dataset is the Swiss national reference system CH1903+ / LV95 with vertical reference to LN02.

Attribut / Attribute / Attributo	Bezeichnung de	Désignation fr	Designazione it	Designation en
BEM	Höhenmodell der Felsoberfläche [m ü.M]	Modèle d'altitude du toit du rocher [m s.m.]	Modello di altitudine del tetto del substrato roccioso [m s.l.m.]	Bedrock elevation model [m.a.s.l.]
TMUD	Mächtigkeitsmodell des Lockergesteins [m]	Modèle d'épaisseur des terrains meubles [m]	Modello di spessore dei depositi sciolti [m]	Thickness model of unconsolidated deposits [m]
Uncertainty	Unsicherheit [m]	Incertitude [m]	Incertezza [m]	Uncertainty [m]
Version	Versionsnummer	Numéro de version	Numero di versione	Version number
VersionAuthor	Numerische Autoren-ID	ID numérique de l'auteur	ID numerico dell'autore	Numeric author ID
Change	Änderung zur vorherigen Version [m]	Changement vers la version précédente [m]	Modifica alla versione precedente [m]	Change to previous version [m]
Prev_BEM	Vorherige Version des Höhenmodells der Felsoberfläche [m ü. M.]	Version précédente du modèle d'altitude du toit du rocher [m s.n.m.]	Versione precedente del modello di altitudine del tetto del substrato roccioso [m s.l.m.]	Previous version of the Bedrock elevation model [m]
Prev_TMUD	Vorherige Version des Mächtigkeitsmodells des Lockergesteins [m]	Version précédente du modèle d'épaisseur des terrains meubles [m]	Versione precedente del modello di spessore dei depositi sciolti [m]	Previous version of the thickness model of unconsolidated deposits [m]
Prev_Uncertainty	Vorherige Version der Unsicherheit	Version précédente de l'incertitude [m]	Versione precedente dell'incertezza [m]	Previous version of the uncertainty [m]
Prev_Version	Vorherige Versionsnummer	Numéro de version précédent	Numero di versione precedente	Previous version number
Prev_VersionAuthor	Vorherige Version – numerische Autoren-ID	Version précédente – ID numérique de l'auteur	Versione precedente – ID numerico dell'autore	Previous version numeric author ID

Table 1: Information provided by the eleven bands of each raster cell.

Approaches

The creation of the swissBEDROCK dataset is largely automated, allowing for regular new releases (yearly). It represents the latest and most up-to-date information on the bedrock interface of Switzerland. To provide the latest information, both regional new data and regional third-party models are integrated (Fig. 1).

In both scenarios, the regional components are seamlessly integrated into the national model. In both cases, boundary adjustment is implemented to ensure a smooth transition between the unchanged and modified parts of the model. The next chapter describes how regional improvements are made.

