# Generation of Data Acquisition Requests for the ASTER Satellite Instrument for Monitoring a Globally Distributed Target: Glaciers

Bruce H. Raup, Hugh H. Kieffer, Trent M. Hare, Jeffrey S. Kargel

## Abstract

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument is scheduled to be launched on the EOS Terra platform in 1999. The Global Land Ice Measurements from Space project has planned to acquire ASTER images of most of the world's land ice annually during the six-year ASTER mission. This article describes the process of creating the Data Acquisition Requests needed to cover approximately 170 000 glacier targets.

## Keywords

glacier monitoring, ASTER, data acquisition planning.

## I. Introduction

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument, to be launched on NASA's Terra platform in 1999, promises to deliver large amounts of image data useful in the study of Earth's glaciers [1]. ASTER has a 60 km × 60 km scene size, with ground instantaneous fields of view in its three subsystems of 15 m (visible and near infrared (VNIR)), 30 m (short-wave infrared (SWIR)), and 90 m (thermal infrared (TIR)). ASTER has along-track stereo capability in band 3 (0.78–0.86 $\mu$m), with approximately 53 seconds between acquisition of the image pairs. Finally, ASTER's cross-track pointing capability in the VNIR will allow imaging up to latitudes of ±85°, almost 300 km more pole-ward than Landsat coverage.

In anticipation of high resolution, stereo image data, H. Kieffer established the project known as Global Land Ice Measurements from Space (GLIMS). This project's goals are 1) to acquire ASTER image data covering all of Earth's permanent land ice (excluding the central portions of the Greenland and Antarctic ice sheets) once per year late in local melt season, 2) to derive glaciological information from the imagery using automated computer techniques, and 3) to archive the results in a widely accessible geographic information system (GIS). Collaborators from around the world have been enlisted to apply analysis tools to images of glaciers in their regions, and the National Snow and Ice Data Center has committed to archiving the derived results. For more information on the organization of the GLIMS project, see its web site at http://wwwflag.wr.usgs.gov/GLIMS/.

The small field of view of ASTER necessitates targeting the instrument for specific observations in response to users' needs. Users will request acquisition of ASTER data by submitting Data Acquisition Requests, or DARs[1] [1]. Each DAR consists of a latitude-longitude polygon (an ordered list of latitude/longitude pairs, or vertices, which describe a polygonal area) defining the area of interest. DAR polygons are limited to 20 vertices. DARs also contain numerous other parameters, including (but not limited to):

1. information about the requester,
2. parameters related to acceptable timing for acquisition,
3. instrument gain setting for each ASTER band,
4. acceptable solar illumination angles,
5. instrument mode (which subsystems are needed),

---

[1] As the GLIMS project is submitting its DARs through the ASTER Science Team, GLIMS DARs are a special category termed "STARs," or Science Team Acquisition Requests, which provide for increased data allocation compared to when DARs are submitted by non-Science-Team researchers.

6. requested data processing level,
7. image map projection and resampling method,
8. constraints on instrument pointing angle,
9. acceptable cloud coverage.

In order to acquire the data needed for GLIMS, we needed to submit to the ASTER system a collection of DARs which covers all Earth's land ice.

Most users requesting ASTER data will be interested in localized targets, the DARs for which consist of only one or a few polygons. Users generally will enter their DARs into the ASTER system via an Internet-based official interactive DAR entry tool.[2] Because Earth's land ice is distributed globally and because the number of polygons required to circumscribe all glaciers is more than 1700, DARs must be generated by GLIMS automatically, rather than manually. This paper describes the entire process of GLIMS DAR generation, from the piecing together of the land ice data base to the automatic generation of DARs from this data base.

Some DAR parameters (e.g. "requester name") are the same for each polygon; others (e.g. acquisition timing parameters) are generally calculated separately for each polygon. Still others (e.g. text string describing the region of interest) may need to be set manually for each polygon, or by groups of adjacent polygons. The GLIMS DAR generation process allows for manual or automatic specification of most DAR parameter values.

