Determining the Antarctic Ice Sheet Grounding Line with Photoclinometry using LANDSAT Imagery and ICESat Laser Altimetry

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Abstract— **During the last century, ocean temperatures increased by approximately 1 Celsius degree. Long-term observations of portions of the coastal Antarctic ice sheet reveal increasing melt rates thought to be due to the ocean temperatures increase. As a result of the warming, ice sheet margins are observed to be retreating from the edge of the ocean by approximately 1 meter per year for each 0.1°C rise in ocean temperature. The area of the Antarctic ice sheet is thus in a state of flux.**

As ice approaches the ocean from its landward, upslope side, it eventually enters the water and begins to float becoming an ice shelf. The relatively warm water at the base of the shelf causes it to melt into the ocean. The "Grounding Line" or GL is considered the point at which the grounded ice, in its continuous movement down-slope toward sea level elevation, enters the water and begins to float. It is more accurately referred to as the Grounding 'Zone' because the actual position fluctuates with tides and wave action.

It is difficult to determine the actual size of the Antarctic ice sheet due to the uncertainty in the location of the GL. Making an accurate determination of its location during a narrow temporal window (perhaps a 3-5 year interval) would be useful in estimating the mass-balance of the southern ice sheet simply by providing a perimeter across which the ice enters the water at a rate of 1 meter per year. This can be compared with the amount of precipitation observed to occur over the continental ice sheet.

Photoclinometry software obtained from NASA Goddard Space Flight Center is used to determine the geographic location of the GL. Photoclinometry uses differences in the surface brightness of LANDSAT scenes of coastal Antarctic, corrected for variations in solar illumination angle to determine relative slopes in a scene. The slopes are adjusted to actual elevations by associating brightness levels with actual elevations along scan paths of the GLAS (Geoscience Laser Altimetry System) laser altimeter GL

Terrain brightness is then compared between scan paths to produce an elevation map of a scene. The team derived an assigned portion of the Antarctic Ice Sheet GL along the coastline recorded by a LANDSAT scene centered at 120° West longitude.

I. INTRODUCTION

In support of a larger NASA International Polar Year (IPY) project to determine the Antarctic's mass balance (i.e. net gain or loss of ice from the Southern continent, the task was to determine the 'Grounding Line' along a specific stretch of the Antarctic Coastline; using NASA supplied computer codes written in Interactive Data Language (IDL), installed and ran in the windows environment. The grounding line defined for the basis of our project is the boundary between the grounded ice sheet and floating ice shelf.

Using LANDSat Imagery and ICESat Laser Altimetry, images of the continent were made available through the Landsat Image Mosaic of Antarctica (LIMA) project on the U.S. Geological Survey website. ICESat (GLAS data) was provided for the purpose of the training, whereas the actual ICESat/GLAS data was downloaded from the National Snow and Ice Data Center website. These images were utilized in the final production of the grounding line.

II. ASAID TRAINING

Antarctic Surface Accumulation and Ice Discharge (ASAID) training, provided by the NASA Goddard Space Flight Center in Greenbelt, MD, assisted the team in becoming acquainted with the necessary

procedures that produced the files for the grounding line location. NASA also provided trial data and IDL software in step-by-step procedures, that included LANDSAT/GLAS images, as well as ICESat Laser Altimetry for the team to learn how to define the grounding line profiles.

A. Landsat Images

LANDSAT -7 Enhanced Thematic Mapper (ETM+) images obtained a complete coverage of the Antarctic through the LIMA project website, as stated in the previous paragraph. To view the desired area assigned to the team, which was 25 degrees longitude and 17 degrees latitude, we selected 'Download Mosaics and Landsat Scenes', that displayed a continental map of the Antarctic data sets. We also selected 'Original Landsat Scenes (NLAPS format)', which diplayed a map of single dots corresponding to the various coordinates for each scene. By clicking on a specific dot another window was opened showing the path and row numbers for the specific scene. If the scene was within the given coordinates previously stated, a URL link was available to initiate a request from USGS Data Center, that can be directly downloaded to windows in a .zip file.

B. Display Landsat Image and GLAS Reference Orbit Ground Tracks

In order to identify the GLAS groundtracks that traverse the Landsat image, and any cropping that was needed to reduce file sizes the following steps was performed to achieve this goal. The GLAS groundtracks or 'reference tracks' are location values only, not data; each track has a unique number and a separate file. Knowing the reference track number is necessary in identifying the GLAS data files.

