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MODELING VARIATIONS OF THE BUBA AND TBILISA GLACIERS AGAINST THE BACKDROP OF REGIONAL CLIMATE CHANGE *

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Abstract. This work is devoted to the study of historical and projected changes in the Buba and Tbilisa glaciers in light of regional climate change. The catalyst for the research was the devastating landslide on August 3 at the Georgian resort of Shovi, induced by the intense melting of the Buba Glacier. This study is the first to assess past, present, and future alterations in the Buba and Tbilisa glaciers through mathematical modeling, an approach never before applied to any glacier in the Caucasus Mountains of Georgia.

Keywords and phrases: OGGM modelling, Buba and Tbilisa glaciers, climate change.

AMS subject classification (2010): 86A40, 86AU10, 74 S30.

Climate change, driven by global warming, is catalyzing the degradation of permafrost and leading to an increase in glacial melt. Consequently, this has been causing more frequent landslides. A notable instance occurred on August 3, 2023, when a landslide devastated the Shovi mountain resort in the Oni municipality of Georgia, situated near the southern foothills of the Greater Caucasus. It should be highlighted that prior to August 3, 2023, the Bubistskali River had not experienced any significant flood flows in over a century. Without extensive glaciological studies and modeling, forecasting the precise or even approximate timing of glacier-induced flood events is nearly impossible.

To investigate the historical, current, and future states of the Buba and Tbilisa glaciers, we conducted all the procedures typical of the OGGM modeling framework. This included determining glacier boundaries, topography, central and flow lines, mass balance modeling, ice thickness estimation, and ice flow modeling [1]. Due to the scope of this paper, we will only present a subset of these steps. Our calculations indicate that the Buba glacier is relatively homogeneous in mass distribution, possessing a single flow line, whereas the Tbilisa glacier features two flow lines. Furthermore, the largest ice reservoir of the Tbilisa glacier is situated in the upper, high-altitude regions, exceeding depths of 120 meters. In contrast, the Buba glacier hosts a singular, substantial ice reservoir covering almost the entirety of the glacier, located at a lower elevation with depths beyond 100 meters. Given these factors, it is conceivable that within the lower strata of this vast and deep glacial reservoir of the Buba Glacier, there exists a body of waterunder high pressureand not ice, which was later implicated in the Shovi tragedy.

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Firstly, we present the past, present, and future states of the mass balance of the Buba and Tbilisa glaciers. The mass balance component of the OGGM entails a temperature index melt model (1) that utilizes monthly gridded climate data [1],

$$m_i(z) = p_f P_i^{\text{Solid}}(z) - \mu^* \max\left(T_i(z) - T_{\text{melt}}, 0\right) + \varepsilon, \tag{1}$$

where m_i represents the monthly mass balance at elevation z, P_i^{solid} is the monthly solid precipitation, p_f is a global precipitation correction factor (default value is 2.5), μ^* denotes the glacier's temperature sensitivity, T_i is the monthly air temperature, and T_{Met} represents the threshold monthly air temperature above which ice melt is presumed to occur (default: -1°C). This value is chosen because melting can transpire even when the monthly average temperature is below 0°C). The term ε accounts for a residual (or bias correction). The temperature sensitivity parameter of the glacier, μ^*, is subject to calibration. Specifically, the calibration of μ^* employed the method outlined in [2].

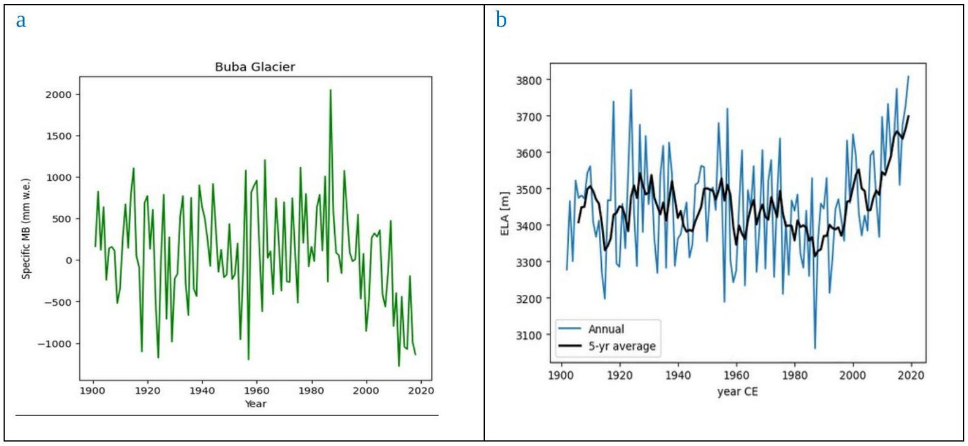

Figure 1: Change in the mass balance of the Buba Glacier from 1900 to 2020 (a); Variation in the Equilibrium Line Altitude (ELA) of the Buba Glacier (b).