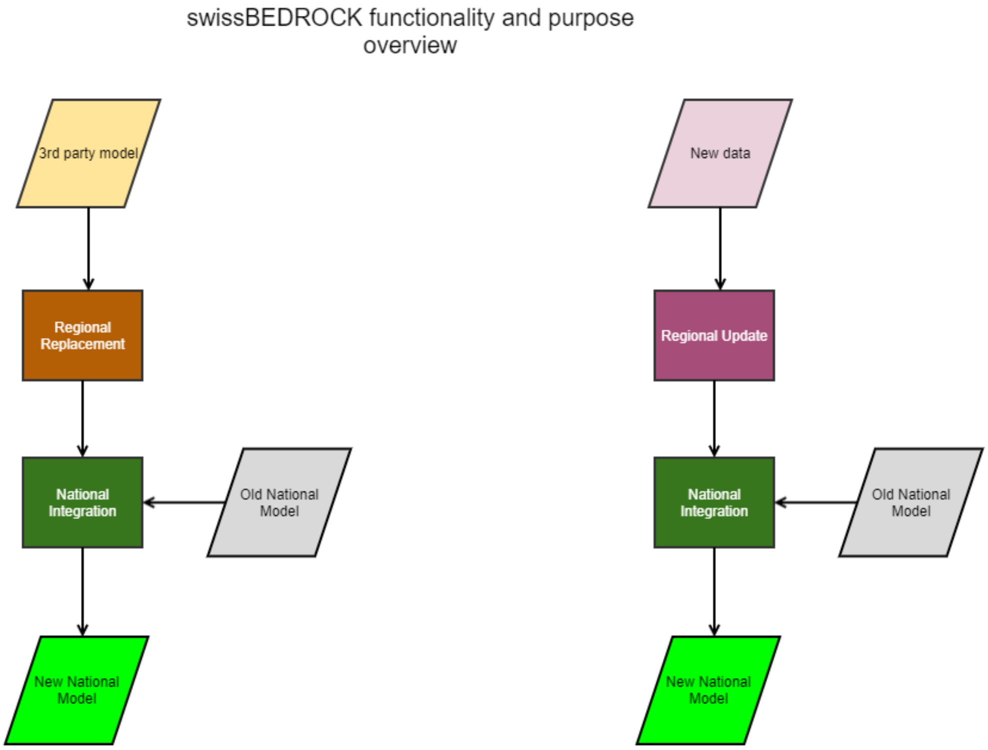


Figure 1: The swissBEDROCK method allows for iterative regional improvements by either replacing part of the nationwide model with a regional third-party model or by updating a region with new data. Automations are represented by rectangular boxes.

Regional Replace automation

To integrate third-party data while maintaining seamless transitions, the Regional Replace approach is applied (Fig. 2). The process begins by identifying and extracting the perimeter of the third party model, provided as a GeoTIFF file where valid data are present. Around this perimeter, a 200-meter buffer zone is created to serve as a transitional area.

Within the perimeter, points are sampled three cells inside the third-party raster. Similarly, three cells outside the buffer zone are sampled from the current swissBEDROCK raster. These points represent “bedrock reached” areas and are used as equality data to guide the modelling process. For more information on modelling, please referrer to the modelling chapter in “ Modelling bedrock elevation” section, where methods are described in more detail. The buffer zone is then used to link up the third-party model with the current swissBEDROCK model:

- Internally: the buffer zone matches the boundaries of the third-party data.
- Externally: it transitions smoothly into the current swissBEDROCK raster.

Finally, the replacement raster, including the buffer zone, is merged into the existing swissBEDROCK dataset. This ensures a consistent and unified model, eliminating abrupt changes while retaining the high-resolution detail that users expect. From the resulting Bedrock Elevation Model (BEM) a new Thickness Model of Unconsolidated Deposits (TMUD) is calculated as the difference between the topography (swissALTI3D resampled at 10m cell spacing) and the BEM. Modeling uncertainties are not attributed (NoData) to the third-party model and are indicated only in the buffer zone, in meters.

