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Repeated terrestrial photography for the assessment of landscape changes in the high mountain environment

Keywords: repeat photography, horizon matching approach, Google Earth, high mountain environment, Alps, Tibetan Plateau, Bhutan

Summary: High mountain environment is exposed to increased societal pressure, augmented by climate change. Deforestation, erosion, and deglaciation are the most obvious consequences. Repeated photography is a visual record facilitating a valuable insight into these processes, in some cases going back to the 1850s. This exceeds the records acquired by satellites and airplanes for decades. The disadvantage of a tilted view, complicating the transfer of information to maps, is outweighed by the public acceptance, helping to promote environmental topics to a wider audience. A novel horizon matching approach for the transfer of features identified in the photographs to the map is be presented together with examples from the Alps, Ethiopia, Tibetan Plateau, and Bhutan.

Introduction

Repeat photography is a method for the analysis of landscape changes using terrestrial iconographic material. It is the most common method used to observe landscape changes over time (Chen et al. 2021) and it extends the record by aerial photography and satellite imaging for several decades.
The history of repeat photography is indeed delimited by the invention of practical photography by Daguerre in 1939. His process relying on light-sensitive silver iodide coating was positive, resulting in reversed images on metallic plates but required only minutes of exposure compared to heliogravure by N. Niépce from 1822, requiring hours of exposure. Daguerreotype was soon followed by Henri Fox Talbot who introduced calotype process which was paper based in 1841. It allowed the production of any number of copies by contact printing. A key development improving the quality of photography was the mathematically based design of lens by Joseph Petzval (Rakich and Wilson 2007) which made shorter exposure times possible.
Historical photographs from the 19th century are often available as books illustrations. Initially, they were reproduced by a mechanical copying on the printing matrices. Later, photographical process was involved, giving rise to photolithography and photoxylography. In these two techniques, the image transferred photochemically on wooden block or lithographical stone, serving as printing matrices, was still manually engraved. The resulting print was a linear black and white image. Reproduction of half-tone images remained a challenge until the development of an efficient method of photogravure by Karel Klíč in 1878 (Mustalish 1997).
Almost two centuries of development and use of photography left behind valuable archives documenting life on the planet Earth both in terms of society and its natural environments. Landscape photography appeared in the very decade after the invention of photography. For instance, a daguerreotype of Matterhorn from Riffelsee was taken by John Hobs and John Ruskin a British writer and art critic in 1949 (Jacobson and Jacobson 2015). The first landscape photographers often started their career as landscape painters as for instance French photographers of the Alps Aime Civiale or Gabriel Loppé. The development of landscape photography in the first decades was complicated by heavy equipment including large format plate cameras and a tent serving as dark room that had to

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be carried. A. Civiale for instance had to accommodate 250 kg of equipment (Brevern 2009) and Bison Brothers were accompanied to high elevations of the French Alps by 25 porters.

Not only Europe was in the focus of the first generations of photographers. High quality photographs were acquired also in regions distant from the centres of technical developments of that era. The explorers exactly as today aim at documenting remote places with contrasting environmental and societal conditions with respect to their countries. For instance, in 1964, Benjamin Simpson (1831-1923), a member of the Bengal Photographic Society, as a medical doctor took part of Ashley Eden's expedition to Bhutan and took probably the first photographs of the remote and independent country (Eden et al. 1865). The Himalayas were photographed already by the pioneer of mountain photography Samuel Bourne (1834-1912) who opened his photographic company in Simla, then the summer capital of the British India, in 1863 and himself took photographs in high altitudes (Sampson 1992). The company ceased to exist only in 2016, being likely the longest-lasting photographic company (Voon 2016). These acquisitions in the Himalayas are surprisingly early compared, for instance, to Krkonoše Mountains in today's Czechia which was probably first time photographed by a French photographer Adolphe Braun on his journey across the central Europe in 1858-62 (Dvořák and Havel 2016).

