MAPPING MT. USHBA – HOW TO CREATE A HIGH-QUALITY MAP PRODUCT FROM OPEN DATA WITH FREE SOFTWARE

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ABSTRACT:

Mt. Ushba is a famous mountain in the Great Caucasus characterized by its iconical double peak. In addition, the surrounding Georgian region of Svaneti is known for its medieval defense towers, what makes the area a rising tourism destination. Climbers, hikers and visitors alike need maps for planning their tours, so there is a demand for a reliable map. The paper aims to present the production of an Alpine Club map to demonstrate how high-quality map production is possible by combining open data and, wherever possible, open-source software. An important result is a widely transferable workflow for mapmakers. It offers low-cost solutions in the production of a digital elevation model, which combines multi-stereo satellite images from Planet Labs and GNSS measurements, and an organized, dynamic mapping with OpenStreetMap. Moreover, free satellite images have been used to derive land cover information. While the final map will be sold as a commercial product, most geo-data are freely available. The OpenStreetMap data is improved and completed through fieldwork, and toponyms are collected in a combination of existing maps, signposts and information by locals. Our contribution may strengthen the spread of this sustainable database to many other digital services, resp. maps, which are using OpenStreetMap. Due to the complexity of the overall project, this paper describes the current status, some aspects are still under development.

1. INTRODUCTION

Mt. Ushba is situated in the Greater Caucasus in Georgia, next to the Russian border. With its nearly symmetrical double peak, it is iconic and a symbol of the historic Svaneti region in Georgia, famous for its mountains, botany, and century-old defense towers. Svaneti is becoming an increasingly popular tourist destination both in summer and winter. Therefore, the German Alpine Club is interested in providing a new map for this region, produced by the Institute of Cartography of TU Dresden. The Svaneti region is still in a process of touristic development and various maps are available (topographic and touristic).

In the age of open data, it is consequential that OpenStreetMap will be an essential source of the new map. Data sharing should make the project more sustainable and inspire people to use free and open-source software for map production as an alternative to the current practice of the German Alpine Club, which applies the commercial software products OCAD[1] and ArcGIS.

2. RELATED WORK

2.1 High Mountain Cartography at TU Dresden

The production of hiking and trekking maps has a successful tradition at the Institute of Cartography of TU Dresden, primarily through the activities of Prof. Manfred Buchroithner resulting in the following Alpine Club maps: Nevado Ojos del Salado (2004), Inylchek, Tien Shan / Kyrgyzstan (2008), Khan Tengri, Tien Shan / Kyrgyzstan (2008) and seven maps of the Working Group for Comparative High Mountain Research e.V.[2].

The paper of Buchroithner and Himpel (2010) provides a detailed description of the fieldwork and cartographic processing to update the Alpine Club map of the Brenta Group (first published in 1908) as an anniversary edition. Herein, terrestrial laser scanning, (stereo) terrain photography, and satellite remote sensing data were applied. In the glacier retreat area, the rock and scree drawing had to be supplemented. This was done classically by hand on enlarged paper printouts to imitate the style of Aegerter-Rohn.

2.2 Map Production Today

Heller et al. (2017) give a brief overview on the development of the high-alpine map production of the climbing associations – Austrian and German Alpine Club. The necessary conversion towards geo-databases and GIS-based cartography is described in the paper. A principal objective is to speed-up and partially automate the map production. The related "AV.MAP" project mainly deals with the use of high-resolution Pléiades satellite images in connection with fieldwork to create high mountain hiking and trekking maps. The workflow has been implemented in ArcGIS Pro and been tested for two Alpine Club maps (Hastik, 2020), the area around the Franz-Senn-Hütte in the Stubai Alps (1:25,000), and the Mt. Kenya National Park (1:50,000 main map, 1:25,000 summit area). Experiences with satellite monitoring and the mapping of tiny glaciers around Mt. Kenya were published by Prinz et al. (2018).

In general, nowadays map creation is heavily influenced by the availability of open data and free software. For the derivation of topographic maps, Usery et al. (2018) describes how map making has changed in the past decades, starting with field data and photogrammetrically collected data to arrive at digital databases and geographic information systems.

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[1] `https://www.ocad.com/`
[2] `https://www.hochgebirgsforschung.de/`

There are many open data sources that can be used to create topographical and thematic maps. Data are made available by voluntary communities as well as by authoritative institutions. The term VGI refers to all geospatial information voluntarily collected by laypersons. Potentials but also challenges associated with the usage of VGI are discussed by Sester et al. (2014). For the production of large and medium scale maps based on VGI, the OpenStreetMap database plays the most prominent role (Ramm and Topf, 2011), while Natural Earth[3] has become an important source for small-scale topographic maps. The integrative use of OpenStreetMap data and public authoritative data for topographic mapping is also described in detail by Kunz and Bobrich (2019).

3. METHODS TO PROCESS MAP CONTENT FROM EXISTING GEOINFORMATION SOURCES

This section is lining out how existing data is integrated into a GIS within this collaborative mapping project. Freely available and open data is collected to create an overview on the mapping area. Figure 1 summarises this chapter by showing the integration of all available data into the WMS project. Copyrights of some of the integrated maps make it necessary to restrict an access to project team members via password.

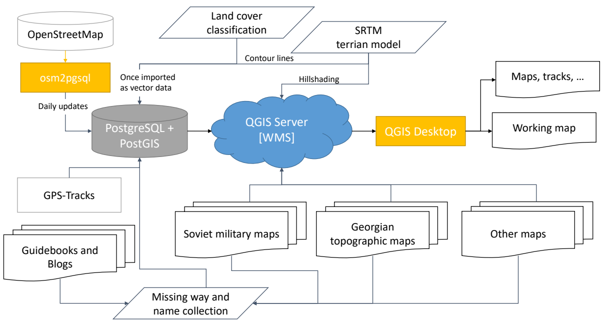

Figure 1. Parts of the WMS for the mapping project show the implemented geodata integration into the service.

