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The Landsat Image Mosaic of Antarctica

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ABSTRACT

The Landsat Image Mosaic of Antarctica (LIMA) is the first true-color, high-spatial-resolution image of the seventh continent. It is constructed from nearly 1100 individually selected Landsat-7 ETM+ scenes. Each image was orthorectified and adjusted for geometric, sensor and illumination variations to a standardized, almost seamless surface reflectance product. Mosaicing to avoid clouds produced a high quality, nearly cloud-free benchmark data set of Antarctica for the International Polar Year from images collected primarily during 1999–2003. Multiple color composites and enhancements were generated to illustrate additional characteristics of the multispectral data including: the true appearance of the surface; discrimination between snow and bare ice; reflectance variations within bright snow; recovered reflectance values in regions of sensor saturation; and subtle topographic variations associated with ice flow. LIMA is viewable and individual scenes or user defined portions of the mosaic are downloadable at http://lima.usgs.gov. Educational materials associated with LIMA are available at http://lima.nasa.gov.

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1. Introduction

Landsat imagery represents the oldest continuous satellite data record of the Earth's changing surface. Milestones in this record are represented by the production of mosaics of all the continents, except Antarctica, for epochs of 1990 and 2000 (http://glcf.umiacs.umd.edu/portal/geocover/). The exclusion of Antarctica was dictated more by financial constraints than interest; however the rapid changes of Antarctica that are reported at increasing frequency and the advent of the International Polar Year increase the value of completing the suite of continental Landsat mosaics with a compilation of the southernmost continent.

The Long Term Acquisition Plan (Arvidson et al., 2001), used to manage the scheduling of imagery from the Enhanced Thematic Mapper Plus (ETM+) sensor on-board the Landsat-7 satellite, included the annual collection of thousands of Landsat images of Antarctica beginning in 1999. These data form the basis of the mosaic described here. It is referred to as the Landsat Image Mosaic of Antarctica (LIMA).

There were many steps required to produce the final products that are now publicly viewable and available on the web site http://lima.usgs.gov/. These steps are described here to give interested users a more complete understanding of the reasoning and the methods applied in the selection, processing, enhancement and management of the nearly 1100 individual images that comprise LIMA, as well as a description of the variety of mosaic products and metadata. The primary steps include: scene selection, Level-1 processing; conversion to surface reflectance; mosaicing (cloud removal and image merging); enhancements; and web service. Each step is described in this document.

The care employed in the production of LIMA has resulted not only in the first-ever true-color, high-resolution mosaic of the Antarctic ice sheet, but of a mosaic where each pixel retains accurate values of surface reflectance. The producers of LIMA have resisted the temptation to blend scene boundaries and artificially create color balance by either uncontrolled or irreversible digital adjustments. As a result, LIMA is more than a pretty picture that can only guide scientists to the original data, rather LIMA can be used directly as a valid scientific data set. At the same time, it serves the public's appetite for a realistic view of the largest ice sheet and the coldest, highest and brightest continent on Earth.

2. Scene selection

Landsat-7 ETM+ scenes were the preferred source of all LIMA data for three principal reasons: the geolocation of the data has been characterized to have a one-sigma accuracy of ±54 m (Lee et al., 2004); extensive imaging campaigns of Antarctica undertaken soon after the April 1999 launch of Landsat-7 provided a large number of available images during the first few years of sensor operations; and the existence of a 15-meter panchromatic band provided the highest spatial resolution available with any Landsat sensor.

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Individual scenes to be used in LIMA were selected from the database of browse images representing all Antarctic Landsat-7 scenes. The full collection of Antarctic browse images are available through the USGS (http://edcsns17.cr.usgs.gov/EarthExplorer/) and also were on hand at Goddard Space Flight Center, having been used for manual cloud cover assessment. Each browse image is a composite of spectral bands 5, 4, and 3 (see http://landsathandbook.gsfc.nasa.gov/handbook.html for a description of spectral characterization of the ETM$^+$). (Here, multiple-band composites will be identified in the usual manner of three numbers whose order represents the bands assigned to the red, green and blue channels, respectively). These browse images are in a compressed jpeg format with an effective spatial resolution of 240 m and provide a good indication of clouds, if present. They do not allow the discrimination of smaller features or very thin cloud.

