Temporal Reduction of the Ice Shelf in Pine Island Bay Antarctica: 1972 - 2003

Ya' Shonti Bridgers *(ECSU)*, Jessica Brownlow *(MVSU)*, Kirsten Hawk *(Spelman)*
Mentor: Dr. Malcolm LeCompte, Assistant Mentor: Mr. Kaiem Frink
Principal Investigator: Dr. Linda b. Hayden
1704 Weeksville Rd, Box 672
Elizabeth City, North Carolina 27909

***Abstract*—In an effort to determine whether the Antarctic ice sheet is growing or diminishing over long time intervals, Dr. Robert Bindschadler led an international team of glaciologists and computer scientists, including Elizabeth City State University (ECSU) students, to obtain an accurate measure of the area of the Antarctic ice sheet. Before the ice sheet's area was determined, the grounding line (GL), or boundary dividing the ice sheet resting on land from floating ice, was located by combining 2003 Landsat imagery and satellite-based laser altimetry.**

Landsat image data contemporary with that used to create the grounding line was compared to earlier Landsat imagery of the same area. A small ice shelf—now known as the *ECSU Ice Shelf*—near the eastern entrance to Pine Island Bay was previously identified as having diminished over an approximate 31-year span and the progressive reduction of its area qualitatively characterized. Here, the area loss of the *ECSU Ice Shelf* is quantified over time from 1972 to its disappearance in 2003.

Departures from perfect geographic pixel registration in Landsat imagery of the *ECSU Ice Shelf* collected before 2003 was corrected with ITT's Visualization Information Solutions' ENVI image processing software using a 2003 Landsat 7 Enhanced Thematic Mapper (ETM) image as a reference. Older images from Landsat 4,5 Thematic Mapper (TM) and Landsat 7 (ETM) were registered to conform to the common fixed geographic control points visible on both images. By overlaying the GL on the registered (warped) images, the area changes in the ice shelf were computed. An average ice shelf area was determined from four independent measurement trials for each of the pre-2003 Landsat image.

Landsat Images from 2003 used in creating the GL were obtained from the United States Geological Survey (USGS) archive. The older, cloud free Landsat 4, 5 TM and 7 ETM images of the Pine Island Glacier region were obtained from another USGS archive.

Results provided: 1. A quantitative description of the disappearance of the ECSU Ice Shelf from 1972 through 2003; 2. Validation of the grounding line's actual location; 3. A survey of Antarctic coastal features that may have experienced climate related change.

Keywords-ENVI; GLAS, ground control points, grounding line; Landsat 7 ETM+; ECSU Ice Shelf

I. INTRODUCTION

In an effort to determine whether the amount of ice was growing or diminishing over long periods of time, NASA's Dr. Robert Bindschadler led an international team of glaciologists, including Elizabeth City State University (ECSU) students, to obtain an accurate measure of the area of the Antarctic Ice Sheet, accurate for the year 2003. Knowledge of the Ice Sheet's area is useful for determining its mass balance. That is, the amount of ice gained or lost over time. However, finding the area requires first determining the location of the Grounding Line (GL)[1]. The GL is defined as an outline of the area of Antarctica that is underlain by solid ground rather than ocean. More simply stated, it "is the boundary between 'grounded' ice resting on land and any associated floating ice comprising a retaining ice shelf". If climatic warming causes ice mass to be diminished by melting, sea level rises and the grounding line migrates landward. If climate cools, accumulating snowfall will increase ice mass, causing the grounding line to move seaward. The NASA effort, entitled: *The Antarctic Surface Accumulation and Ice Discharge* (ASAID), established the continental ice sheet's GL using LANDSAT 7 Enhanced Thematic Mapper (ETM) and Geoscience Laser Altimeter System (GLAS) data accumulated temporally proximate to the year 2003.

Research reported by the U.S. Geological Survey (USGS) has documented the retreat of every ice front in the southern part of the Antarctic Peninsula during the interval from 1947 to 2009" [2]. Figure 1 shows the Antarctic continent with the USGS study area identified. The same figure also shows the location of the ECSU ice shelf encircled in red lying at the mouth of Pine Island Bay, the subject area of the research reported here. Note that this study area lies slightly south of the USGS study area.

