

Remote sensing of glaciers in Afghanistan and Pakistan

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ABSTRACT

Glaciers in Afghanistan and Pakistan are parts of an Asian “critical region” having significant roles in rising sea level, local and regional water resources, natural hazards, and geopolitical stability. The two countries lack fundamental and reliable quantitative information regarding glacier fluctuations. As part of the Global Land Ice Measurements from Space (GLIMS) project, we used satellite imagery and field observations to assess a relatively large number of glaciers in both countries. In Afghanistan, many glaciers have systematically been observed to be retreating and downwasting. Many glaciers have lost significant ice mass and have evolved into numerous smaller individual ice masses. Furthermore, the glaciers around the Kohi Bandakha massif in southern Badakshan Province are significantly more debris covered than other regions in Afghanistan. In Pakistan, the situation is more complex, as many glacier termini are variably stationary, advancing, or retreating. There appears to be a spatial trend with more retreating glaciers in the western Hindu Kush. To the east we observe more advancing glaciers and surging glaciers associated with an increase in precipitation. These observations suggest that glacier response to climate forcing is very different in Pakistan compared with conditions in the central and eastern Himalaya.

23.1 INTRODUCTION

The glaciers in Afghanistan and Pakistan represent parts of an Asian “critical region” having significant impacts on rising sea level, local and regional water resources, natural hazards, and geopolitical stability (Haeberli et al. 1998, Bishop et al. 2007). Little is known about spatiotemporal climate–glacier responses due to a variety of factors including: (1) complex regional climate dynamics; (2) lack of systematic data collection networks including climate monitoring and glacier mass balance–monitoring programs; (3) logistical difficulties associated with rugged terrain; (4) lack of quality baseline information including maps, aerial photos, and geodetic control points; and (5) numerous technical issues involving information extraction from satellite imagery. Consequently, the region lacks fundamental and reliable quantitative estimates regarding glacier distribution and ice volume, equilibrium line altitudes (ELAs), advance and retreat rates, ablation rates, supraglacial lake development, catastrophic outburst flood potential, as well as glacier and regional mass balance estimates (Dyurgerov and Meier 2004, Haeberli 2004, Shroder and Bishop 2010a, b).

Some glaciological studies, however, have been conducted in both countries. In Afghanistan, Gilbert et al. (1969) worked on small glaciers near Mir Samir in the central Hindu Kush, Braslau (1972) on

Keshnikhan Glacier in the Wakhan Hindu Kush, and Breckle and Frey (1976a, b) near the Pakistan border. In Pakistan much of the early work was concentrated on the ice associated with famous peaks (e.g., Mason 1930, Auden 1935, Finsterwalder 1937, 1960, Mott 1950, Pillewizer 1956, Loewe 1959). More recent glaciological studies included the British International Karakoram Project (IKP) (Goudie et al. 1984, Miller 1984), the Chinese (BGIG 1979, 1980, Shi and Wang 1980, Wang et al. 1984), and research conducted on numerous glaciers (e.g., Gardner 1986, Gardner and Jones 1993, Mayer et al. 2006, Mihalcea et al. 2006).

The early Landsat series of satellites had insufficient resolution to do a fully adequate job of inventorying the many small glaciers in Afghanistan, and the political situation and remoteness was not conducive to field-based mapping of glaciers. Photo-based mapping from the air was the best option in the 1980s; Shroder (1980, 1989) started the beginnings of a glacier inventory of Afghanistan for the World Glacier Monitoring Service (WGMS) using photo-derived (from the air), small-scale (1:100,000) maps to study glacier distributions. With the advent of better satellite imagery and computer technology, several remote-sensing and geographic information system (GIS) studies were conducted. For example, Landsat multispectral scanner data were also used to provide baseline information for the country (Shroder and Bishop 2010a). In addition, the Russians conducted several studies (e.g., Maksimov and Perugina 1975, Kravtsova 1990, Kotlyakov 1996).

Remote-sensing studies of Pakistan glaciers includes work by our group (e.g., Bishop et al. 1995, 1998, 1999, 2000, 2004, Shroder and Bishop 2010b), Russian scientists (e.g., Kotlyakov 1996, Osipova and Tsvetkov 2002, 2003), the Italians (e.g., Mayer et al. 2006, Smiraglia et al. 2007), and others. Recently, Pakistani government organizations have become interested in inventorying glaciers and meltwater resources; this has resulted in the production of a basic inventory based on Landsat Thematic Mapper data (Roohi et al. 2005, Roohi 2007). Although the aforementioned field and remote-sensing research has contributed to our knowledge of selected glaciers in both countries, there is an urgent need to better characterize glacier response to climate forcing at a regional scale.

Previous research and regional extrapolation based on modern studies and climate modeling

suggests that the glaciers in both countries should be exhibiting terminus retreat and/or downwasting (Mayewski and Jeschke 1979, Aizen et al. 2006, Khromova et al. 2006, Mayer et al. 2006, Berthier et al. 2007, Hasnain 2007). In Afghanistan, the general lack of field studies and spatiotemporal assessments makes it difficult to predict how glaciers are responding to climate forcing, although prior work (de Grancy and Kostka 1978, Haritashya et al. 2007, 2009) indicates that glaciers in the Wakhan Corridor are retreating and downwasting. The situation in Pakistan appears to be more complex due to extreme topography and increases in precipitation in the eastern region (Fowler and Archer 2006, Treydte et al. 2006, Roohi 2007). Furthermore, there are many surging glaciers in the Karakoram (Hewitt 1969, Wang et al. 1984, Diolaiuti et al. 2003, Copland et al. 2011). Consequently, our objectives are to report on our new spaced-based and field observations of glaciers in Afghanistan and Pakistan, as part of the Global Land Ice Measurements from Space (GLIMS) project.

23.2 REGIONAL CONTEXT

23.2.1 Geology

The main glacierized orogens of Afghanistan and Pakistan are the highly eroded product of collage tectonics due to the continuing collision of the Indo-Australian Plate with the Eurasian Plate and isostatic rise of overthickened crust. Collectively, this includes the multiple ranges of the Hindu Kush, Pamir, Hindu Raj, Karakoram Himalaya, Nanga Parbat Himalaya, and other diverse mountains (Shroder 2011a, b), resulting in a high-altitude setting with some peaks >8 km in altitude (Tables 23.1, 23.2). Both countries have a complex juxtaposition of geologic units that originally migrated laterally across the Tethys Sea (now the Indian Ocean) since Mesozoic time to collide and thrust up multiple rock units into mountains. The structural framework of these mountains results from the collision and suturing of parts of three crustal plates; the Arabian Plate in the southwest, the Eurasian Plate in the north, and the Indo-Pakistan Plate (also known as the Indo-Australian Plate) in the south and southeast. Several smaller slivers of continental masses had broken off earlier as small islands that moved across the Tethys, a volcanic island arc formed in the seaway and then was