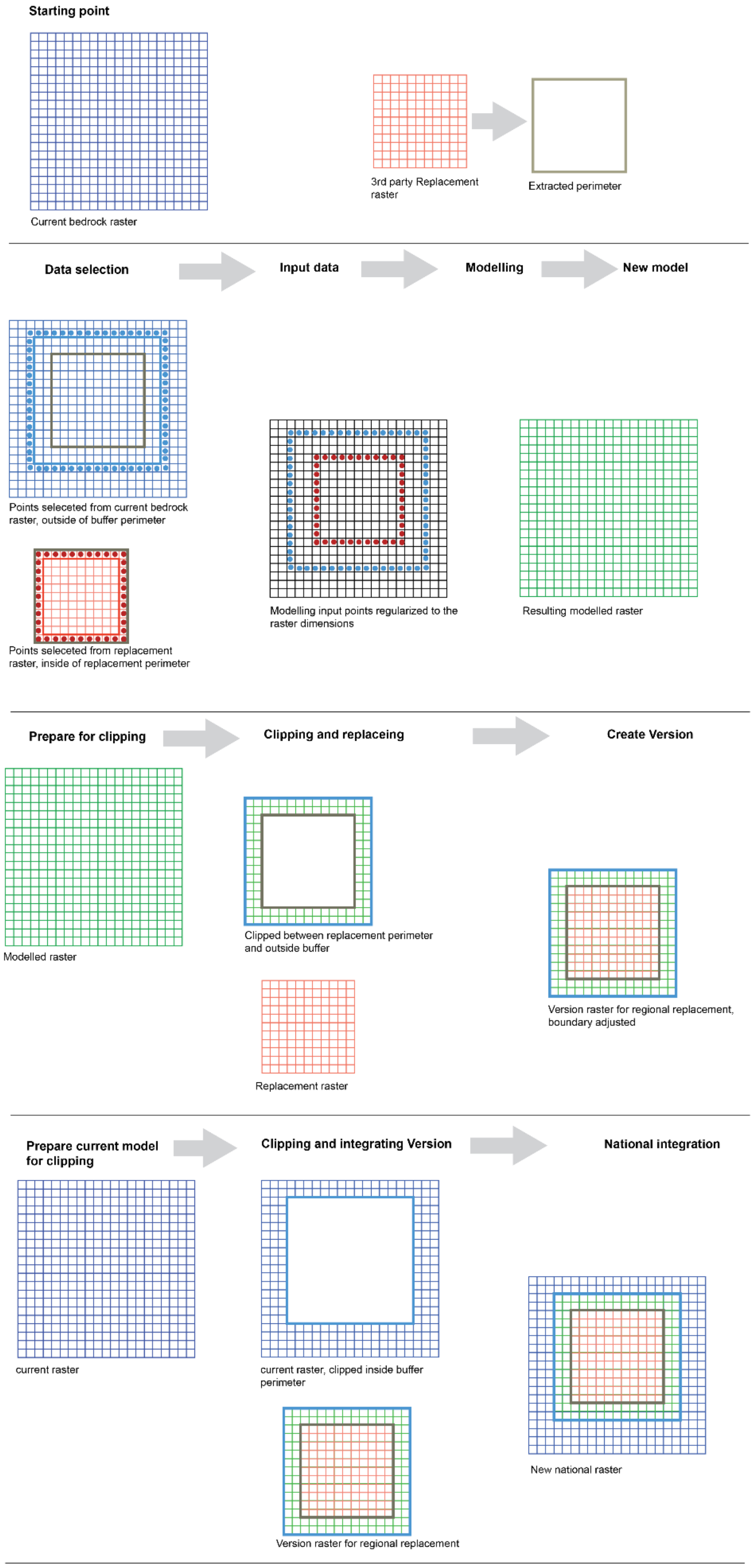


Figure 2: the Regional Replace automation. A replacement raster is supplied by a third party. From this model, the replacement perimeter is extracted. A buffer zone is then defined (200m) outside of the replacement perimeter. Data on either side of the buffer zone are extracted from the replacement raster and the current raster, respectively. After regularizing and modelling, the new model is clipped to include the buffer zone, basically allowing for a boundary adjustment. Inside the replacement perimeter, the replacement raster is implemented, creating a Version. This Version is then integrated into the national raster. Blue corresponds to the current raster, green corresponds to the new raster and red corresponds to the replacement raster.

Regional Update automation

The Regional Update approach aims to update a specific region within Switzerland with new data. The only input required from the user for this automated process is a Shapefile with a perimeter polygon that defines the region of interest.

Data extraction

In principle, any point data that contains direct or indirect information on bedrock elevation [m.a.s.l.] or unconsolidated sediment thickness [m] can be used. The swissBEDROCK method relies heavily on automation. Therefore, standardized data stored in databases is a prerequisite. Currently, borehole data (from boreholes.swisgeol.ch, swisstopo internal) and GeoCover are used.
In principle, geophysical datasets can also contribute to swissBEDROCK, provided they are processed into a form that directly relates to bedrock elevation or the thickness of unconsolidated deposits. Geophysical signals without depth information (e.g., resistivity, seismic or georadar travel times) cannot be used directly in the modelling workflow. Instead, they must first be interpreted and converted into point data in the elevation domain (absolute bedrock surface elevation in meters above sea level) or, where applicable, into thickness values of unconsolidated sediments. Only such derived geophysical points are compatible with the swissBEDROCK input requirements and can be treated in the same way as borehole or GeoCover data.
The provided perimeter file is used to automatically extract data from the databases of the region. For boreholes that have reached bedrock, we can take the bedrock elevation directly; for boreholes that have not reached bedrock, we take the well-bottom elevation (as the maximum elevation for the bedrock surface). For GeoCover, the outcrop between Bedrock and Unconsolidated is taken. The vertices of the outcrop lines are given an elevation from swissALTI3D. Buffer points may also be generated from the outcrop lines. These are artificial points placed within the polygons of unconsolidated deposits and serve to constrain the model, ensuring that it remains below the topography.