The overview of the DAR generation process for GLIMS is as follows:

1. compile an Arc/Info[3] data base containing a layer of polygons delineating the world's permanent land ice (see Section II);
2. process the Arc/Info data base to simplify polygons; (see Section III);
3. associate with each simplified polygon any manually-set values of DAR parameters that will override automatically calculated ones;
4. export from the Arc/Info data base an ASCII file containing the polygons and their attributes for each target;
5. read these polygons from the file and produce for each one a DAR (in the binary format expected by the ASTER system), which includes all the necessary parameters, some of which are calculated automatically on the basis of location (see Section IV).

These steps are described in detail below.

## II. Glacier Data Sources

The GLIMS project has compiled an Arc/Info data base of land ice from a variety of sources with differing formats. Arc/Info is a commercial geographic information system (GIS) package which represents data as layers (known as "coverages") of geographic entities (e.g. latitude-longitude polygons) and associated attributes (e.g. best imaging season for the area circumscribed).

The sources for data included in the GLIMS land ice map are:

1. Digital Chart of the World (source of most of the data), an Arc/Info product from Environmental Systems Research Institute, Inc. (ESRI). It includes layers of geographic information covering the whole world, is based on the United States Defense Mapping Agency's Operational Navigation Charts ([2], [3]), and includes a GIS coverage of land ice.
2. World Glacier Monitoring Service (WGMS) data base (http://www.geo.unizh.ch/wgms/; see also [4]). As this data base locates each glacier with only a single latitude-longitude pair, rather than a polygon, these glaciers were imported into the GLIMS land ice data base as approximately circular polygons of correct area, which is listed in the WGMS data base.
3. National Snow and Ice Data Center Eurasian Glacier Inventory (http://www-nsidc.colorado.edu/NOAA/glacier_inventory/). Information about glaciers in this data base

---

[2] The Earth Observation System Data and Information System (EOSDIS) DAR tool will soon become available (http://asterweb.jpl.nasa.gov/asterdata/darexplain.htm). GLIMS will use a specially designed tool as described here.

[3] The description of our use of this commercial software does not represent an endorsement of the product.

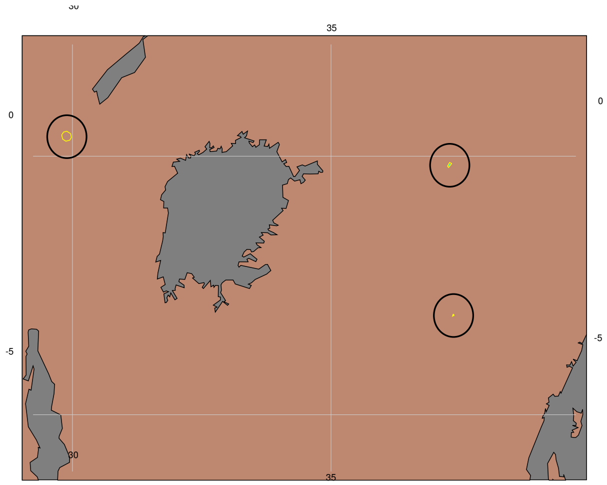


Fig. 1. Ice Map: Central Africa. The black circles, which are not DAR polygons, highlight the location of the small imaging targets, which include Mt. Kenya, Mt. Kilimanjaro, and the Ruwenzori mountain range.

also does not include polygonal outlines, but rather point locations and areas; hence these glaciers were imported as approximately circular polygons of correct area.

4. Miscellaneous atlases for a few small glaciers. Simple square polygons enclosing the glaciers were input for a few regions (e.g. Colorado (USA), Ruwenzori Range (Congo/Rwanda border, Africa), Pyrenees (Spain/France border)) for the purpose of data acquisition only.

5. Arc/Info data base of Alaskan glaciers from Wrangell St. Elias National Park (http://www.nps.gov/akso/gis/wrst/wrst_ctp.htm). These data are from U.S. Geological Survey 1:2 000 000 Digital Line Graphs (DLG).