Rephotography has been often used for documentation of glacier retreat in the Alps. For instance, glaciers in the Eastern Alps were focused on by Finsterwalder (1953). A large Rephotographic Survey Project which aimed at repeating Western American survey photographs taken in the 1860s and 1870s was organized in the USA in the 1970s (Klett 2011). A current project worthwhile mentioning is the project of rephotography of high mountain images by Vittorio Sella called On the Trails of Glaciers (https://onthetrailoftheglaciers.com/the-project/). V. Sella, born on the foothills of the Alps, (1859 – 1943) was an outstanding photographer in high altitudes who visited Caucasus, Karakoram, Ruwenzori, Sikkim Himalayas and Alasca.

Data and methods

Overview of existing methods

The key issue in repeated photography is the process of finding the vantage point called relocation. A simple parallax-based method of relocation was proposed by Malde (1973). It relies on alignment of objects in middleground and background. The basic approaches in repeat photography (rephotography) were reviewed for instance by Klett (2011). He suggests that rephotography either strives for exactly same geometry of the field of view or tries to capture the landscape in a representative way by adjusting the geometry. The vantage points of historical photographs are not randomly distributed in the landscape, they tend to be limited to easily accessible locations close to roads and trails offering panorama views which often allowing to build time series of photographs and to combine them with recent photos available via applications such as Mapy.com or Google Earth (Kropáček et al. 2024).

Historical images can be related to real world coordinates in monoplotting approach. It was implemented for example by Bozzini et al. (2012) in software package called WSL Monoplotting Tool which is freely available. It can be used for establishing a geometric model that relates the photograph with wantage point and the landscape using a group of points of known coordinates and elevation identified in the photograph. The finding of such point can be a challenge due to changes in the landscape or its character which does not provide easily identifiable points, such as continuous tree canopy. This model allows vectorization of features in the historical photograph and their export to GIS compatible formats. The processing involves an estimation of camera parameters including focal distance, radial distortion and position of principal point which are in case of historical photographs typically unknown. The WSL Monoplotting tool was tested and evaluated for the use in various fields of landscape research (Stockdale et al. 2015; Gabellieri and Watkins 2019).

Horizon matching approach

This approach relies on the matching of a historical image with a simulated view in Google Earth which is a representation of digital globe. Google Earth allows 3D representation of very high-resolution satellite imagery draped over a digital elevation model. The viewing geometry is governed by central perspective which is analogous to photography. Furthermore, it allows placing of the vantage point to the ground and provides the possibility of storing its position, altitude, azimuth and elevation angle, distance to the intersection of the viewing direction with the terrain and coordinates of the intersection in point file in KML format. Google Earth also allows a simulation of the view from the relocated point. The simulated image itself can be under favorable conditions used for the evaluation of landscape changes with respect to the historical photograph (Kropáček 2019; Kropáček et al. 2024).

After a rough relocation based on the name of the image, maps of the journey, published diary of the author or other auxiliary information, horizon matching approach can be applied. In the horizon matching, the window of the simulated view in Google Earh is placed over the window showing the historical photograph. Then a partial transparency of the superimposed window is accomplished by WindowTop utility, facilitating a comparison and matching of the horizons in the simulated image and in the historical photograph. Highlighting of several distinct topography features by colored points and lines can be useful to increase their visibility in the overlay. During this process the vantage point of the simulated image can be adjusted in Google Earth. Additionally, some features in middle ground and foreground can be used for matching. This process can lead to high accuracy of relocation. The tools available in Google Earth allow also vectorization of features in the historical photograph superimposed by the partially transparent simulation image. The transparency can be adjusted in the range from 0 to 100%. The vector files can be subsequently saved and integrated into maps or imported into the GIS environment, combined with other geodata and analyzed. Unfortunately, in the case of highly oblique viewing angles, Google Earth allows vectorization only in areas lower than the vantage point. In another words, the features seen under positive elevation angle from the vantage point cannot be captured. This is a serious drawback that might be solved in some future version of the software.

Case studies

Deglaciation (Alps)

The photograph by A. Civiale reproduced by photogravure (Fig. 1) documents the extent of glaciarization in the Bernese Alps shortly after the Little Ice Age (LIA). The former right tributary glacier of Aletschgeltscher the Mittelaletschgletscher sourcing on the east face of Aletschhorn (4,194 m a.sl.) became disconnected and retreated dramatically. The lateral moraine which appeared due to the retreat of Mittelaletschgletscher and thinning of Aletschgletscher on the former glacier confluence documents the massive volume change.