Data uncertainty

All data carry some degree of uncertainty, and it is essential to account for this variability in the modeling efforts. For GeoCover, the uncertainty is represented by an elevation range of 10 meters around each data point.

For borehole data, the uncertainty is determined using a combination of the xy location accuracy of the borehole start and the borehole method. The range of borehole location accuracy is categorized as follows:
- 0.1 meters (for DGPS or Theodolite measurements)
- 5 meters (for GPS measurements)
- 10, 50 or 100 meters (for unspecified or reconstructed measurements).

Each borehole's starting location is analyzed across four possible positions within these uncertainty ranges. These positions are compared with the swissALTI3D elevation data to derive a range of starting elevations. This range directly influences the elevation of the bedrock (or the borehole's endpoint), which is the primary focus here. For the borehole method, the chosen uncertainty ranges in meters are 0.5 (rotary coring), 2 (rotary drilling), 2.5 (direct push soil sampling), 3 (dynamic probing), 3.5 (manual drilling), 4 (shaft drilling), 4.5 (trench), 5 (grab drilling) and 7 (unknown). By integration the uncertainties for each borehole, a total range can be given. This total corresponds to the maximum uncertainty for the given borehole and is used in the modelling process.

Data selection and regularization

In the selection of data, a filter is applied to exclude boreholes that should not be incorporated into the model because of known issues.
Before modeling, the data must be regularized to match the grid dimensions used in the process. For a grid 10 x 10 meters, this involves combining multiple data points within a single cell into a single representative value.

Cell type	Description	Elevation	Uncertainty	Equality/Inequality
1	One data per cell	Use	Use	Equality/Inequality
2	Multiple equality per cell	Mean	Total range	Equality
3	Multiple inequality per cell	Deepest	Range from deepest	Inequality
4a	Mixture, deepest is equality	Mean of equality	Range from selection	Equality
4b	Mixture, deepest is inequality	Mean of deepest inequality and equality	Range from selection	Equality

Table 2: Rules for determining the representative elevation value for a cell.

If only one data point occurs in a cell, the value is used directly, along with its range as an estimate of uncertainty. However, if multiple data points exist within a cell, rules are applied to determine how the representative value should be derived (Table 2).