3.1 Existing Maps

White spots on maps are history: surveyors, cartographers, remote sensors, and GPS track uploads are widening our geodata day by day. The challenge is in seeking and assembling extant data for a first impression on the region, and for a precise planning of a systematic closure of information deficits. While the book "World mapping today" of Parry and Perkins (2000) is quite outdated but still delivers basic information, the broad range of services by FID Karten[4] (Koch, 2019) – search of maps and geodata, and digitization service – proved to be very helpful for our project. We received (name of map collection and scale): Current topographic map of Georgia (Geoland): 25 k and 50 k, Touristic maps (Geoland): 50 k, Polish hiking map: 70 k, Soviet military maps: 50 k

After scanning and georeferencing, a password-protected WMS using the QGIS Server allows project members to view and work with the maps. They have two roles, geodata source, and resource for designing and validating the map product in production. Comparing existing maps reveals gaps in map features and toponyms, and becomes one basis for the necessary tours during the field trips which, in return, lead to improvements in OpenStreetMap. Two layers specifically serve the identification of missing or non-existing paths and the toponym collection. The latter is still in process, will be verified by locals and, finally, be used to update OpenStreetMap.

[3] https://naturalearthdata.com/
[4] German for "Specialist information service maps"

3.2 Existing Data and OpenStreetMap

A closer look at OpenStreetMap allowed us to estimate that it is a rich data source. The systematic comparison to the existing maps leads to the conclusion that OpenStreetMap is the most valuable data source and already contains most of the map data needed. A further comparison to maps and guidebooks identified focus areas where data checks and complementations seemed necessary in preparation for the fieldwork.

Besides data comparison, sources and history of OpenStreetMap capture have been explored by means of the ohsome API. Figure 2 shows the number of nodes, ways, and relations over time: two older mapping campaigns could be identified. There was an import of data from JumpStart International and the #tct-mapping to create map data along the long-distance Transcaucasian Trail[5]. It was some kind of organized mapping with OpenStreetMap called humanitarian mapping (Herfort et al., 2021) and is still visible by various drawbacks such as inconsistent geometric precision, mapping errors and generic attributes created from mappers who were not on site. It is mandatory to follow some basic rules defined by the OpenStreetMap Foundation (Foundation, 2022). The requirements are fulfilled, and a page in the OpenStreetMap Wiki offers the necessary information[6] and provide information about the project. Many small contributions to OpenStreetMap were made by travelers; it seems that there is no mapping community in Svaneti.

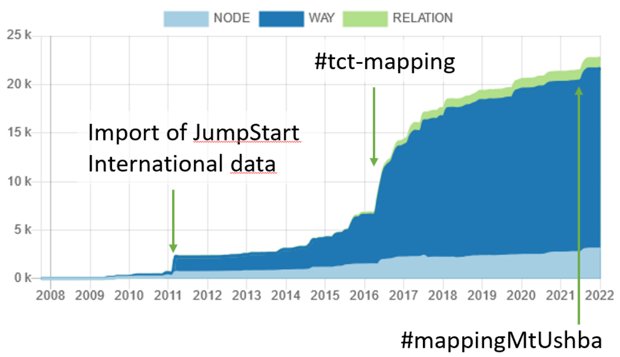

Figure 2. Contributions over the year to OpenStreetMap with marking for specific mapping campaigns, diagram created by the ohsome API (Raifer et al., 2019)

Evaluation, use and improvement of OpenStreetMap data should help others through digital reuse in a different context, and also guarantees sustainable data storage. A working version of the map is derived mainly from OpenStreetMap data, as figure 1 shows. This map gets dynamically improved by all new contributions to OpenStreetMap from the mapping team or other volunteers. It currently uses the SRTM digital elevation model (Farr et al., 2007) in a complementary way to OpenStreetMap for all elements of relief depiction and will later be replaced by a customized DEM of the area as described in chapter 5.

[5] https://transcaucasiantrail.org/en/home/
[6] https://wiki.openstreetmap.org/wiki/Organised_Editing/Activities/Mapping_Mt_Ushba

3.3 Further Information Sources

Besides geodata and maps, there is other meaningful information: early travelers and their reports, such as Freshfield (1902) and Merzbacher (1901), current guidebooks for mountaineers (Bender, 1991; Bærug, 2019; Kramm, 2019), travel blogs[7], and collections of GPS tracks. Verbal descriptions can hardly be integrated into the WMS for sharing. Only route descriptions and toponyms could manually be digitized to be added. At last, conversations with locals and travelers during the first field trip of 2021 have to be counted among valuable information sources.

3.4 Map Production

For the work on the map, it is necessary to combine all data components of the area around Mt. Ushba as shown in Figure 1. In a first step, the updated OpenStreetMap data is imported into a PostgreSQL database with PostGIS extension. In a second step, an automated generalization is carried out. It is tuned to the final map scale of 1:33,000, and comprises in particular schema transformation, aggregation, and simplification. For the visualization, QGIS is utilized: one project containing all data layers with their visualizations serves as WMS. It enables team members to inspect the current map and access all data without any redundant local storage. Figure 3 gives an overview on preparatory work for the 2021 field work and the data flow leading to an identification of missing features.

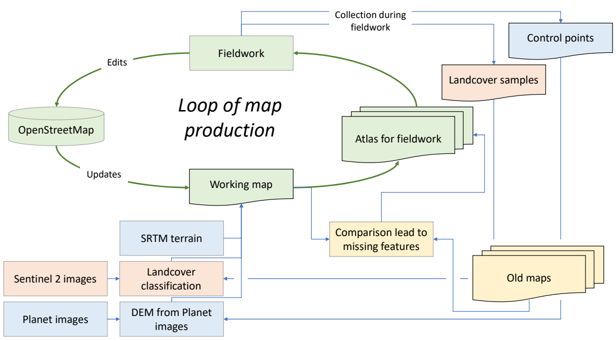

Figure 3. The use of dynamic working map and field atlas in the process of updating and augmenting geodata.

