Improved Geometric Modeling of 1960s KH-5 ARGON Satellite Images for Regional Antarctica Applications

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Abstract

Long-term observations of the Antarctic ice sheet will contribute to a quantitative evaluation and precise prediction of the sea level change induced by global changes in climate. This paper proposes an improved rigorous geometric modeling method for the declassified KH-5 ARGON satellite images collected in Antarctica in 1960s. The scanned film images are preprocessed beforehand to enhance the quality for further analysis. Systematic errors such as lens distortion and atmospheric refraction are also considered and corrected. A scheme is proposed to measure the ground control points for the historical images based on modern image mosaic and DEM products. The bundle adjustment results of four blocks in regions in East Antarctica present a geometric positioning accuracy of less than one nominal pixel resolution (140 m) in both horizontal and vertical directions, outperforming the published results. A regional DEM of the ice sheet that represents the topography in 1963 is then generated from the stereo ARGON images for the first time, the evaluation of which shows its consistency with the modern product but with great value for studying the recent change history of the ice sheet.

Introduction

Environmental issues resulting from global climate change can considerably influence human society and natural environments. According to the Intergovernmental Panel on Climate Change's report (IPCC, 2013), it is highly probable that the increased warming and sustained mass loss of glaciers and ice sheets would further accelerate the rate of global sea level rise. It is of great significance to carry out comprehensive observations over Antarctica given that it holds a major proportion of the freshwater on earth. Numerous studies have been performed to investigate the change of the ice sheets, the mechanism of their interaction with the ocean and responses to global climate change (Bindschadler and Vornberger, 1998; Rignot *et al.*, 2008; Zwally *et al.*, 2015). Although long-term analysis is desirable, it is often impractical due to the lack of historical records. Although some early data collected by *in situ* measurements in the 1950s or even earlier are available, they only cover regions of a limited scale and cannot be used to support change analysis of ice sheets on a large scale. Fortunately, a remarkable data source, namely, Declassified Intelligence Satellite Photography (known as DISP), collected by a series of film-based reconnaissance satellites (KH series), including ARGON, CORONA, and LANYARD, has been made available (McDonald, 1995). DISP provides a unique opportunity to research early ice sheet configurations, thus greatly extending the time period of the Antarctic surface observations.

Geometric processing is required as a critical procedure to utilize these historical scanned satellite films for further scientific applications. Nonetheless, the handling of these film-based data presents a variety of challenges, such as the imperfections of the early imaging mechanisms, artifacts of the films, deformation through long-period storage, and others (Zhou *et al.*, 2002a; Galiatsatos *et al.*, 2007; Gheyle *et al.*, 2011). Previous research associated with the processing of film-based images primarily focused on mathematical modeling, orthophotos, and Digital Elevation Models (DEM) generation in non-polar regions. For example, Galiatsatos *et al.* (2007) proposed a methodology to geometrically process CORONA imagery and generated a DEM in the area of Syria using ground control measured from Ikonos imagery and map-based contour lines. Surazakov and Aizen (2010) reconstructed the image geometry of six KH-9 images captured in Central Asia through Bundle Adjustment (BA) with Ground Control Points (GCPs) from QuickBird images. Sohn *et al.* (2008) introduced three mathematical modeling methods for geometrically processing CORONA KH-4B images. They then generated a DEM in Seoul with horizontal and vertical accuracies of 1.5 pixels.

Numerous related studies have managed to retrieve the image geometry of historical scanned films with the aid of additional GCPs, but it is not easy to perform the processing steps in Polar Regions where the ground control is difficult to access. Only three ARGON satellite missions (mission numbers 9034A, 9058A, and 9059A) captured the scenes of Antarctica in the 1960s (Bindschadler and Seider, 1998). They are considered a precious resource by investigators for detecting the surface changes of Antarctic ice sheets in the 1960s, e.g., the margin changes of ice streams (Bindschadler and Vornberger, 1998), the large-scale structure changes on the surface of ice shelves (Glasser *et al.*, 2009), and the terminus changes of outlet glaciers (Miles *et al.*, 2013). Most of the studies employed ARGON imagery by registering to other more recent data using GCPs. However, the geometric reconstruction involved was usually not extensively discussed, nor were the various distortions existing in the film-based images.

To reduce the geometry-induced errors and further exploit these valuable historical images, some efforts were made to establish a mathematical model for ARGON imagery in Polar Regions. Sohn *et al.* (2000) applied least squares adjustment to refine the Exterior Orientation (EO) parameters derived from the space resection technique. The horizontal accuracy of the orthorectified ARGON images was estimated to be approximately 150 m. Kim *et al.* (2001) employed a similar technique to generate an orthorectified mosaic along the coast of Queen

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