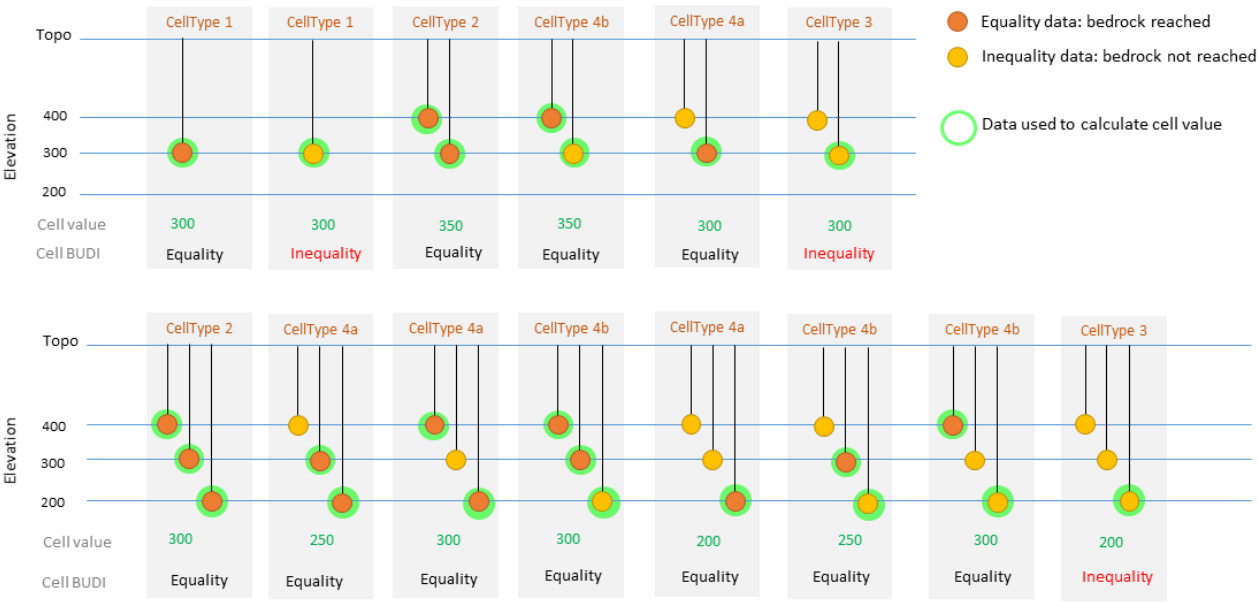


Figure 3: Schematic overview of all possible configurations of equality and inequality data. The representative cell value using the rules from Table 2 is indicated.

Finally, at a distance of 3 cells outside the supplied perimeter, values are extracted from the existing raster to ensure that the resulting model seamlessly integrates into the existing dataset.
After this process, the modeling input is fully prepared and ready for use. An overview including the modelling step is given in Figure 4.