The IDL program, 'LANDSAT_SUBSET_INFO.sav' was ran to view the reference tracks. When the program is displayed the image is already rotated to align the coordinate system with the solar illumination direction (sun direction), along with the superimposed reference tracks and the regular grid.

The regular grid is used in the specification of the location and size of a smaller sub-image, for which the grounding line was traced and the elevations calculated. The next IDL program that was ran is GLAS_REFERENCE_VIEWER1, which displayed the sub-image stated in the previous paragraph, along with the superimposed reference track numbers. The program also calculates and displays the geographic coordinates range for the sub-image.
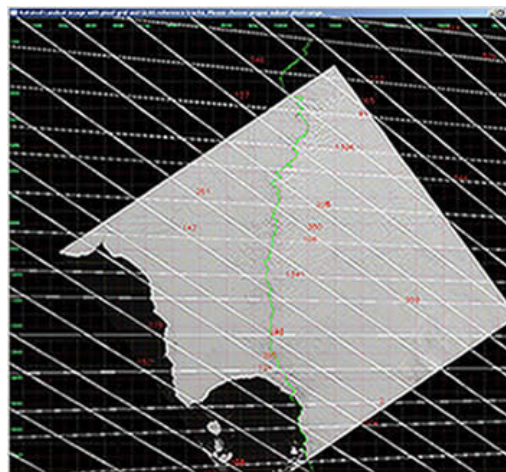

Fig. 1. Image of LANDSAT_SUBSET_INFO file. The white lines represent the laser reference tracks, and the red numbers indicate the path numbers and elevation points. The green is the 'predicted' grounding line.
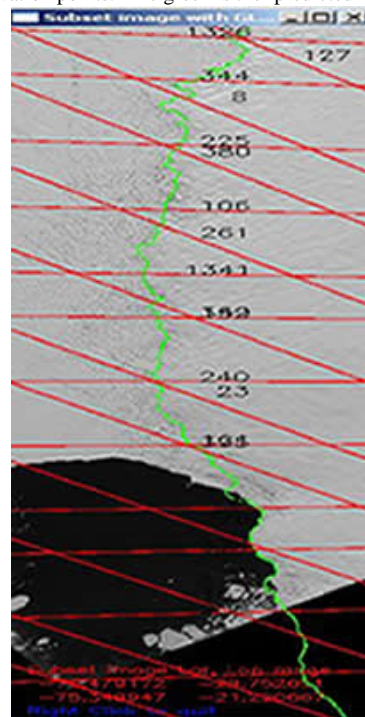
C. Downloading ICESat/GLAS Data

Downloading the ICESat/GLAS Data was obtained from the National Snow and Ice Data Center website. The data profiles had to be between October 4, 2003 and the present day for improve results. Once at the website, the team selected 'GLAS/ICESat'. After this selection, we click to highlight 'GLAS/ICESAT L1B GLOBAL ELEVATION DATA V028', and under 'Choose Search Area' we entered the longitude and latitude as displayed in the previous figure. We also selected the highest number of granules (e.g. 1000) to be certain that all GLAS data is captured. To verify that all track data files were downloaded, the track number is found in a .DAT file. A typical file name for a reference track number 5 is

GLA06_228_1102_002_0005_3_01_0001.DAT.

D. GLAS Data File Trimming

A new IDL program, 'GLAS_DATA_TRIMMER' is ran to trim the GLAS data to only the points that fall within the given longitude and latitude range of the sub-image. The image displayed is generally larger than the sub-image, but yet it reduces the size of the GLAS data files. But before the 'GLAS_DATA_TRIMMER can be ran, three parameters in 'PHOTOCLINOMETRY_INPUT.txt' was updated: 'GLAS_LOCATION', DIR_NGAT_RESULT', and NGAT_DIR'. The program internally called another program called, 'NGAT', to write a series of files of trimmed GLAS data, one file is for each cycle of the reference profile. The new GLAS files were written to the specified directory in DIR_NGAT_RESULT in the PHOTOCLINOMETRY_INPUT.txt file.