A number of factors were weighed in the decisions of which scenes to use in LIMA. Surface coverage (therefore, minimal cloud cover) obviously was very important, but date and year of acquisition, especially of coastal scenes where large date differences emphasized changes in the sea ice cover, was also considered. Selection decisions attempted to minimize large variations in sun elevation of adjacent scenes. To minimize the number of scenes, minimal overlap was sought; however, the geolocation details of individual scenes were not available. Instead, the mean coordinates for every World Reference System-2 scene was assigned to the browse image and a public-domain software package (Geomatica FreeView V9.1) was used to compile a working version of the emerging mosaic. In some cases, the most desirable Landsat-7 scene available contained Scan Line Corrector-off data gaps (http://landsat.usgs.gov/data_products/slc_off_data_products/index.php). In all, LIMA contains 1073 Landsat-7 images (only 39 with SLC-off): 397 from the 1999–2000 austral summer, 75 from the 2000–2001 austral summer, 220 from the 2001–2002 austral summer, 342 from the 2002–2003 austral summer and 39 from later summers. Fig. 1 illustrates the distribution of images used to generate LIMA, along with color representing the range of sun elevations. Landsat coverage has a southern limit at 82.5°S. To complete the continental coverage with a more pleasing visual product, data from the MODIS Mosaic of Antarctica (Haran et al., 2005) were used in a manner described later in this paper.

At one stage, a small number of ASTER images were considered as a viable means to replace a cloudy portion of Landsat images, however, in the final analysis, the color balancing became too difficult and the ASTER scenes were omitted from the final mosaic.

3. Level-1 processing

All scenes selected for LIMA were processed from the Level-0 raw data to a Level-1T orthorectified product using the National Landsat Archive Processing System (NLAPS) at EROS (details at http://edc.usgs.gov/guides/images/landsat_tm/nlaps.html). Three digital elevation models (DEMs) were investigated to supply the elevation data necessary for orthorectification: the Radarsat Antarctic Mapping Project (RAMP version-2) DEM, (http://nsidc.org/data/nsidc-0082.html); the ICESat DEM (http://nsidc.org/data/nsidc-0304.html) and a combined radar altimeter-ICESat DEM (provided by J. Bamber).

The three DEMs were intercompared at a 5-km resolution (the supplied post spacing of both the ICESat and radar altimeter-ICESat DEMs). Differences were examined to help discern how they might affect the orthorectification process in different parts of Antarctica. The deciding factors were coverage and accuracy in mountainous regions. The ICESat DEM was not complete to all edges of the continent, and the radar altimeter-ICESat DEM was not able to include the extreme topographic variations of the mountainous regions. Because Landsat's field of view is nadir and near-nadir, orthorectification corrections are largest in areas of high relief and at the scene edges. For these reasons,

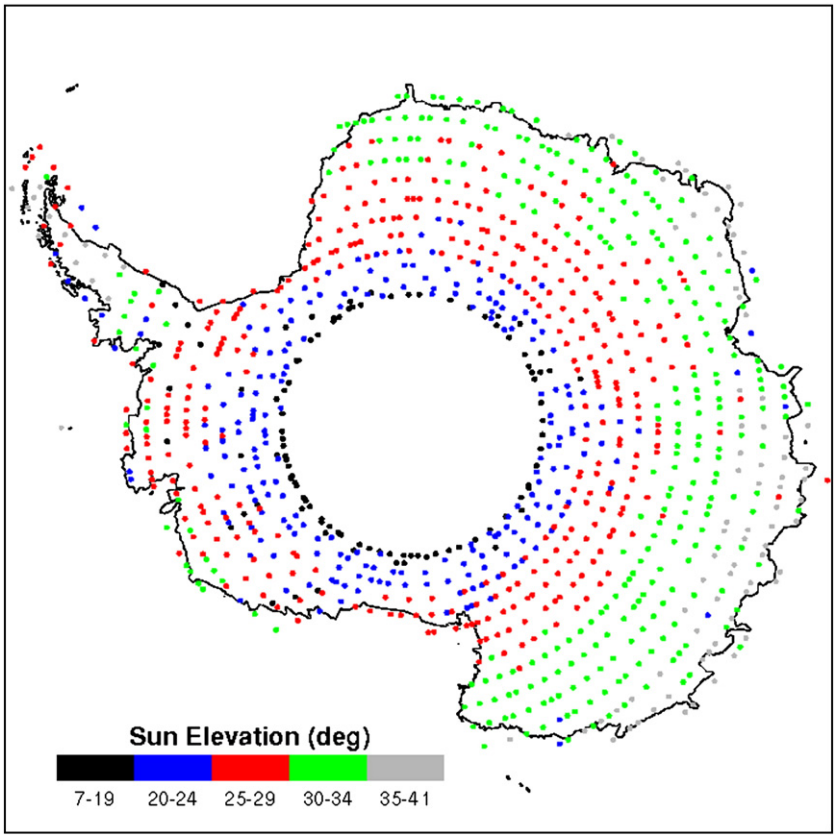

Fig. 1. Scenes selected for use in LIMA. Dot color indicates sun elevation value. In 36 cases there were multiple images from the same path/row location: 32 with two images each and 4 with three images each. In these cases, the highest sun elevation value is shown.