The mass balance data of the Buba Glacier between 1900 and 2020, calculated by (1)as featured in Fig. 1(a), indicates periodic significant fluctuations around the zero line from the early 1900s to the 1980s with notable mass losses occurring around the 1920s and between the 1950s and 1960s. In the period leading up to 1990, a sharp increase in the glacier mass was recorded, followed by a consistent decline in the mass balance thereafter. The trends depicted in Fig. 1(b) demonstrate annual and 5-year mean changes in ELA over the span of 120 years (1900 to 2020), allowing assessment of mass balance trends. Generally, the ELA started at lower elevations around the 1900s, indicating an expanded accumulation area above the ELA and a resulting increase in the mass balance until the 1990s, which recorded the lowest ELA position. Post-1990s, there has been a pronounced rise in ELA elevation, signaling a growing ablation zone below the ELA, which implies that the Buba Glacier has continuously lost mass at an increasing rate and seen diminishing mass gains. The Tbilisa Glacier exhibits a comparable pattern in mass balance from

1900 to 2020, likely due to their geographical closeness and similar environmental and meteorological conditions.

Understanding glacier dynamics is crucial for numerous glaciological and hydrological studies. Ice mass flux through the glacier's cross-section and the average ice velocity integrated over depth, are calculated using (2) and (3), respectively [1][2].

$$q = US, \quad (2)$$

$$U = \frac{2A}{n+2} h \tau^n, \quad (3)$$

where q is the ice flow, S is the cross-sectional area of the glacier, U is the average velocity, A is the ice creep parameter, n is the flow-law exponent from Glen's law, h is the ice thickness, τ is the basal shear stress.

The area of the glacier S is determined using the nonlinear equation (4), which takes into account the mass balance (1), slope, width, and bottom topography along the flow line as follows [1]:

$$\frac{\partial S}{\partial t} = w \cdot \dot{m} - \nabla \cdot (US) \quad (4)$$

where $\dot{m}$ is the mass balance rate, and w symbolizes the width of the glacier.

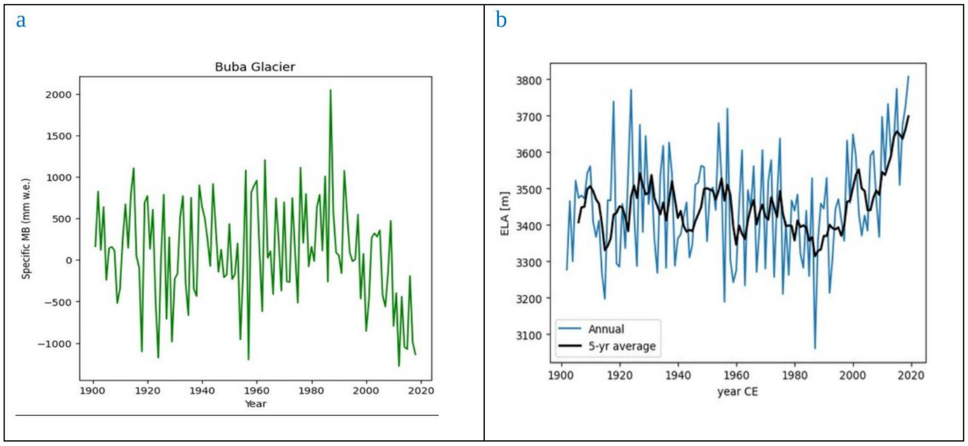

Figure 2: Calculated mass movement velocity vectors of the Buba Glacier (a); Projections of changes in the area S of the Buba Glacier until 2100 (b).

Fig. 2 presents outcomes from the OGGM v.1.6 model concerning the velocity vectors of mass movement and alterations in the glacier area S for the Buba Glacier. As illustrated in Fig. 2(a), high activity in the mass movement of ice is observed primarily in the central part of the glacier's large reservoir. Similar patterns of movement are found in a secondary, smaller ice reservoir situated at a higher elevation within the upper sections of the glacier, where velocity vectors tend to mirror those in the central zone of the larger reservoir. Fig.

2(b) outlines the anticipated changes in the glacier's area up to 2100, derived from OGGM computations based on Equation (4). The data depicted in Fig. 2(b) indicates that there is a marked diminution of the Buba Glacier's area from 2024 to 2040. Importantly, it should be noted that the contraction of the glacier commenced around the year 2000, with the pace of reduction intensifying notably post-2024, corresponding to recent events, including the tragic landslide in 2023. Comparative analysis of the OGGM v.1.6 model's results with various observational data sets reveals a substantial correlation between the modeled and measurable observed data across different periods. Consequently, this substantiates the effectiveness of the OGGM v.1.6 model in reliably simulating the evolution of the Buba and Tbilisa Glaciers over diverse temporal scales.

REFERENCES

1. Maussion, F., Rothenpieler, T., Dusch, M., Recinos, B., Vlug, A., Marzeion, B., Landmann, J., Eis, J., Bartholomew, S.L., Champollion, N., Gregor, P., Butenko, A., Smith, S. & Oberrauch, M. OGGM/oggm: v1.1. Available online: https://doi.org/10.5281/zenodo.2580277https://doi.org/10.5281/zenodo.2580277, 2019.
2. Marzeion, B., Jarosch, A.H., & Hofer, M. Past and future sealevel change from the surface mass balance of glaciers. *The Cryosphere*, 6, 1295–1322. Available online: https://doi.org/10.5194/tc-6-1295-2012https://doi.org/10.5194/tc-6-1295-2012, 2012.
3. Hutter, K. Theoretical Glaciology: Material Science of Ice and the Mechanics of Glaciers and Ice Sheets, *Springer Netherlands*, 1983.

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