Figure 1: Comparison of Aletschhorn in the Alps on the photograph by A. Civiale from 1859-1868 as seen from a ridge (46.431369°, 8.094046°, 2922 m a.s.l.) across Aletschgletscher, and simulation image in Google Earth showing a profound deglaciation in the time span of one and half century.

In some cases, other iconographic materials such as engravings acquired well before the discovery of photography can be used for the analysis of landscape changes even in quantitative manner. Engravings were often sketched in the field and finalized by an engraver who never visited the site which can introduce certain bias mainly in details (Kropáček et al. 2024). The overall geometrical quality can be still very high if some mechanical-optical techniques were used during sketching phase. This includes camera obscura, in fact the predecessor of photographic camera, or camera lucida, based on a glass prism fixed on a pole with attached plate on which the image of the landscape could be observed through the prism. Camera lucida was most likely used in the case of the engraving of Monte Rosa, published in the book by Ludwig von Welden from 1824. The geometric quality is remarkable when compared with the simulated image (Fig. 2). L. von Welden was an Austrian army officer who took part of the mapping of Monte Rosa when he served as a head of the army topographical office.

Figure 2: Engraving based on drawing by L. Welden from 1824 shows the glacierized Eastern face of Monte Rosa the second highest mountain in the Alps, and the terminus of Belvedere Glacier with multiple lobes, one of them drained by Anza River, sourcing from a glacier gate marked by an arrow. The lobe terminates much higher in the valley as seen on a simulation image in Google Earth based on a 2017 satellite acquisition. The image was sketched from a point close to the settlement of Pecetto (45.973789°, 7.948840°, 1401 m a.sl.).

Landsliding in Ethiopia

Quickly expanding town of Dessie is located in north-central Ethiopia on the major road connecting Addis Abeba with the Red Sea coast. It is well known for multiple landslides directly in and at the margin of the town (Fubelli et al. 2013; Vařilová et al. 2015). The series of images shows the transformation of an area dissected by Borkena River (Fig. 3). The area was formerly off the town in 1936-1941. Later it has been affected by extensive urbanization accompanied by reforestation as documented on the images from 2013 and 2023 (Fig. 3 b and c). The building activity has reached a large landslide (Kera Landslide) described in detail in (Kropáček et al. 2019). The historical image evidences its age exceeding about 80 years. The 2013 and 2023 images allow the comparison of a repeated photograph and simulated image. While patches of trees and buildings are better represented in the photograph, the simulation does not suffer from atmospheric scattering and provides clear view of distant slopes close all the way to the horizon.

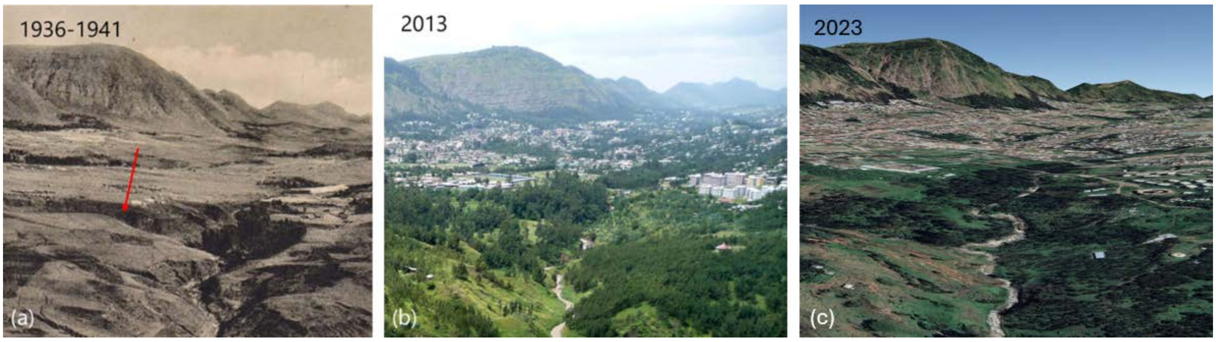

Figure 3: Landsliding area on the margin of the rapidly expanding town of Dessie with Borkena River valley in the foreground on the postcard from 1936-41, photograph by Z. Vařilová, and simulated image in Google Earth based on Pléiades satellite image from 2023. A large landslide nowadays covered by vegetation is marked by a red arrow. The vantage point is on Doro Mezleya hill (11.114600°, 39.648340°, 2540 m a.s.l.)