The result of this compilation is a fairly complete digital map of permanent land ice on Earth. The resolution and accuracy of this map are not good enough for answering most scientific glaciological queries, but it should be sufficient for guiding acquisition of ASTER imagery of the world's glaciers. It will be iteratively improved using the ASTER data which will be acquired using this map. Examples from the map are shown in Figures 1–4; the complete map can be viewed on the GLIMS website at http://wwwflag.wr.usgs.gov/GLIMS/.

The blue filled polygons in Figures 2–4 show the location of ice at the highest resolution of our data base — that is, before any processing to simplify the polygons, as discussed below. These polygons correspond to actual glacier boundaries. Red and yellow unfilled polygons are the simplified areas of interest (DAR polygons) submitted to the ASTER Ground Data System (GDS, the body in charge of scheduling ASTER image acquisitions); yellow polygons indicate high priority targets and red polygons indicate medium priority; GLIMS has no low priority targets. For large collections of DARs such as that of GLIMS, the ASTER GDS has allowed a combined maximum target area of 400 000 $\text{km}^2$ to be requested at high priority. The remaining requests must be set to a lower priority.

The high priority regions were selected on the basis of the following desires and considerations:

1. wide variety of glacier types;
2. global distribution;
3. high local scientific interest;
4. inclusion of some regions between approximately 82.6° and 85° latitude (in both hemispheres), which ASTER can image by pointing, but which are beyond the imaging capability of Landsat and other similar instruments;
5. emphasis on areas of special interest to our international collaborators.

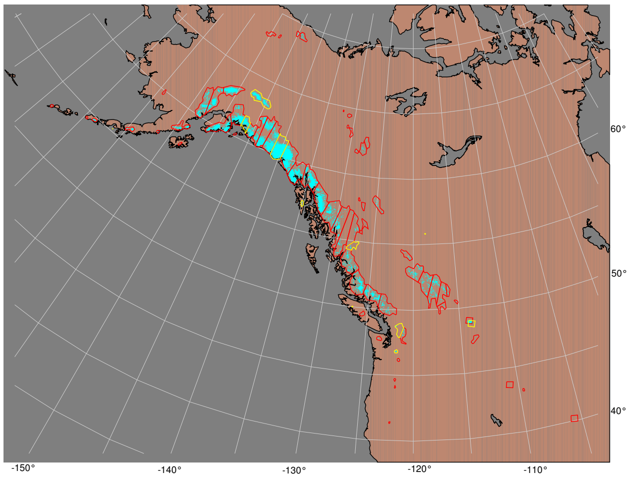


Fig. 2. Ice Map: Alaska. Yellow polygons indicate high priority imaging targets; Red polygons indicate medium priority. Blue filled polygons represent the location of land ice as currently recorded in our data base.

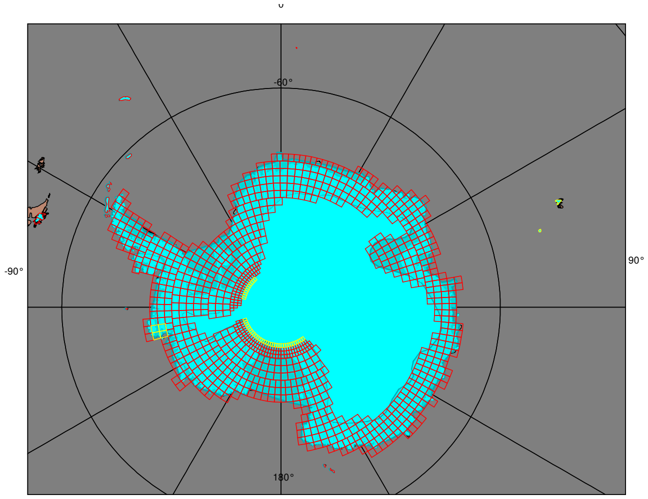


Fig. 3. Ice Map: Antarctica. Colors are the same as in Figure 2.