4. METHODS TO CAPTURE AND TRANSFORM MAP CONTENT FROM FIELD WORK

Existing data cannot simply be imported to a quality map. Data need to be verified, updated, and completed. In case of OpenStreetMap it is plausible and well known that only frequently visited areas are depicted in a comprehensive and detailed mode (Koukoletsos et al., 2011; Hecht et al., 2013): For rural mountain areas as Svaneti this is not the case. This forms one principal trigger of field work. A second is the need for precise, target-oriented training data captured to steer the land cover classification from remote sensing data; herein, a focus was set on samples for different vegetation associations. A third one is the measurement of precise ground control points that strongly supports the creation of a digital elevation model by means of photogrammetric software. Field work has been done in July 2021 and will be continued in July 2022.

[7] For example: `https://www.caucasus-trekking.com`

4.1 Mapping with and for OpenStreetMap

One principal goal of the first field campaign was the verification of communication links in the touristic area: ways, paths and tracks. A second campaign will now fill identified evaluation gaps and will check paths and tracks known from other maps. Practically, the field map of our choice was not OpenStreetMap Field Papers[8], but a specifically designed atlas of A4 map sections in a scale of 1:20,000. It shows only relevant features from the working map stemming from OpenStreetMap, from the elevation model, and a rock and ice classification by Schröder (2020) as outlined in section 5. The booklet was enriched with an overview map, a legend, a table specifying important parameters of vegetation cover, another dedicated to GNSS measurements. The main part is made up of sheets for OpenStreetMap mapping with extra pages for additional notes.

The daily plan during the field work was adjusted to identified unexplored focus areas and the weather forecast. Normally, two-person teams did their own tours, but in hard and risky or very remote terrain rather four people with mountaineering experience took over. Every group carried at least one GPS device for tracking and measuring defined control points. Structured notes in the field atlas and commented photos became an essential part of capturing information. All photos and tracks for each hike were collected and stored together for later inspections.

The actual OpenStreetMap mapping was mostly done during bad weather days. Two participants had a profound knowledge in OpenStreetMap mapping and assisted technically, whenever persons had no previous experience in contributing to OpenStreetMap. The mapping was mainly done using JOSM because of an unreliable internet connection. Tracks and photos were a pretty secure basis for mapping, and made it easier to reconstruct spatial configurations. Notes in the atlas worked well for the open landscape. Within settlements, however, more space for notes and inscriptions will have to be provided in a future atlas for settlements. Despite good field documents, the task was time-consuming due to exhausting long hikes, and a partly unstable internet connection.

4.2 GNSS Measurements

Control point measurements are usually done with expensive and heavy professional GNSS receivers combined with post-processing, and leading to coordinate measurements accurate down to a millimeter range. Transport of such devices in a high-mountain environment is unpleasant; customs regulations may also be critical, and a one meter accuracy is sufficient in all our mapping tasks, in particular in referencing the PlanetScope images with a spatial resolution of 3.7 meters. The Garmin GPSMAP 66sr (Lachapelle et al., 2018) is a valuable solution, it looks like an ordinary GPS device but has unique features. It measures the signals of multiple satellite systems in two frequencies (GPS and Gallileo), and stores the observations in the RINEX exchange format for full post-processing. The resulting measurement setup is a GPSMAP 66sr hanging on a hiking pole. This prevents multi-path distortions and easily reveals the height above ground over 30 minutes of observation. Precise point measurements were mostly chosen in advance and already marked in the field atlas. Objective one was to check the calculated terrain model's accuracy in a sensible point distribution, and, secondly, their use in referencing the images. In some cases, the conditions for were rather unfavourable because of

[8] `http://fieldpapers.org/`

overgrowing vegetation and a topographic setting that was significantly limiting the visibility of satellites. The table in the atlas associated to GNSS measurements took up the point ID, the observation time, and the device height above ground. The post-processing considers the GPS and Galileo L1 and L5 signal in PPP mode. For more details, please see Wanninger et al. (2022), who supported us in doing and evaluating the measurements. For the processing, the commercial WaPPP software was used. Open-source or free software solutions were not available in that specific case. 21 points were measured with an accuracy of up to 10 centimeters. As a newly found potential alternative, we can name Net_Diff[9] software, which also processes two frequency signals for GPS and Galileo.

4.3 Characteristic Vegetation Associations

There is no binding general scheme of vegetation cover for Alpine Club maps. The generic requirement of best fitness for orientation and movement in alpine terrain rather calls for a well adapted classification that portrays the vegetation zones of the map in a highly generalized way. Both, in terms of orientation and 'walkability', different wood associations make sense: high stands dominated by deciduous and coniferous trees, low-stands along rivers and open birch stands, but also the upper wood continuation of low-growing krummholz, here often dominated by rhododendron. A separation of grass and herbs land into alpine pastures and natural grass flora is not always clear, not even in the field, and probably unrealistic. Garden land and small arable patches in low location might, however, find entrance into the land cover key. The named categories are definitely not contained in the OpenStreetMap data base. A quick check of this data revealed rather obvious quality differences in a delineation of forests. In one mapping segment, the forest was simply horizontally cut-off by the image edge that had served as mapping reference. Targeting at a consistent result, the team has decided to use open optical remote sensing data of Landsat and Sentinel-2 for vegetation mapping.