Land cover changes on the Tibetan Plateau

Tibet has been traditionally difficult to access. The first photographs in Tibet were taken secretly by Russian geographer Gombojab Tsybikov disguised as a Buddhist pilgrim as late as in 1899 - 1902 (Andreev 2013; Kropáček 2019). Half century later two Czechoslovak film makers Vladimír Sís and Josef Vaniš, sent to Tibet by Czech Army Film Company to document the construction of the first motorable road connecting China with Lhasa via Eastern Tibet, could see the land undergoing pronounced changes (Bělka 1922) which have been graduating since then. The pair of images of a mountain west from Bamog in SE Tibet (Fig. 4) shows dramatic changes in the valley. A lot of houses and infrastructure appeared on the bottom of the valley and on the low ridge in the middleground on the course of the last fifty years.

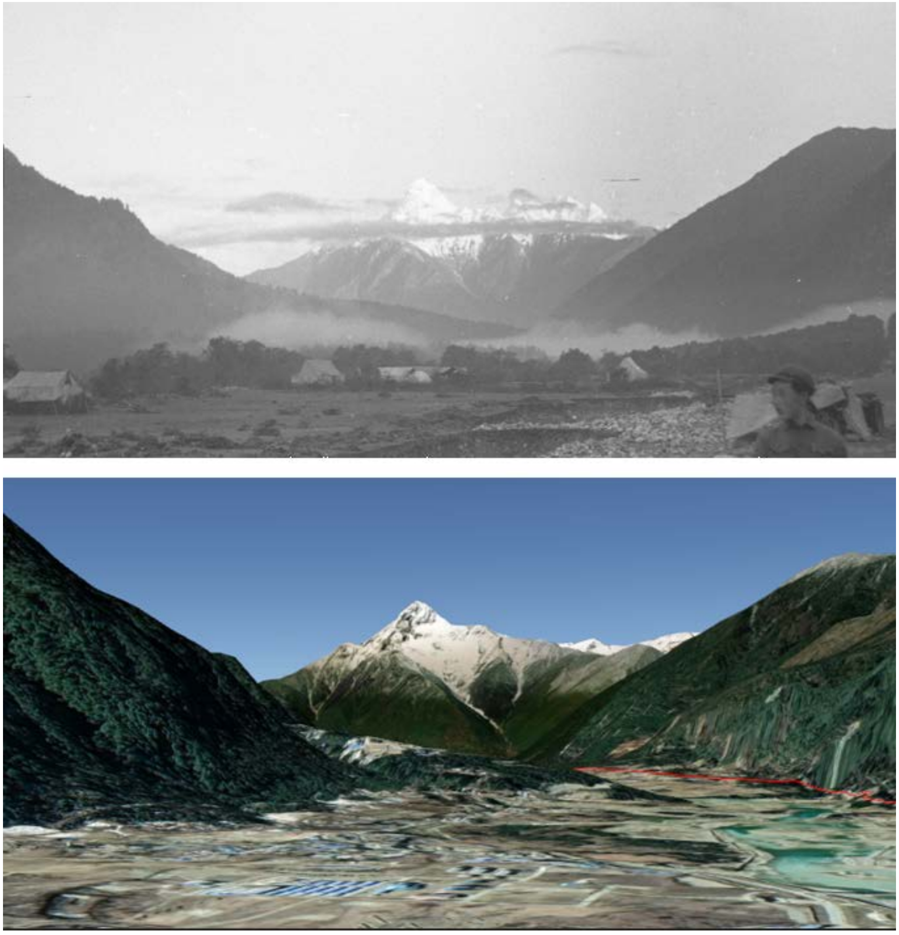

Figure 4: A comparison of a photograph by J. Vaniš from May 1954 with the simulated image of a view close to Bamog in SE of Tibet in westward direction towards a mountain with altitude of 5,401 m a.s.l. shows a large change in landcover of the valley. The vantage point is at 29.863927°, 95.755814°, 2731 m a.s.l.