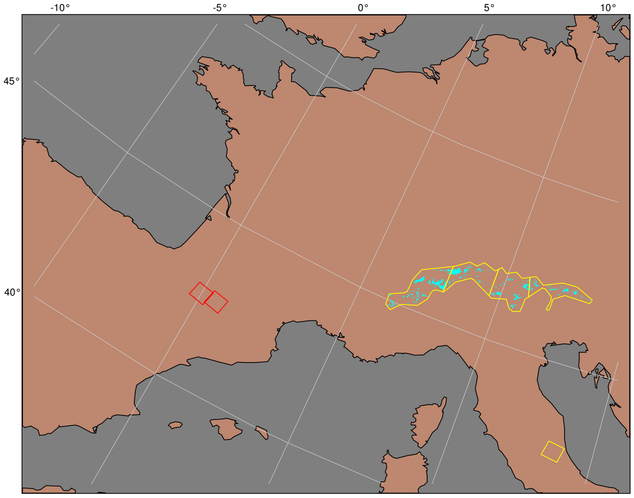


Fig. 4. Ice Map: Europe. Square polygons over the Pyrenees were inserted for data acquisition; they represent the location, but not boundaries, of glaciers. Colors are the same as in Figure 2.

## III. POLYGON PROCESSING

In its raw, unsimplified form, the GLIMS Arc/Info data base of glaciers described in section II contains more than 10 000 polygons. Submitting that many DARs to the ASTER system is not feasible. The ASTER Ground Data System also has set a limit of 20 vertices per DAR polygon. For data acquisition, a smaller number of larger, simplified polygonal areas that cover all the glaciers must be submitted. We also desire these polygonal areas to be efficient, so that they do not lead to unnecessary acquisition of images not containing glaciers. We thus process the polygons in two ways in order to reduce the number and complexity of the polygons:

1. Replace groups of closely spaced polygons[4] with larger polygons circumscribing the entire group.
2. Remove vertices from each polygon so that each area is represented by a simpler polygon, thus reducing the total number of vertices in the data base.

Both steps were carried out within the Arc environment. The precise steps were as follows (see Figure 5). Arc command names are included in brackets. Each polygon was expanded by a distance equivalent to half a scene width, 30 km for ASTER, in all directions [BUFFER]; all interior sections in intersecting polygons were removed (e.g. two intersecting circles would come to resemble the outline of a figure eight) [DISSOLVE]; the number of vertices defining each resulting polygon was reduced [GENERALIZE]; each polygon was reduced in size by one-third a scene size (20 km for ASTER) in all directions[5] [BUFFER, with a negative argument]; the number of vertices in each polygon was further reduced [GENERALIZE]. Two steps to thin out vertices were required in order to meet the ASTER GDS requirements with a minimum of distortion of the polygon shapes. Even after thinning, many polygons had to be split into two or more polygons in order to meet this tight requirement on vertex count, such as in the polygons covering Alaskan glaciers in Figure 5.

Further considerations had to be given to the large ice masses of Greenland and Antarctica. First, the interior portions of these ice sheets will not be targeted by GLIMS due to the limited scientific payback compared to the large required expenditure of resources. Second, as there may be times when the GLIMS team will need or want to cancel a DAR for a particular region[6], we allow for greater control by keeping the size of polygons to no more than a few image scenes. The polygons over these large ice masses are therefore simple rectangles approximately four ASTER scenes in extent.

This processing results in a reduced total of 1757 polygons, each containing 20 or fewer vertices, which are output to a plain ASCII file. The next step is to run the DAR-generating program, `glims_xar`, which uses this file as input, to produce a DAR, in a format suitable for input into the ASTER system, for each polygon contained in the ASCII file.

## IV. DAR PARAMETERS

The parameters in a DAR are numerous; this section describes the algorithms for generating a few of the key ones automatically.

In our system, DAR parameters which depend on latitude are generally calculated automatically, but they can be manually overridden. The ASCII polygon file may contain values for DAR parameters which are associated with particular polygons. If such values exist, then those values are used for that polygon, overriding the automatic calculations.