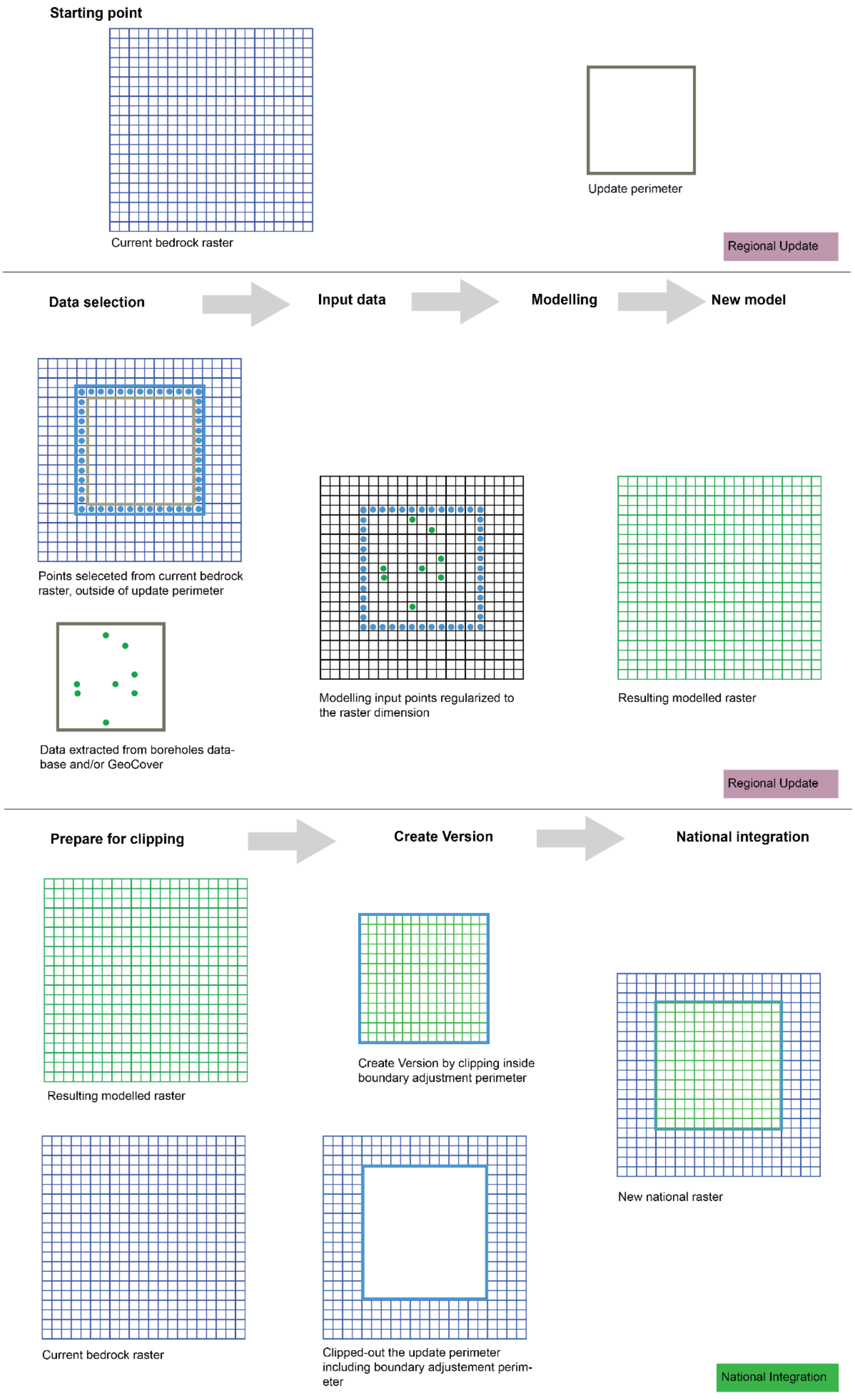


Figure 4: the Regional Update automation. Starting only with only an update-perimeter Shapefile, data are selected from the databases and from a zone beyond the perimeter in the current model (needed for boundary adjustment). After regularizing and modelling, the new model is clipped with the update perimeter to obtain a Version. This Version is then integrated into the national raster. Blue corresponds to the current raster and green corresponds to the new raster.

Modelling bedrock elevation

The modelling module is a Python tool developed by the University of Neuchâtel and integrated into the swissBEDROCK workflow. It is triggered automatically during both Regional Replace and Regional Update processes.
The module applies the Local Differential Approach (LDA) in combination with Gaussian Random Fields (GRF) as the interpolation method. In this approach, the existing bedrock model is compared with the supplied data points, and the differences between the two, rather than the absolute values themselves, are interpolated. This procedure allows the large-scale structure of the model to be preserved while locally adapting it to new information. Gaussian simulation (kriging) is then performed using an isotropic covariance (variogram) model inferred from the available data. The results of each simulation are exported and stored in a data frame. For every modelling run, the mean of all realizations provides the best estimate of the bedrock surface, while the standard deviation quantifies the associated uncertainty. If required, all individual realizations can be saved for further analysis. To ensure reproducibility and transparency, a logging system based on the Python logging package accompanies each run. The log file records key steps, warnings and errors, providing a valuable resource for diagnosing issues or tracking model behavior.
It is important to note that in the case of Regional Replace, the “data” used by the LDA consists exclusively of the extracted points from either side of the buffer zone (see Figure 2). These points define the transition between the third-party model and the existing swissBEDROCK dataset and form the basis for the interpolation.

Uncertainty and thickness of unconsolidated deposits

Additionally, the covariance model, inferred from the data, can also be exported. By using a substantial number of realizations, a robust and reliable assessment of the model predictions and uncertainty can be obtained.

From these results, the thickness of unconsolidated sediments is inferred by subtracting the mean bedrock elevation from the topography. Here the areas where GeoCover shows bedrock at the surface are replaced with the topography model.

Validation and quality control

A two-phase validation is carried out after the automations Regional Replace/Update and National Integration. After the Regional Replace/Update, an automated qualitative validation is implemented by cross validating the modelling results against the modelling data (and validation dataset if selected) within the uncertainty of the input data. This generates an overall validation percentage for the modelled and validation datasets. The calculation is performed for each input point (see regularization chapter) even if it is correct. This means that for equality data, the resulting model (plus or minus the standard deviation) falls within the bounds of uncertainty for the input point. In this way, each input point has all the information even if the model at that location is correct. This approach is useful when performing manual qualitative validation. In the final step, the model is automatically checked to ensure that it nowhere exceeds the topography.

