BOOK REVIEW

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Hot Ice: Glaciers in the Tropics are Making the Press

Tropical Glaciers. International Hydrology Series

Georg Kaser and
Henry Osmaston (Eds.)

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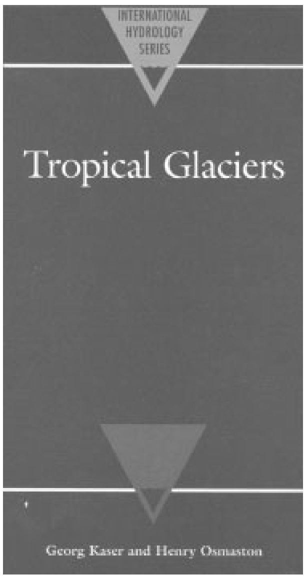

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When I describe my glacial hydrological research in Peru, I am often asked with bemusement, 'Are there really glaciers in the tropics?' Occasionally, I am able to dispel some of this confusion or even evoke a flash of recognition by referring to the famed 'Snows of Kilimanjaro', but a persistent geographic unfamiliarity typically prevails. The general populace is simply more ready to associate the tropics with warm sandy beaches than perennial ice masses. Yet, despite being an oxymoron to many people, tropical glaciers have recently drawn significant attention within the scientific community and even been featured in the popular press. They comprise an intriguing, elusive, and rapidly disappearing component of the cryosphere that holds many important clues to our understanding of climate history and dynamics.

Alarming statements from scientists have predicted that much tropical glacier ice will disappear within the next couple of decades, removing valuable archives of climatic information as well as a fresh water resource (e.g. Whitfield, 2001). The legendary glaciers on Kilimanjaro themselves have decreased in area by 82% between 1912 and 2000, and soon the only remaining ice will be that retrieved and stored in universities for palaeoclimate analyses (Alverson *et al*., 2001). Moreover, tropical glaciers crown an ecosystem of profound dimensions. Half of the Earth's surface area lies between the tropics of Capricorn and Cancer, wherein a staggering 75% of the global population resides (Thompson, 2000). For communities of people living in mountainous regions, the disappearance of glaciers could have large implications for water resources. In a pretext for the United Nations declaration of 2002 as the International Year of the Mountain, it has been acknowledged that 80–90% of the fresh water supply for the arid to semi-arid regions of the tropics and subtropics originates in mountainous regions, affecting more than half of humanity, principally in the developing world (Messerli, 2001).

Geographers Georg Kaser and Henry Osmaston have recently brought to hard cover form an assimilation of their research experience into these peculiar ice masses. Their 207 page book is entitled simply *Tropical Glaciers* and is printed within the International Hydrological Series by the Cambridge University Press and UNESCO, selling for £75. Kaser is the primary author, with over 20 years of research studying glaciers in Africa and South America as well as the European Alps. Osmaston was invited to provide a final chapter later in the manuscript review process, and supplies a perspective on tropical glaciers over the entire Quaternary based on broad experience in Africa and Asia. Though not

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a comprehensive review of research, this timely publication provides both an important theoretical benchmark for ongoing work on tropical glaciology and a thorough geographic documentation of changes to these climatically sensitive components of our integrated Earth system.

Linking third-world engineering and tropical climate dynamics

Kaser opens the book with a Prologue that gives testimony to recent changes in tropical glaciers of the Cordillera Blanca, Peru, having dramatic implications for human society. Melting glaciers have formed dangerous proglacial lakes that are prone to outburst floods in this steep, tectonically active, third-world mountain environment where suitable engineering solutions are confounded by socio-political instability and a lack of consistent funds or institutional support. The consequences can be catastrophic, as evidenced by the 1970 earthquake and subsequent landslides that killed tens of thousands in the Cordillera Blanca. By relating the story of his involvement with a local Peruvian project to secure one such unstable lake, Kaser frames his subsequent theoretical assessment of tropical glaciers within a colourful personal portrait of people coexisting with their environment. In so doing, he establishes how this work is relevant to policy makers and engineers, as well as climate researchers.

Yet neither recent publicity nor societal relevance should belie the overall dearth of basic theoretical and empirical knowledge on the dynamics and climate response of tropical glaciers. Only a few explorers and scientists have accessed the remote and even hostile tropical mountains to make (relatively *very* few) observations over the past century. Moreover, historical observations of ice-covered highlands in the tropics either remained in obscure anecdotal manuscripts or were even overtly discredited by dubious European society until late in the 19th century. The first reliable measurements of tropical glaciers date to European geographical explorations of the early to mid 20th century. It has only been very recently (less than 20 years) that these glacial observations have been systematically compiled, and basic dynamical conceptions theorized. This stands in contrast to the much better developed models of mid-latitude glaciers that have resulted from intensive research programs over the last century.