### *A. DAR Timing*

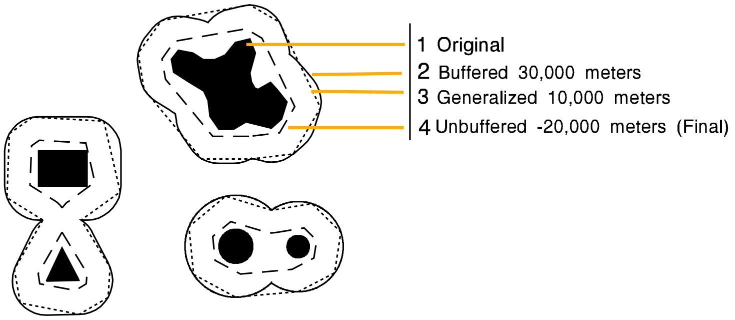
The parameters that specify the time during which a DAR is active consist of a start time and an end time for the "acquisition window"; the DAR will be a candidate for data acquisition only between these

---

[4] "Closely spaced" means closer than an ASTER scene size, which is 60 km.

[5] This number is smaller than the expansion length in order to account for the reduced number of vertices.

[6] One example of when we might want to cancel acquisition in a particular region: the ASTER cloud discrimination algorithm is expected to have difficulty with images of snowy regions. As it may incorrectly classify fresh snow as clouds and automatically reschedule such scenes for acquisition, we may need to cancel DARs manually that have entered an "infinite loop" in the ASTER acquisition scheduler.



a) Simple example with artificial polygons

b) Example from south-central Alaska, USA

Fig. 5. Method for reducing the complexity of glacier polygons. Filled blue polygons represent the original high resolution data; these polygons are expanded and intersected with each other (red), leaving only the exterior outline; vertices are thinned out (green); polygon is contracted to close to the original size (unfilled blue). Note that the Alaska example contains polygons which need to be split into multiple pieces in order to meet the requirement for maximum vertex count.

times. The best imaging season for a given glacier depends strongly on its latitude. For high-latitude glaciers, the best season generally is toward the end of the summer, when most of the previous winter's snow has melted, but before new snow has begun to fall with the new autumn. The best season for low-latitude glaciers is determined more by regional climate patterns. We consider glaciers within 20° of the equator to be "low-latitude." High-latitude and low-latitude cases are treated separately below.

### A.1 High-latitude DAR Timing

The time window for a given high-latitude DAR is calculated as follows: a "closing day" (the last probable snow-free day, or the last day with enough sunlight) and an "opening day" (the first desirable day for image acquisition) are determined from simple linear relationships with latitude. A time window of nominal length is then set as late as possible between those two days. If the number of days between "opening day" and "closing day" is smaller than the nominal window width, the time window is set to that difference, down to a minimum width. This is schematically illustrated in Figure 6. The endpoints for the lines defining "Closing Day" and "Opening Day" are shown in Table I. A few regions, such as the Himalaya, had to be set manually, as this simple algorithm did poorly there, due to summer monsoon cloud cover and a characteristically dry autumn season.

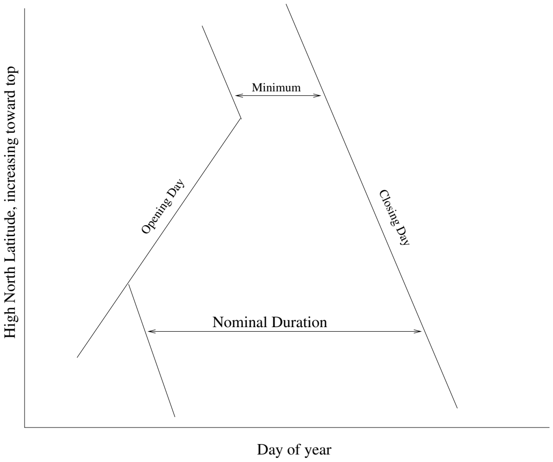


Fig. 6. Schematic showing method for determining DAR timing. Acquisition windows are always fit within interior region. See text for full explanation.