Qualitative validation is also a key aspect of the process and follows a standard procedure. First the reason for revision is described and then the input data are checked. For Regional Replace, this means checking that the input model is correct. For Regional Update, GeoCover and boreholes are checked for completeness (i.e. whether equality and inequality are correctly attributed, whether the elevation of bedrock is attributed). Whether the actual values make sense in a geospatial sense is not yet checked at this stage.
After the checks, the modelling results are analyzed in combination with both the input data and the validation data to identify possible issues. The modelling results include BEM, TMUD and the change,

which is the difference between the newly calculated model and the existing model. This step provides a quick visual overview of areas where significant changes have occurred, serving as a useful starting point for qualitatively validating the model. Qualitative validation is done by assessing major changes and inferring the reason for the change. If a change is the result of invalid input data, the data must be corrected at the source before performing a re-run.

National Integration automation

Once all major changes have been addressed and are deemed valid, the regional model can be integrated into the nationwide model. This is also an automated step, after which another round of validation occurs to make sure that the national integration was done successfully. Since the swissBEDROCK dataset is stored as tiles, only the affected tiles are involved in the national integration, and a backup of the affected tiles is made. At this stage, the regional model is successfully integrated into the nationwide swissBEDROCK dataset.

Automation

In the past, many of the steps needed for updating or replacing a portion of the model involved manual steps. This method made updates time consuming, costly, less reproducible and less transparent (Dürst Stucli 2015 and swisstopo 2021). Automation is a key benefit of the swissBEDROCK framework. It allows for the quick generation of new modelled regions. This means that unsatisfactory results can be quickly and easily redone. Also, each step can be rerun under the same conditions, giving the same result.

Automation has been achieved by a combination of FME Server, FME and Python. Each of the three automations (Regional Replace, Regional Update and National Integration) are fully automated. Starting on FME Server by entering a limited number of parameters and triggering the automation is the only manual step. After each automation, manual quality control is done complementary to the automated validation.

The automated systems are built modular. This has a benefit that modules can be adjusted individually, if necessary. During each run of an automation, all parameters and data used are stored. In this way, the process becomes reproducible, documentable and more efficient.

Further Information

swissBEDROCK is a system that is planned to be continually improved, meaning that the contents of the model description may change over time. The validity of this document with respect to the swissBEDROCK releases is noted at the bottom of the title page.

Disclaimer

The swissBEDROCK modelling process and the resulting 3D models represent a simplification of the real geological setting. While every reasonable effort has been made to ensure that the modelling procedures and the information contained in the published results are as accurate and reliable as possible, no guarantee can be given that the data correctly reflect the subsurface at a specific location. Both the modelling workflow and its outputs are subject to inherent uncertainties arising from input data quality, methodological assumptions and limitations of the modelling approach.
Under no circumstances will the publisher be liable for any loss or damage of a material or immaterial nature resulting from access to, use or non-use of the modelling process or its outputs, or from misuse, misinterpretation or technical malfunction.

Known issues

Buffer zone in Regional Replace
The buffer zone modelling in Regional Replace is currently constrained only by input points on either side (from the existing and new raster respectively, see Figure 2) and by the topography. This means that during interpolation, the model will fit to either side and will remain below the topography. However, since no additional data constrain is applied (boreholes or GeoCover), we have observed that on occasion the model is subsurface where GeoCover shows outcrop. In future work, additional data will be added to further constrain the buffer zone.

Uncertainty
There are currently two main limitations regarding the uncertainty estimation:
a) General reliability – Although great care has been taken, the overall reliability of the uncertainty estimates is still under development. The current values do not yet fully capture the variability of the model.
b) Loss of uncertainty in progressively modeled areas – In areas that are modeled more than once, the uncertainty estimate is lost. This is a consequence of the LDA estimation method rather than the data themself. Work is being done to address these issues.

References

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