A first attempt to classify satellite imagery for vegetation classes made use of geo-referenced Flickr photos (Hallett, 2020), since the pandemic of 2020 prevented the team from selecting training areas in the field. Though quite some indicative photos could be retrieved, an unsolved problems of such referencing is that a camera position is not telling the exact position of the motive of interest, which might be located somewhere in the middle or background of a take. Consequently, representative sites had to be visited and be collected during the 2021 fieldwork by marking sites in the atlas and taking photographs. Only fieldwork helped to gain a more profound knowledge of the region, its climate, and vegetation. That makes it now possible to provide a sensible scheme of vegetation types, which are both relevant and discriminable.

5. METHODS TO PROCESS MAP CONTENT FROM REMOTE SENSING DATA

5.1 Generation of a Digital Elevation Model and Elements of Relief Representation

A detailed relief depiction is a central element of an Alpine Club Map. Relief properties along with land cover characteristics probably dominate decisions on the most suitable path, especially in cases where no existing tracks will be used.

[9] http://center.shao.ac.cn/shao_gnss_ac/Net_diff/Net_diff.html

5.1.1 Relief Information Capture for Alpine Club Maps

An important historic technique to acquire mountain relief information was given by terrestrial photogrammetry (Kaufmann and Ladstädter, 2008). Introduced as early as 1912 it has been established as a surveying standard in Alpine Club cartography in 1922 (Brunner and Welsch, 2002). Aerial photogrammetry came in to reduce field work in hard terrain, and was associated with a more consistent geometric accuracy. It became the dominant source for alpine terrain surveys from 1967 onwards (Brunner and Welsch, 2002). During the era of analogue photogrammetry, the primary relief information extracted from images was spot elevations and contours.

5.1.2 DEM Generation Existing, freely available DEMs are not really precise enough (Gorokhovich and Voustianiouk, 2006) for the planned large-scale mountain map. SRTM-30 data of version 3 is commonly regarded as the best freely available choice of a semi-global DEM (Olla et al., 2020), also for its small elevation bias. Its 30-m grid resolution, however, will appear as a 1 mm spacing in the target scale, too coarse if critical parts of the terrain shall be displayed precisely. Moreover, larger patches of voids within primary SRTM data occur in particular in mountains, where foreshortening, layover, and shadows inhibit interference measurements (Dowding et al., 2004).

Dedicated 3D mapping satellites with an off-nadir viewing capability as Pléiades deliver an excellent 3D mapping performance: Final 3D error vectors are reported to stay below a superb 1.5 m at tests within heterogeneous terrain constellations (conf. (Jacobsen and Topan, 2015), (Perko et al., 2019)). Data acquisition was, however, exceeding the project budget. But we could fortunately test PlanetScope satellite data for a customized DEM generation. These high-resolution optical data have been made available by courtesy of Planets Inc. via a RESA grant for scientific applications, in total 48 scenes from 2018 and 2019. The performance of the PlanetScope sensors (Saunier et al., 2020) cannot be expected to reach the above-mentioned quality since these cameras observe the earth uniformly from a near-nadir view angle, and have a nominal ground resolution of around 3.6 m in comparison to the Pléiades sensor with 0.7 m (panchromatic band). The ground resolution (or ground sampling distance GSD) of the PlanetScope sensors fits however well to a rule of thumb concerning its usability for mapping; the rule is stating that 0.1 mm in the map scale (3.3 metres in our case) should be reached by the GSD of imagery (Büyüksalih and Jacobsen, 2002).

Baseline height ratios are one determinant of possible DEM accuracies. Whilst the stereo correlation coefficients slowly decrease with a longer base-line and more divergent view angles, the DEM accuracy rises to reach an optimum at baseline to height ratios between 0.65 and 0.9 (Hasegawa et al., 2000). A narrow field of view along with low viewing axis convergence minimizes on the other hand uncorrelated image sections in steep terrain, which would be obscured within one or more scenes under a more oblique view. The use of PlanetScope images for generating surface models is still a bit exotic, but the approach had been rated successful before (Ghuffar, 2018).

The stack of PlanetScope scenes was selected to stereoscopically cover the mapping area with minimum cloud cover, low snow cover, and a comparatively high sun elevation. The second issue in image selection is a temporal decorrelation of image partners due to seasonal dynamics (e.g. sun elevation and cast shadows, foliage, snow cover) or singular events causing surface modifications (e.g. avalanches, debris flows, rockfalls, man-

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made developments). Clearly, coherence between image signals is best if only seconds pass between data taken along one orbit. Seasonally, all scenes fall into a high summer situation between the 9th of August and the 9th of September.

An extensive performance test has been carried out for the core area of the map, Mt. Ushba and surroundings. The DSM (Digital Surface Model) generation uses 11 images, all from the 2019 stack. A DSM is the initial result prior to a "refinement" into a DEM. The period from the first data taken to the last is 8 days; a low temporal decorrelation can be expected. Time constraints of a Master's thesis by Jaspersen (2021) have triggered a software choice for this initial DSM: a test version of Agisoft Metashape, a professional photogrammetric suite after an unfortunately unsuccessful attempt with the open-source photogrammetry software MicMac (Rupnik et al., 2017) Currently, we continue processing the whole map area using the free, open-source product AMES Stereo Pipeline (Beyer et al., 2018).

At the time of this initial DSM generation the bundle adjustment was done exclusively by RPC-files (rational polynomial coefficients) provided with the scenes. After this step including the filtering of insecure tie points, 11 scenes are connected by around 325,000 tie points. Now, a dense matching follows. It makes use of semi-global matching, a context-sensitive approach applied to epipolar images (with stereo parallaxes being reduced to one dimension) in "combining matching costs along independent one-dimensional paths through the image" (Dall'Asta and Roncella, 2014, p. 188) The calculated disparities have then been transformed into a gridded DSM by the Agisoft software; grid resolution was set to the "original" 3.6 m. UTM zone 38 using WGS 84 along with ellipsoidal heights has been chosen as a spatial reference in the sampling of DSM cells. The colour-coded DSM output is shown in figure 4.