3.4 Changes in vegetation cover (Bhutan)

Changes in land cover is one of the most frequent uses of rephotography. Figure 5 shows the surroundings of Punakha in Bhutan, then the capital of the county. In this case the vantage point was shifted with respect to the historical photography to capture the landscape unobscured by vegetation around the road. Mo Chu river with a cantilever bridge in the same location as now can be seen in the photograph taken by Henri Hyslop in 1907. There are more trees in the riparian zone in the recent photograph from 2024. Hillslopes covered by succession forest dominated by blue pine trees on formerly almost baren hills can be seen in the background (Fig. 5).

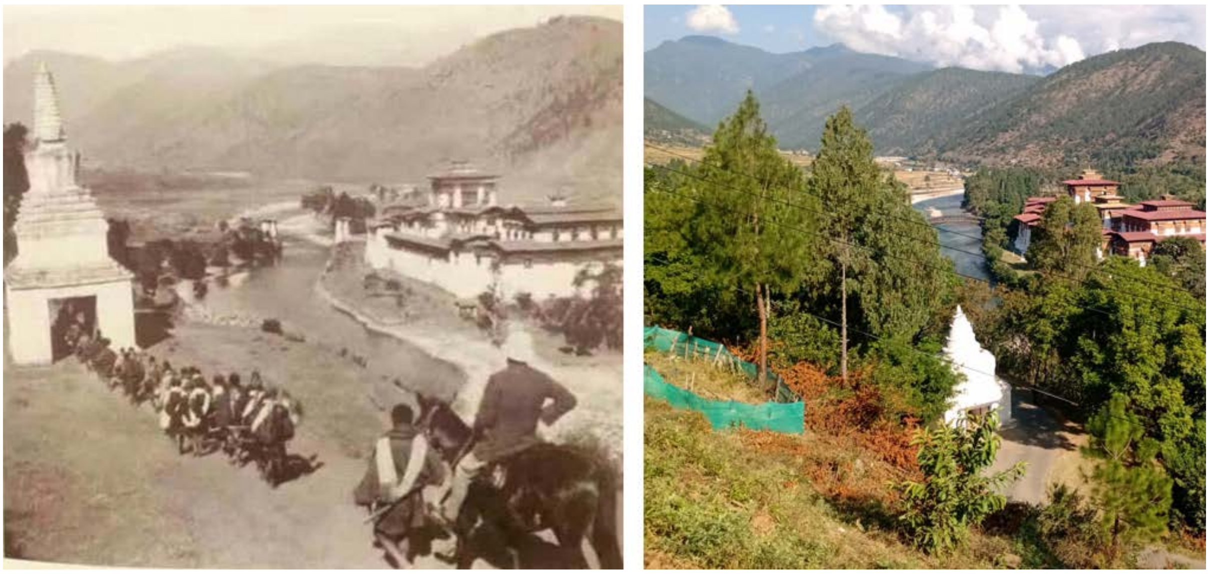

Figure 5: The photograph by H. Hyslop showing British envoys on their way to the coronation of Bhutanese king in December 1907 shows fortress-monastery Punakha with almost baren slopes on the background which are nowadays covered by secondary forest as photographed by the author in 2024 (27.578381°, 89.863074°, 1277 m a.s.l).

Discussion and Conclusions

Quantitative evaluation in repeat photography is challenging due to several reasons. It can hardly compete with evaluation possibilities of aerial photography featuring the geometry of vertical view. However, the ground perspective provides easy interpretation by non-specialists. This makes repeat photography suitable for communication of environmental topics to the public. It helps to reach more attention to the consequences of global change.

This paper presents horizon matching, a novel approach for the quantitative evaluation of historical photographs. The approach utilizes the combination of Google Earth and WindowTop for semi-transparent visualization of juxtaposed simulation image and historical photograph and vectorization of features of interest. No collection of identical points and camera parameters are necessary; however, the accuracy is compromised by neglect of the camera distortions. On several examples, the utilization of repeat photography for the research of high mountain environment was demonstrated.

References

Andreev, A. I. (2013). Tibet in the earliest photographs by Russian travelers: 1900-1901, Studio Orientalia, New Delhi.