Quantifying tropical glaciology

Kaser establishes the lack of tropical data as justification for the deductive, comparative approach he uses to model glacier dynamics in Part I (Chapters 1–5) of the book. He aptly expands the latitudinal boundaries imposed by solar geometry to define a tropical climate domain featuring 'thermal homogeneity' where the diurnal variation of air temperature exceeds the variation of annual mean temperatures. This substantiates a simplified boundary condition that assumes a complete lack of thermal seasonality and a constant altitude of the 0 °C isotherm. Tropical precipitation is predominantly limited to one or two wet seasons as a function of the annual migration of the 'meteorological equator,' as Kaser terms the intertropical convergence zone (ITCZ). While implying the ITCZ remains continuous over tropical land masses, a depiction that has more recently lost favour in the scientific community, this simplified circulation pattern provides Kaser with an effective and consistent global dynamic to define both a tropical and an outer-tropical glacier climate regime. The outer-tropical regime features a dry season where subtropical conditions are predominant, and in both tropical regimes the behaviour of glaciers is distinct from those of the mid-latitudes. Instead of the discrete winter accumulation period offset by a summer ablation period, tropical glaciers feature ablation throughout the year, and actually have coincidental maxima in ablation and accumulation during the wet season. Kaser has become well cited for this neat characterization of tropical glaciers, initially published in earlier papers and complete with a handy schematic diagram (Fig. 4·51).

Chapter 5 presents a substantive assessment of the tropical glacier model variables in comparison with empirical data, and explores the implications for glacier morphology, ice structure, dynamics, and hydrology. Kaser's basic approach involves modifying a mid-latitude glacier mass and energy balance model to fit the boundary condition of his two tropical regimes, and making comparative evaluations of key variables for exemplary locations where he has done work. The model builds from the vertical mass balance profile, an 'essential' characterization of the glacier–climate interface, using theory developed with other researchers in Austria based on the data-rich Hinterferisner glacier in the Inner Otz valley of the Alps. Kaser applies the model in varied form to characterize glacier behaviour in both the inner, equatorial tropics (the Rwenzori Mountains of Africa) and more outer tropics (the Cordillera Blanca at about 9 °S in the Peruvian Andes). He is also able to adapt his particular model approach, based on mass balance equilibrium, to hypothesize alternative climatic forcing scenarios for changes in glacier mass balance over time. Various combinations of climate variables can be quantified to account for the observed changes in the position of the equilibrium line altitude (ELA), a widely utilized parameterization for the altitude of zero net balance on a glacier. Kaser goes even further to explore how. This is the most quantitative chapter of the text, and readers will benefit from basic calculus literacy and a familiarity with variables of mass and energy exchange. However, Kaser derives his equations with intermediate steps, interspersed with helpful emboldened sections of prose that summarize key points throughout the text and make the book accessible to the less mathematically inclined readers.

Accounting for a century of changes

Part II is the largest section of the book, and is dedicated to providing a chronicle of fluctuations of tropical glaciers since the Little Ice Age in the Rwenzori Mountains and the Cordillera Blanca, as well as commenting on climate forcing. In Chapters 6 and 7, detailed reconstructions of the 20th century glacier extents are painstakingly compiled from historical photographs, expedition accounts, and personal observations. The evidence for overall glacier recession is clear, seemingly mirroring the fate of alpine glaciers worldwide as harbingers of climate change (Dyurgerov and Meier, 2000). Though the total mass change is not quantifiable, Kaser goes to great effort to synthesize the existing data in Chapter 8 and speculate on some possible causal mechanisms. He tabulates the disparate glacier surface area information, giving a detailed and methodical presentation of relative and absolute glacier surface area changes over the century. He summarizes the available data with a composite curve of relative mass gain from 1920 (Fig. 8·1·1), which reveals a consistent overall ‘global character’. The data show a general retreat with a few surprising changes in slope, notably a rapid retreat from the 1920s to the 1950s, and some actual net mass gain/advances in the 1960s and 1970s. This provides and intriguing baseline to consider the climatic forcing. While he does not venture into much discussion on global climate forcings, he does qualitatively outline specific combinations of different consequent effects on local mass balance. Kaser summarizes the available results from other studies with his own modelling to postulate the possible climate causes of the observed local glacier fluctuations in his study sites.