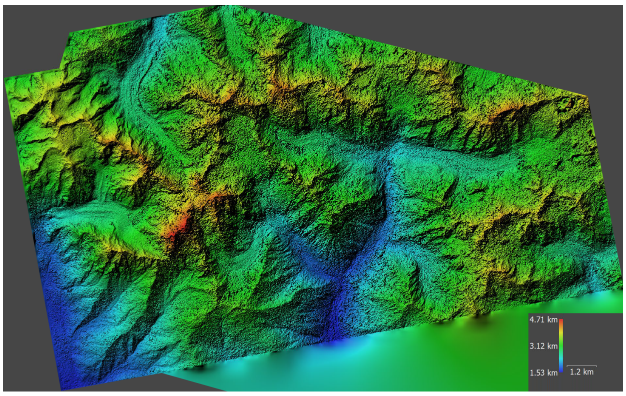

Figure 4. Colour-coded DSM calculated from 11 PlanetScope scenes from Jaspersen (2021).

All elevation controls have so far been done in open terrain, where each point can securely be classified as a ground point. Accuracy of the resulting model of around 45 km^2 coverage is not completely constant and very likely depends on factors as number of scenes covering a point, correlation within one or across orbits, baseline height ratio, and, obviously, local image quality and type of mapped terrain (comp. Gesch (2019)). A probably positive elevation bias of non-corrected (DSM) data over forests might be enhanced by the fact that images have been taken in a full foliage situation. With the completion of a DSM for the whole map, a land-cover based elevation reduction will be applied to reduce the DSM to a DEM.

Absolute elevation references are scarce. We did use precision GPS measurements from our field campaign and also less precise spot elevations from the 1:25,000 scale maps of the area. All readings were transformed into ellipsoidal heights to be comparable. Only a minimum bias has been found in the PlanetScope DSM in comparison to the geometrically pretty stable SRTM 30 data, whereas the mean difference value amounted to 2.1 m. The same can be said in a comparison to the precise GPS measurements that resulted in an RMSE error of 14.3 m of the model, again with a small bias below 3 m. These results are promising and only slightly exceed the target to minimise the average height error to half of the equidistance (12.5 m).

5.1.3 Relief Depiction from the DEM In a comprehensive book contribution of Hurni (2009) one can find a systematic treatment of the challenges, techniques and solutions of mountain map design as it has already systematically been treated by Eduard Imhof (1895-1986). Contour lines are the most important relief element where the dominant inclination still allows a display without graphic merge of individual lines, and, at the other flat end, without an excess mutual line distance that inhibits the visual perception of their interplay. A high frequency elevation variability in the calculated model produces a "very shaky" look of contours when derived from the unmodified version. This would hamper a relief perception by the map reader.

Two constraints have been defined for contour smoothing: best-possible preservation of major terrain structures, such as ridges and drain lines, and of the dominant surface curvature. So-called structure lines (ridges and runoff lines) could be identified using hydrological analysis tools of GIS software. Cell values along a narrow edge zone along the structure lines have not been subject to smoothing (Jaspersen, 2021). The smoothing proper was realised by two alternative methods, multi-step low-pass filtering and second-order polynomial fit. The latter has recently been implemented to enforce a rule that multiple inflection points in x and y are unwanted within a very short map distance of only few millimetres. The type of polynomial enforces such behaviour. Contour results are shown in figure 5 (from left: unfiltered, multiple low-pass, polynomial method).

Furthermore, a hill shading has been generated from a smoothed DSM. Blender, a widely used free 3D modelling suite, has been used following the ideas of Huffman (2017). A DSM or DEM is imported as a displacement map for a horizontal plane mesh that can be linked to a potentially infinite number of different material properties influencing the interaction with light. The Blender software allows not only one single (parallel) illumination source to be traditionally positioned in the NW of the model for a good visual perception, but has the opportunity to emphasise distinct relief elements by skilfully positioned secondary light sources.

Mainly Swiss and Austrian cartographers have a tradition in creating optimised design variants of rock drawings (Jenny et al., 2011) that combine visual clearness, a link to the natural look of the rock structure, and a minimum of geometrically exact information given by contour lines. These criteria require compromises, since the drawing space is limited. We could benefit from the freely available software solution Piotr that automatically creates a Swiss style rock depiction (Geisthövel, 2017); we have to refer to the original publication for a technological description of the program features in the scope of this paper. Finally, a glimpse on the current, draft look of a relief depiction that combines contours, shading and rock depiction as produced by Jaspersen (2021) can be given by figure 6.