Bělka, L. (2022). Czechoslovak Filmmakers, Journalists and Traders: Six Years in Tibet, in: L. Bělka, D. Berounský, P. Jandáček, J. Ptáčková (Eds.), Experiencing Tibet from the Heart of Europe, edition Tethys, Potsdam, pp. 107-126.

Bozzini, C., Conedera, M., & Krebs, P. (2012). A new monoplotting tool to extract georeferenced vector data and orthorectified raster data from oblique non-metric photographs. International Journal of Heritage in the Digital Era, 1(3), 499-518.

von Brevern, J. (2009). Counting on the unexpected: Aimé Civiale's mountain photography. Science in Context, 22(3), 409-437.

Chen, J., Liu, L., Dyck, M., Lv, J., & He, H. (2021). Mapping the scientific research on natural landscape change with rephotography. Ecological Informatics, 64, 101387.

Dvořák J. and Havel, J. (2016). Fotografové Krkonoš - Od počátků fotografie po současnost, Správa Krkonošského národního parku (KRNAP), Vrchlabí, ISBN: 978-80-7535-033-6

Eden, A., Pemberton, R. B., & Bose, K. K. (1865). Political missions to Bootan. Printed at the Bengal Secretariat Office.

Finsterwalder, R. (1953). Die zahlenmäßige Erfassung des Gletscherrückgangs an Ostalpengletschern. Wagner.

Fubelli, G., Guida, D., Cestari, A., & Dramis, F. (2013). Landslide hazard and risk in the Dessie town area (Ethiopia). Landslide Science and Practice: Volume 6: Risk Assessment, Management and Mitigation, 357-362.

Gabellieri, N., & Watkins, C. (2019). Measuring long-term landscape change using historical photographs and the WSL Monoplotting Tool. Landscape History, 40(1), 93-109.

Jacobson, K., & Jacobson, J. (2015). Carrying off the palaces: John Ruskin's lost daguerreotypes. Quaritch.

Klett, M. (2011). Repeat photography in landscape research. The Sage handbook of visual research methods, 114-131.

Kropáček, J., Vařilová, Z., & Nyssen, J. (2019). Historical aerial and terrestrial photographs for the investigation of mass movement dynamics in the Ethiopian Highlands. Land Degradation & Development, 30(5), 483-493.

Kropáček, J. (2019). Erosion dynamics in the southern Tibetan Plateau at a century time scale from historical photographs. Journal of Arid Environments, 161, 47-54.

Kropáček, J., Nüsser, M., & Schmidt, S. (2024). Exploring the potential of historical images for the investigation of glacier changes: The case of Belvedere Glacier, Italian Alps. Acta Univ. Carol. Geogr, 59, 240-254.

Malde, H. E. (1973). Geologic benchmarks by terrestrial photography. US Geological Survey Journal of Research, 1(2), 193-206.

Rakich, A., & Wilson, R. (2007). Evidence supporting the primacy of Joseph Petzval in the discovery of aberration coefficients and their application to lens design. In Novel Optical Systems Design and Optimization X (Vol. 6668, pp. 106-118). SPIE.

Sampson, G. D. (1992). The success of Samuel Bourne in India. History of photography, 16(4), 336-347.

Stockdale, C. A., Bozzini, C., Macdonald, S. E., & Higgs, E. (2015). Extracting ecological information from oblique angle terrestrial landscape photographs: Performance evaluation of the WSL Monoplotting Tool. Applied Geography, 63, 315-325.

Vařilová, Z., Kropáček, J., & Zvelebil J. (2015). Reactivation of mass movements in Dessie graben, the example of an active landslide area in the Ethiopian Highlands [J]. Landslides, 12(5), 985-996.

Voon, C. (2016) World’s Oldest Operating Photo Studio Closes in India, https://hyperallergic.com/306564/worlds-oldest-operating-photo-studio-closes-in-india/

von Welden, L. (1824) Der Monte-Rosa: eine topographische und naturhistorische Skizze, nebst einem Anhange der von Herrn Zumstein gemachten Reisen zur Ersteigung seiner Gipfel: mit einer topographischen Karte und mehreren Steinabdrücken. Carl Gerold, Wien.