Kaser makes important observations on the climatically relevant properties of tropical glaciers, linking to important concepts established in other work, but his coverage is not exhaustive. He provides a quantitative, dynamic explanation of physical features of glaciers originally observed by early European explorers. By including the actual citations from reports by Ramondi, exploring the Cordillera Blanca in 1873, and De Filippi, reporting on the Italian expedition to the Rwenzori by the Duke of Abruzzi in 1906, Kaser colourfully elucidates the historical heritage of this science. However, recent work from French researchers is notably absent from the text. A large research initiative by French investigators of IRD (formerly OSTROM) has developed a program focusing on monitoring glacier climate and hydrology along an Andean transect with sites in Ecuador, Peru, and Bolivia. With the most instrumented observations, this work has provided important contributions (e.g. Ribstein *et al.*, 1995; Francou *et al.*, 1995a,b, 2000; Wagnon *et al.*, 1999a,b). As Kaser notes in his Chapter 3, 99% of global tropical glaciers are located in the Andes of South America. While more than 70% are in the Cordillera Blanca, delimited by Kaser as outer-tropical, a larger continuous span of Andean sites including the inner and outer tropics should provide promising insights.

Using his model under the constraint of tropical thermal homogeneity, Kaser draws attention to the critical role of atmospheric humidity, which has been identified in other work to have important implications for glacier hydrology and climate response. Runoff from the outer-tropical Zongo glacier in Bolivia has shown intriguing patterns related to shifts in the latent heat budget caused by increasing humidity in the early wet season (Wagnon *et al.*, 1999a,b). Preliminary observations of glacier hydrology in the Cordillera Blanca also show a strongly seasonal component to glacier melting that directs attention to humidity flux (see Figure 1). Extrapolating to global patterns of heat and humidity, such as El Niño–southern oscillation, across the span of the

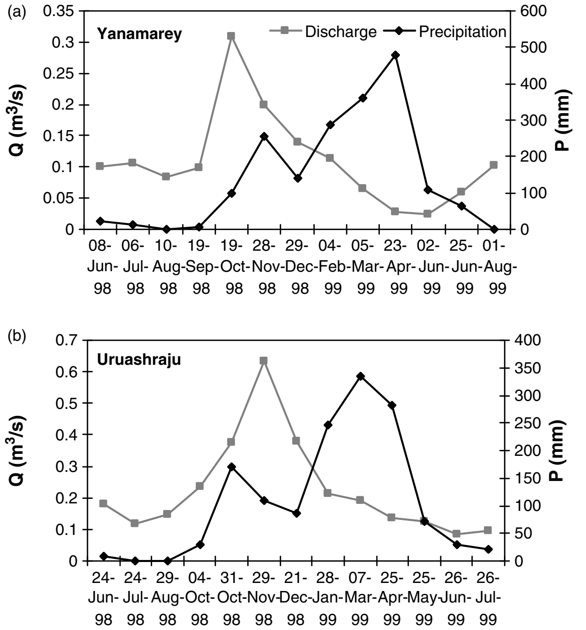

Figure 1. Monthly measurements of discharge Q ($m^3 s^{-1}$) plotted with the monthly precipitation totals P (mm) as observed over the 1998–99 hydrological year in two glaciers in the Cordillera Blanca, Peru: (a) the Yanamarey glacier; (b) the Uruashraju glacier (modified from Mark (2002)). These results show that maximum glacier runoff precedes the maximum precipitation, implying enhanced meltwater production in the austral spring, when total net radiation is enhanced with conditions of lower surface albedo and increased humidity.

Andes is a very interesting avenue of research (i.e. Francou *et al.*, 1995a,b, 2000). Rising freezing levels with enhanced hydrological cycling have been noted to be a feature of the tropics affecting glacier recession (Diaz and Graham, 1996). On larger scales of time, theorists have posited that water vapour plays a significant role in the story of glacial changes on a global scale (Broecker, 1995). Humidity complicates any climatic information derived from changes in glaciers and remains a difficult variable to measure in real time and in proxy form, but Kaser is correct in indicating its crucial role in ongoing research.

Considering climatic changes over longer time scales

The tropics have also 'heated up' in the context of palaeoclimate research, and it is to the changes of tropical glaciers over the Quaternary Period that the book turns in Part III. Globally, the environment at the last glacial maximum (LGM) featured extreme contrasts in climatic boundary conditions, which are of great interest for climate modellers calibrating computer-simulated climate with actual geological evidence. Yet, in the tropics, important inconsistencies in the proxy data have challenged the scientific community to resolve better the nature and timing of climate change during the LGM. Whereas the global sea surface reconstructions of CLIMAP (1981) indicated the tropical climate remained relatively constant and unchanging during massive climate shifts of the Quaternary, glacial evidence seemed to indicate much colder temperatures and greater climate variability. Extant moraines herald the size and position of much larger ancient glaciers, and the ELAs reconstructed from these moraines using a variety of methods indicate a tropical snowline depression during the last glacial maximum of 800–1000 m (Porter, 2001). Subsequent terrestrial evidence and modelling experiments have shown inconsistencies with CLIMAP reconstructions (e.g. Rind and Peteet, 1985; Stute *et al.*, 1995; Thompson *et al.*, 1995; Bush and Philander, 1998). The latest multiproxy palaeoclimate data synthesis has shown that tropical climate changes at the LGM have coherent regional differences, indicating an alteration of lapse rates (Farrera *et al.*, 1999). Furthermore, long sedimentological records from the Andes have indicated that the actual timing of deglaciation in the tropics preceded Northern Hemisphere warming (Seltzer *et al.*, 2002), and did so during a wet interval, implicating the role of tropical temperatures in driving glacial–interglacial changes globally (Baker *et al.*, 2001).