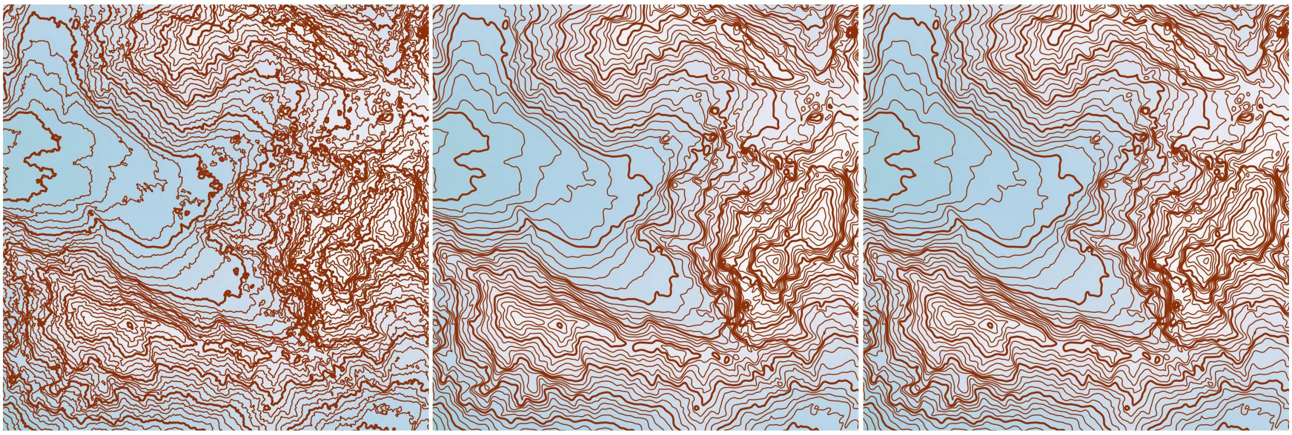

Figure 5. Exemplary result of contour line derivation around the two Ushba peaks (right centre) and the Ushba Glacier. From left: unmodified DSM, multiple low-pass filtered DSM, smoothed using polynomial method. Scale 1:80,000, equidistance 50 m.

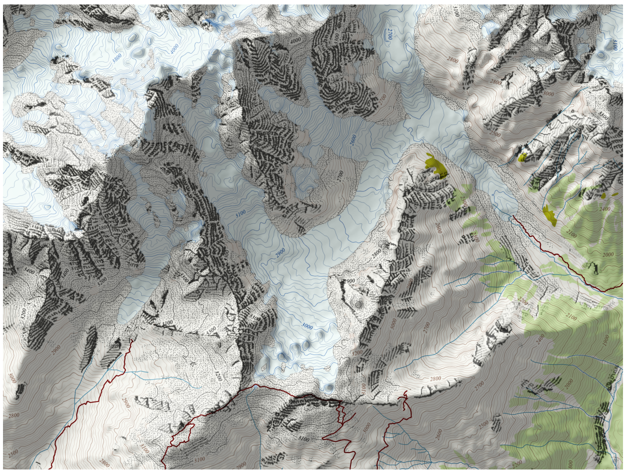

Figure 6. Relief depiction preview around Mt. Ushba from Jaspersen (2021) as generated from the customized DEM, rock and ice masks from Schröder (2020), and tracks and forest mask from OpenStreetMap. Scale 1:33,000.

5.2 Mapping Glaciers and Rock-Covered Surfaces

Glaciers, rock and scree typically invade and cover parts of the alpine elevation belt, and become dominant surfaces in the belt of snow and ice. While the lower vegetation-covered belts are typically comparatively more stable (and safe), ice and loose rock in steep terrain are permanently exposed to strong gravitational forces that lead to erosion, transport and temporary or semi-permanent accumulation features further downhill.

5.2.1 Rock and Ice Mask Generation The tasks of generating a glacier mask and a rock mask are related. Both surface types bear no higher vegetation cover, and are excluding each other. Where ice retreats, rock components become exposed. Problematic is a secure identification of supra-glacial debris. This imposes a serious challenge in attempts of a topic glacier delineation from satellite imagery (Alifu et al., 2015; Doyle, 2017), and requires a combination of the spectral signal from optical imagery along with morphometric parameters from a DEM and topological relations between ice and debris cover.

The classification of these features has been handled by Schröder (2020) on the basis of a multi-temporal stack of Sentinel-2 images (European Space Agency 2020). The principal idea is to use a topic image stack covering the snow depletion phase from late spring to its typical end at the onset of lasting snow fall in autumn in a dense spacing over 2 years. In 2018 it contains 12 scenes, and in 2019 18 with no or very sparse cloud cover.

For the glacier ice the detection model tries to detect glacier surfaces at the point of a maximum local snow depletion; if "all" snow is gone, detected ice surfaces can be attributed to a glacier with a high security. The ice indicator used is the Normalised Differential Snow Index (NDSI); using the difference between reflectance in the short wave infrared and the visible green.

The rock surfaces are not ice-covered at the maximum snow depletion time and they show hardly any seasonal vegetation dynamics, since their vegetation cover is, if ever, minimal. This also means that a vegetation indicator remains below a low threshold even at vegetation peak time. A measure for the abundance of active vegetation is the Normalised Differential Vegetation Index (NDVI), which makes use of the difference between reflectance in the near infrared and the visible red.

The glacier mask has been composed by the computer-classified ice mask using the (NDSI) at times of maximum snow depletion, and manual interpretations and adjustments based upon the glacier inventory data from Tielidze and Wheate (2018) and high-resolution PlanetScope Data. Finally, morphological operations have been applied. They result in a drop of small isolated ice patches on one hand, and a connection of polygons over probably false thin ice gaps, on the other hand. It could not always be completely resolved where the lateral ice edge was and moraine material with no ice underneath starts.

Unvegetated rocky ground could be securely classified using a seasonal NDVI maximum along with a maximum seasonal NDVI variation. All technical surfaces (roofs, airstrip, wider roads) will also be caught using the mentioned criteria. They could, however, automatically be cleared on the basis of OpenStreetMap data, which cover buildings and transport features. The previously detected glaciated area is likewise eliminated.

6. CONCLUSIONS

The use of free data and free software enables a production of mountain maps in a quality standard as required for the Alpine Club maps. OpenStreetMap can be accessed dynamically in the course of map generation; a fully automated digital workflow has been developed which transforms comprehensive and actual data into the required map design. Since the data collection of the mapping team is made available again by swift uploads to OpenStreetMap, other users of the platform and the locals, including their business, can benefit as well.