TABLE I
PARAMETERS DEFINING "OPENING DAY" AND "CLOSING DAY". DATES IN PARENTHESES ARE FOR NON-LEAP YEARS.

| Latitude | Opening Day of Year | Closing Day of Year |
|---|---|---|
| 80 | 166 (15 June) | 206 (25 July) |
| 40 | 135 (15 May) | 274 (1 October) |
| -30 | 317 (13 November) | 92 (2 April) |
| -70 | 348 (14 December) | 24 (24 January) |

### A.2 Low-latitude DAR Timing

For DARs whose average latitudes are within 20° of the equator, approximately monthly average cloudiness patterns, rather than sun angle, determine the best imaging season. The time of the observation window is set to coincide with the least cloudy time of year, which is determined from cloud cover data obtained from the National Oceanographic and Atmospheric Administration (NOAA). Each DAR's position is used to look up the twelve monthly average cloudiness values from a 2.5 degree resolution data set based on AVHRR imagery. See http://www.ncdc.noaa.gov/ogp/papers/kidwell.html and other nearby Web locations for more information.

## *B. ASTER Gains*

The VNIR and SWIR bands have three and four (respectively) gain levels which can be specified by the user [1]. We calculated gain levels for each band by calculating the sun angle for each DAR at the middle of its image acquisition window. Since ASTER will be in a sun-synchronous orbit, sun angle depends only on time of year and latitude. These calculations were optimized for snow targets (300 $\mu$m grain size) and assumed a Lambertian reflection model ([5]). The Lambertian assumption for snow has been found to be valid for nadir observations [6]. Other assumptions include:

1. all acquired ASTER scenes are near-nadir; pointing capability of ASTER was not considered;
2. contributions from path radiance in the atmosphere are negligibly small. For the VNIR, snow reflectances are high, so directly reflected radiation tends to dominate the received radiance. Reflectances for snow are lower in the SWIR, but the atmosphere scatters SWIR radiation little. Also, aerosol loading in the atmosphere tends to be low in glacierized regions, which reduces path radiance. See, for example, [7].

TABLE II

Pass bands for the ASTER instrument, solar spectral irradiances in each band, maximum input radiances for the ASTER instrument, and snow reflectances in each band (grain size approximately 300 $\mu$m).

| Band | Low Edge ($\mu$m) | High Edge ($\mu$m) | Solar Spectral Irradiance ($\mathrm{W\,m^{-2}\mu m^{-1}}$) | Maximum Input Radiance ($\mathrm{W\,m^{-2}\mu m^{-1}sr^{-1}}$) | Snow Reflectance |
|---|---|---|---|---|---|
| 1 | 0.52 | 0.60 | 1845.78 | 427. | 0.95 |
| 2 | 0.63 | 0.69 | 1555.93 | 358. | 0.88 |
| 3 | 0.76 | 0.86 | 1108.27 | 218. | 0.75 |
| 4 | 1.6 | 1.7 | 232.86 | 55.0 | 0.15 |
| 5 | 2.145 | 2.185 | 80.10 | 17.6 | 0.10 |
| 6 | 2.185 | 2.225 | 74.58 | 15.8 | 0.20 |
| 7 | 2.235 | 2.285 | 68.57 | 15.1 | 0.30 |
| 8 | 2.295 | 2.365 | 59.59 | 10.55 | 0.20 |
| 9 | 2.36 | 2.43 | 57.29 | 8.04 | 0.15 |