Osmaston authors this final chapter on Quaternary glaciations in the tropics, combining a summary of published evidence with intriguing insights into the unique form of tropical glaciers. After a review of the methods used to reconstruct snowlines from glacial moraine evidence, he compiles the existing evidence for former glacier extents throughout the tropics globally. While unaware of Porter's similar review (Porter, 2001), Osmaston gives detailed attention to East Africa, where he has done extensive work. In this context, Osmaston has aptly demonstrated the application of a more sophisticated area–altitude balance method, and his work stands out for its rigour and critical assessment of both temperature and humidity changes from ELA shifts. His thorough mapping of moraines is incorporated in the excellent map of the Rwenzori Mountains included with the

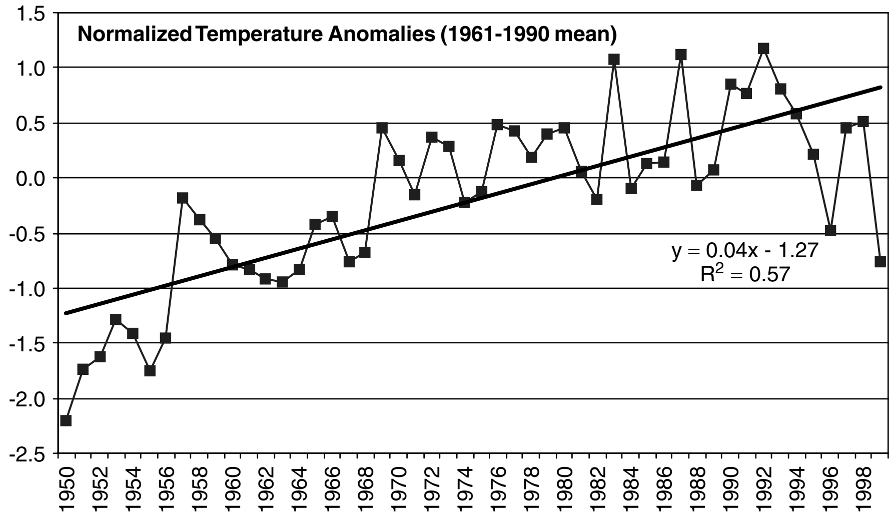

Figure 2. Normalized anomalies of monthly mean temperature from the 1961–90 averages from 29 Peruvian stations located between 9 and 11 °S, and ranging in elevation from 20 to 4600 m a.s.l., from 1950 to 1999. The regression line is added, showing average warming trend of 0·35 °C/decade. This was produced following the first-difference procedure described in Vuille and Bradley (2000), and compares with the accelerated rate of warming they report for the last 25 years (0·32–0·34 °C/decade).

text. Osmaston also provides stimulating discussion of key issues of resolving temperature and humidity changes at the LGM. He challenges the notion of altered atmospheric lapse rates at the LGM as a resolution to the tropical proxy data inconsistencies, citing a range of evidence, but overlooking the strong evidence for regional lapse rate differences (Farrera *et al*., 1999). Nevertheless, Osmaston assimilates the evidence for large changes in humidity and temperature at the LGM in combination with the homogeneity of tropical climate described by Kaser to propose an, ‘LGM equatorial valley glacier type’ to explain the large characteristic moraine forms. This should be a fruitful hypothesis to test with further fieldwork and modelling studies.

Published amidst a small flurry of dramatic press, *Tropical Glaciers* is a testament to the integrating discipline of geography in posing important research questions relevant to both climate sensitivity and human impact. Continued research will refine models of glaciers as climate indicators, even as the tropical climate continues to register dramatic changes (Figure 2). Yet, equally important are the practical concerns of water resources and public safety posed by Kaser. This human–environmental dynamic is an essential quality of geography, and gives a very suitable context for a text on glaciers in a region of global significance. Moreover, the ability to predict future changes in climate demand a better understanding of past climates; proxy record research has shown us that the changes we are experiencing now have not been witnessed for thousands of years (Bradley, 2000). Osmaston has evaluated the use of past tropical glacier evidence in untangling the past climate, highlighting areas where future research will refine these techniques, and ultimately model future changes better. Finally, the observational and topographical data are all compiled using GIS technology to produce an abundance of clear maps, a fitting legacy of the modern geographer. Not only will this book be a helpful source for climate modellers, upper-level undergraduates, and graduate students, but it will also broaden the geographic appreciation of anyone travelling to tropical highland regions.

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