We draw the following conclusion from our experience for data choice and assembly: POIs, buildings and streets are well covered by OpenStreetMap, but supplements or updates are sometimes necessary. Tracks and paths are essential in an Alpine Club map; to exclude ambiguities and insecurities, they must be comprehensively verified and "re-tracked". OpenStreetMap may contain information on land cover, in particular basic vegetation classes and glacier cover. Referring to these features, an automated classification from satellite images is capable to produce a deeper structured, geometrically more accurate, more topic, but, above all, more consistent representation. Essential for the type of Alpine Club maps is a detailed and graphically complex representation of the terrain. It embeds contour lines, shading, rock and scree representation. With a given map scale of 1:33,000, this sub-task calls for a reliable digital terrain model with a grid spacing of at least 10 m, which is not freely available in many parts of the world. The attempts to derive such a DEM from PlanetScope images are promising, but require a complex and skillful processing.

The total time demand for the production of the Alpine Club map is comparatively high. In addition to planning and implementation of two field campaigns, each with around 10 participants, 6 master theses dealt with various aspects of the project and required a scientific supervision. Moreover, 2 student assistants were part-time employed over 6 months in total. One cartographer has invested on average one day per week over the past two years into project tasks such as geodata management, administration of the spatial data infrastructure, generalization, adaptation of the Alpine Club map style, and extensive semi-automated cartographic editorial work.

The following software tools were used (if not indicated free and open source): in processing of OpenStreetMap data: JOSM and ID, in geodata management and spatial data infrastructure: osm2pgsql, PostgreSQL/PostGIS, QGIS, in processing remote sensing data: "R", Snap, in photogrammetric processing: AMES Stereo Pipeline, Agisoft Metashape (proprietary), in GNSS post-processing: WaSoft (proprietary), in map generation: QGIS, Blender, PostGIS and Piotr.

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REFERENCES

Alifu, H., Johnson, B. A., Tateishi, R., 2015. Delineation of debris-covered glaciers based on a combination of geomorphometric parameters and a TIR/NIR/SWIR band ratio. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 9(2), 781-792.

Bender, F., 1991. *Kaukasus*. J. Berg, München.

Beyer, R. A., Alexandrov, O., McMichael, S., 2018. The Ames Stereo Pipeline: NASA's Open Source Software for Deriving and Processing Terrain Data. *Earth and Space Science*, 5(9), 537–548.

Brunner, K., Welsch, W., 2002. High-mountain cartography of the German and the Austrian Alpine Clubs. *ISPRS Journal of Photogrammetry and Remote Sensing*, 57(1-2), 126-133.

Buchroithner, M. F., Himpel, T., 2010. The Centennial Edition of the 1908 Alpenverein Map of the Brenta Massif, Italy. *Erdkunde*, 64(2), 195–202.

Büyüksalih, G., Jacobsen, K., 2002. Mapping with pleiades pan-sharpened images. *European Remote Sensing: Progress, Challenges and Opportunities*, EARSeL.

Bærug, R., 2019. *Svaneti, the Essence of the Caucasus*. Ushba Press, Riga - Twebish.

Dall'Asta, E., Roncella, R., 2014. A Comparison of semi-global and local dense matching algorithms for surface reconstruction. *Int. Arch. of the ISPRS*, 45.

Dowding, S., Kuuskivi, T., Li, X., 2004. Void fill of SRTM elevation data - principles, processes and performance. *ASPRS Images to Decision: Remote Sensing Foundation for GIS Applications*, 12-16.

Doyle, K., 2017. *Glacier Extents of the Greater Caucasus mountain range derived from manual interpretation and digital classification of Landsat satellite data*. TU Dresden.

Farr, T. G., Rosen, P. A., Caro, E., Crippen, R., Duren, R., Hensley, S., Kobrick, M., Paller, M., Rodriguez, E., Roth, L. et al., 2007. The shuttle radar topography mission. *Reviews of geophysics*, 45(2).

Foundation, O., 2022. Organised editing guidelines. wiki.osmfoundation.org/wiki/Organised_Editing_Guidelines. Accessed: 2022-05-06.

Freshfield, D. W., 1902. *The Exploration of the Caucasus*. Arnold, London.

Geisthövel, R., 2017. Automatic Swiss style rock depiction. PhD thesis, ETH Zurich.

Gesch, D., 2019. Accuracy assessment of elevation data. significant topographic changes in the united states. www.usgs.gov/special-topics/significant-topographic-changes-in-the-united-states/science/accuracy-assessment#overview. Accessed: 2022-05-11.

Ghuffar, S., 2018. DEM generation from multi satellite PlanetScope imagery. *Remote Sensing*, 10(9), 1462.

Gorokhovich, Y., Voustianiouk, A., 2006. Accuracy assessment of the processed SRTM-based elevation data by CGIAR using field data from USA and Thailand and its relation to the terrain characteristics. *Remote sensing of Environment*, 104(4), 409-415.

Hallett, M. J., 2020. *Mapping the Vegetation of the Caucasian Ushba Region (Georgia Russian Federation) as a contribution to an Alpine Club Map*. TU Dresden.

Hasegawa, H., Matsuo, K., Koarai, M., Watanabe, N., Masaharu, H., Fukushima, Y., 2000. DEM accuracy and the base to height (B/H) ratio of stereo images. *International Archives of Photogrammetry and Remote Sensing*, 33(B4/1; PART 4), 356-359.

Hastik, R., 2020. Österreichischer Alpenverein: Neue Methoden in der Kartographie. arcgis.esri.de/oesterreichischer-alpenverein-neue-methoden-in-der-kartographie/. Accessed: 2022-04-29.

Hecht, R., Kunze, C., Hahmann, S., 2013. Measuring completeness of building footprints in OpenStreetMap over space and time. *ISPRS International Journal of Geo-Information*, 2(4), 1066–1091.