E. GLAS Cycle Selection

The GLAS Cycle profile selection involved the team browsing through a series of profiles that aided us in selecting the best cycle or elevation profile for each reference track. The file used to run the profile selection is GLAS_DATA_VIEWER to examine all the cycles of a single reference track.

When the file is ran the sub-image stated in the previous paragraphs is displayed, along with two other windows opened. The sub-image is a copy of itself with the superimposed longitude and latitude reference tracks numbers. In the other two windows, the left window is a line plot of the elevation points versus the latitude, and the plot on the right showed the difference of each elevation profile from the mean of all cycles. Although this right plot was not needed in the training and final production of the grounding line, it may help in highlighting tidal variations of floating ice captured by the different cycle phases of the tide.

An important tool the team used is an analysis tool where the profile plots was linked to the sub-image; moving the mouse over either plot that caused a second cursor to appear in the corresponding location in the sub-image. This allowed us to view which data gaps that fall inside or outside the sub-image boundaries, enabling us to choose the best cycle for each track. The criteria for selecting the most desirable cycle is there were no gaps between the data, **meaning…** Once we selected the best cycle for each track, we recorded the cycle number in the file PHOTOCLINOMETRY_INPUT.txt on the line following 'GLASLIST=', where we could now view the new selected cycles in the sub-image.
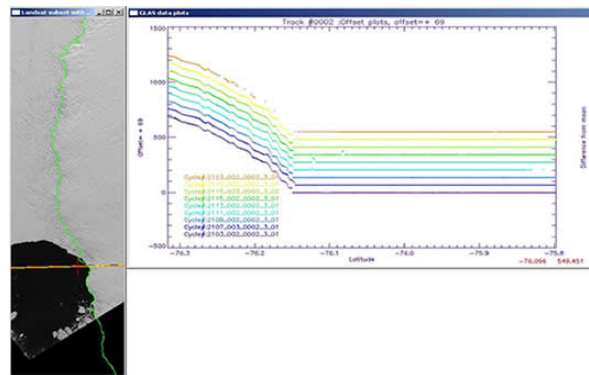
Fig 3. Screenshot of GLAS_DATA_VIEWER file. Left window is the sub-image and the window on the right is the elevation profile cycle of each reference track corresponding to the sub-image.

Fig 4. Screenshot of PHOTOCLINOMETRY_INPUT.txt file. Displays the location of the Landsat file and Landsat Header file is located, as well as the list of the cycle numbers selected from the GLAS Cycle Selection step.

F. Generation of Elevation Field

The generated elevation field was performed by the interpolation between the GLAS profile elevations using Landsat imagery. PHOTOCLINOMETRY1 is the program file used to and execute the photoclinometry. The interpolation produced a field of elevations between all the possible pairs of GLAS profiles, that is displayed in three windows; a color version of the elevation field, the sub-image with the elevation points and the GLAS tracks superimposed, and a contour version of the elevation field.

G. Grounding Line Determination

This is an interactive step, where the team draws our predicted grounding line and saves the result in a grounding line file. We began this by running the program 'ROI_TOOL', 'ROI' referring to the region of interest. Once started, a window opened asking us to specify the directory that contained the data to be analyzed; the directory was the path-row date which is a default naming convention created by the software program. From this directory, the program read the sub-image and two elevation fields, returning a set of two linked windows, one with the color map version of the elevation field and the other is the sub-image. The linked window in the lower left hand corner has the image and elevation information allowed us to trace the grounding using this information. The cursor was placed on the sub-image, and by a click of the mouse the grounding line is drawn as line segments between points.

III. RESULTS

Software to provide photoclinometric analysis of the ice sheet surface topography was under continuous development during the 2008-2009 academic year.

In addition to ASAID software training, the team's primary activities during this period were photoclinometry software test and evaluation. The software finally reached a state of operational readiness at the end of March 2009. While grounding lines were successfully defined on the Antarctic coast present in the LANDSAT image supplied as part of the training package, the future team will build on their efforts to apply knowledge on the assigned coastlines.

IV. CONCLUSION

We used our skills and knowledge to complete the training, and will ultimately determine the grounding line. Our future work will be to apply our knowledge to the assigned coastline to determine a grounding line.

V. FUTURE WORK

Our future works will be to continue to map the Antarctic grounding line. We will also use the

newly updated software and correct files to map and produce a final grounding line.

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