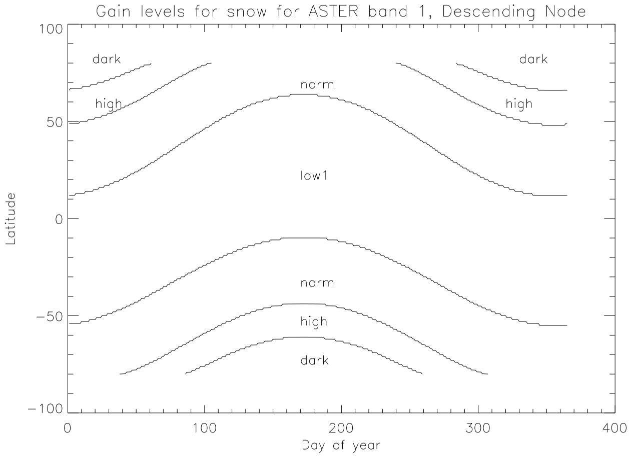


Fig. 7. Contour plot of gain levels for snow for ASTER band 1, descending node. Gain settings range from “low1” to “high”; “dark” indicates regions where the solar angle is too low for imaging.

Table II summarizes the inputs to the calculations, which were taken variously from [8] (pass bands and maximum input levels), [9] (solar spectral irradiance), and [10] (snow reflectance). Calculations of sun angle are based on standard spherical trigonometric relations.

Figure 7 is an example of a contour plot of gain level as a function of latitude and day of year; this example is for Band 1. In addition to different gain levels, this plot also shows regions (times of year in certain latitude ranges) where sunlight is not adequate for imaging. These calculations were used not only to determine the optimal gain setting for each band in the VNIR and SWIR, but also as constraints on timing for image acquisition, as explained in Section IV-A.

## V. Summary

The GLIMS project promises to provide the glaciological community a wealth of new high resolution multispectral and stereo image data via the ASTER instrument. The process of scheduling ASTER observations optimized for such a global study of land ice has involved compilation of a complete and reliable map of land ice, simplifying this map into a manageably small number of polygons, merging Data Acquisition Request parameter values (such as gain settings and desired acquisition timing) with the polygons, and producing a file of DARs suitable for input into the ASTER Ground Data System. This work is complete, and we eagerly await the launch of the EOS Terra satellite.

## ACKNOWLEDGMENTS

We are grateful for corrections and comments on our land ice map provided by M. Brugman, G. Cogley, M. Dyugerov, B. Fitzharris, C. Georges, C. Haggerty, S. Madsen, R. March, and N. Reeh.

## References

[1] Yasushi Yamaguchi, Anne B. Kahle, Hiroji Tsu, Toru Kawakami, and Moshe Pniel, "Overview of Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 36, no. 4, pp. 1062–1071, July 1998.

[2] David M. Danko, "The digital chart of the world project," *Photogrammetric Engineering & Remote Sensing*, vol. 58, no. 8, pp. 1125–1128, 1992.

[3] Inc. Environmental Systems Research Institute, "Development of the digital chart of the world," Tech. Rep. AD-A265-097, U.S. Department of Commerce, National Technical Information Service, Sept. 1992.

[4] W. Haeberli, "Historical evolution and operational aspects of worldwide glacier monitoring," in *Into the Second Century of World Glacier Monitoring — Prospects and Strategies*, W. Haeberli, M. Hoelzle, and S. Suter, Eds., pp. 35–51. UNESCO Publishing, 1998.

[5] Robert A. Schowengerdt, *Remote Sensing: Models and Methods for Image Processing*, Academic Press, San Diego, CA, 1997.

[6] Stephen G. Warren, Richard E. Brandt, and Patricia O'Rawe Hinton, "Effect of surface roughness on bidirectional reflectance of Antarctic snow," *Journal of Geophysical Research*, vol. 103, no. E11, pp. 25 789–25 807, Oct 1998.

[7] John R. Schott, *Remote Sensing: The Image Chain Approach*, Oxford University Press, New York, NY, 1997.

[8] H. Fujisada et al., "Algorithm theoretical basis document for ASTER Level-1 data processing, ver. 3.0," Nov. 1996, http://asterweb.jpl.nasa.gov/.

[9] World Climate Research Programme (WCRP), "Publication series no. 7," Oct. 1986.

[10] Stephen G. Warren, "Optical properties of snow," *Reviews of Geophysics and Space Physics*, vol. 20, no. 1, pp. 67–89, Feb. 1982.