Heller, A., Ladner, M., Erhard, A., Steinicke, E., 2017. Das neue Bild des Mt. Kenya. *Innsbrucker Jahresbericht 2016-2017*, Institut für Geographie der Universität Innsbruck in Zusammenarbeit mit der Innsbrucker Geographischen Gesellschaft.

Herfort, B., Lautenbach, S., Porto de Albuquerque, J., Anderson, J., Zipf, A., 2021. The evolution of humanitarian mapping within the OpenStreetMap community. *Scientific reports*, 11(1), 1–15.

Huffman, D., 2017. Creating shaded relief in blender. somethingaboutmaps.wordpress.com/2017/11/16/creating-shaded-relief-in-blender/. Accessed: 2022-05-11.

Hurni, L., 2009. Cartographic relief presentation revisited - forty years after Eduard Imhof. *Landform-Structure, Evolution, Process Control*, Springer, 1–20.

Jacobsen, K., Topan, H., 2015. DEM generation with short base length Pleiades triplet. *Int. Arch. of the ISPRS*, 40(3W2), 81-86.

Jaspersen, A., 2021. *Mapping the Relief of Mount Ushba (Georgia) as a Contribution to an Alpine Club Map*. TU Dresden.

Jenny, B., Zurich, E., Geisthövel, R., Hurni, L., 2011. Rock drawing for topographic maps. *Proceedings of the 12th meeting of the ICA Commission on Mountain Cartography*.

Kaufmann, V., Ladstädter, R., 2008. Application of terrestrial photogrammetry for glacier monitoring in alpine environments. *Proceedings of the 21st Congress of ISPRS*, Proceedings of Congress of ISPRS, XXXVII, B8, Int. Arch. of the ISPRS, 813–818.

Koch, C., 2019. Kein Aprilscherz: Geodaten in Bibliotheken - digital, analog oder doch historisch? Eine Betrachtung auf dem Weg zu einem Arbeitsinstrument des FID Karten an der Staatsbibliothek zu Berlin. *KN - Journal of cartography and geographic information: an official journal of DGfK, SGK and ÖKK*, 71(4), A-17–A-23.

Koukoletsos, T., Haklay, M., Ellul, C., 2011. An automated method to assess data completeness and positional accuracy of openstreetmap. *GeoComputation*, 3, Citeseer, 236–241.

Kramm, N., 2019. *Georgien: Kleiner und Großer Kaukasus: 45 Touren*. Rother Wanderführer, 2., aktualisierte Auflage edn, Bergverlag Rother GmbH, München.

Kunz, P., Bobrich, J., 2019. Multiscale cartographic visualization of harmonized datasets. *International Journal of Cartography*, 5(2-3), 178–194.

Lachapelle, G., Gratton, P., Horrelt, J., Lemieux, E., Broumandan, A., 2018. Evaluation of a Low Cost Hand Held Unit with GNSS Raw Data Capability and Comparison with an Android Smartphone. *Sensors*, 18(12), 4185.

Merzbacher, G., 1901. *Aus den Hochregionen des Kaukasus 1*. Duncker & Humblot, Leipzig.

Olla, C. M., Igbokwe, J. I., Ojiako, J. C., Igbokwe, E., 2020. Investigation and Validation of SRTM v3 and ALOS PALSAR Accuracy Over Landcover/Landuse Types in Federal Capital Territory (FCT), Nigeria. *International Journal of Geoinformatics and Geological Science*, 7(3), 31-37.

Parry, R. B., Perkins, C. R., 2000. *World mapping today*. 2. ed. edn, Bowker-Saur, London.

Perko, R., Raggam, H., Roth, P. M., 2019. Mapping with Pléiades - end-to-end workflow. *Remote Sensing*, 11(17), 2052.

Prinz, R., Heller, A., Ladner, M., Nicholson, L. I., Kaser, G., 2018. Mapping the loss of Mt. Kenya's glaciers: an example of the challenges of satellite monitoring of very small glaciers. *Geosciences*, 8(5), 174.

Raifer, M., Troilo, R., Kowatsch, F., Auer, M., Loos, L., Marx, S., Przybill, K., Fendrich, S., Mocnik, F.-B., Zipf, A., 2019. OSHDB: a framework for spatio-temporal analysis of OpenStreetMap history data. *Open Geospatial Data, Software and Standards*, 4(1), 1–12.

Ramm, F., Topf, J., 2011. *OpenStreetMap: using and enhancing the free map of the world*. UIT Cambridge, Cambridge.

Rupnik, E., Daakir, M., Pierrot Deseilligny, M., 2017. MicMac – a free, open-source solution for photogrammetry. *Open Geospatial Data, Software and Standards*, 2(1), 14.

Saunier, S., Beaton, A., Albinet, C., 2020. *TN on Quality Assessment for PlanetScope (DOVE)*. esa.

Schröder, M., 2020. *Erfassung und Kartierung von Fels- und Eisbedeckung in der Region Uschba (Georgien) mit multitemporalen optischen Fernerkundungsdaten*. TU Dresden.

Sester, M., Jokar Arsanjani, J., Klammer, R., Burghardt, D., Haunert, J.-H., 2014. Integrating and generalising volunteered geographic information. *Abstracting geographic information in a data rich world*, Springer, 119–155.

Tielidze, L. G., Wheate, R. D., 2018. The greater caucasus glacier inventory (Russia, Georgia and Azerbaijan). *The Cryosphere*, 12(1), 81–94.

Usery, E. L., Varanka, D. E., Davis, L. R., 2018. Topographic Mapping Evolution: From Field and Photographically Collected Data to GIS Production and Linked Open Data. *The Cartographic Journal*, 55(4), 378-390.

Wanninger, L., Heßelbarth, A., Frevert, V., 2022. Garmin GPSMAP 66sr: Assessment of Its GNSS Observations and Centimeter-Accurate Positioning. *Sensors*, 22(5), 1964.