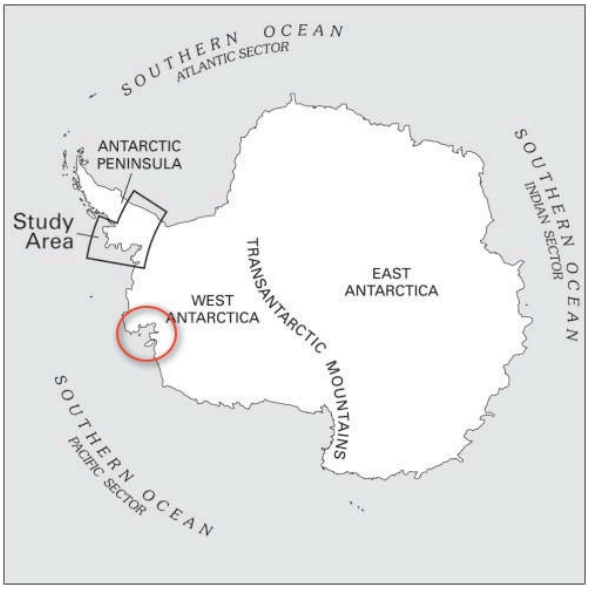


Figure 1. Antarctic continent showing study areas of USGS study area, in black outline and ECSU research within red circle encompassing Pine Island Bay [1].

The dissolution of the Larson Ice Shelf A in 1995 and that of its B portion in 2002 has been attributed to global climate change [3]. In 2011, an ECSU student team discovered that an ice shelf—now known as the ECSU Ice Shelf—had apparently disappeared by the time that the grounding line was established in 2003. Prior work provided a qualitative description of the ice shelf's disappearance. The actual area reduction of the ECSU Ice Shelf over time remained to be quantitatively evaluated.

The grounding line established a reference that allowed measurements of mutually consistent Ice Shelf areas over time. Areas at different time can be measured using of images from three different online archives hosted by the United States Geological Survey (USGS)[1]. These sources included Global Visualization Viewer (GloVis)[2], Earth Explorer, and Landsat Image Mosaic of Antarctica (LIMA)[3].

"As the Nation's largest water, earth, and biological sciences and civilian mapping agency, the USGS collects, monitors, analyzes, and provides scientific understanding about natural resource conditions, issues, and problems" [4]. The USGS has its headquarters in Reston, Virginia, and its website hosts archives from several different sources.

"GloVis is a browse image-based search and order tool that can be used to quickly review the land remote sensing data inventories held at the USGS Center for Earth Research Observation and Science (EROS)"[5]. It is updated daily with the most recent satellite acquisitions and allows users to select and view any area of interest worldwide through the use of images from a number of different Landsat data sets.

"The Landsat Program is a series of Earth-observing satellite missions jointly managed by the National Aeronautics and Space Administration (NASA) and the USGS" [6]. The Landsat data sets that were most used by the ECSU Ice Shelf Investigation (EISI) Team were Landsat Multispectral Scanner (MSS) 1 and 3; Landsat Thematic Mapper (TM); and Landsat 7 Enhanced Thematic Mapper Plus (ETM+). These satellites have been collecting information about Earth since 1972 when Landsat 1, carrying a camera and MSS, was launched. It operated until 1978. Considered an experiment project, Landsat 3 was launched March 5, 1978—3 years after Landsat 2. It carried a camera, a Return Beam Vidicon (RBV) and the MSS, and it was operated by NASA until 1979. Significantly different than the previous Landsats, Landsat 4 was launched July 16, 1982 without the RBV instrument. Also, in addition to the MSS, it carried the TM that allowed the satellite to capture a wider area and more detail on the ground. The Landsat 4 TM had 7 spectral bands and was decommissioned in 2001. On March 1, 1984, NASA launched Landsat 5. It carried the same tools as Landsat 4. In 1987, Landsat 5's Ku-Band failed, making it impossible to obtain data acquired outside the United States data acquisition circle. The MSS instrument was turned off in August 1995, while the TM instrument still operates some 24 years after its planned design life. On April 25, 1999, government owned Landsat 7 ETM+ was launched with capabilities replicating those of the TM instruments on Landsats 4 and 5. It included features that made it a more versatile and efficient instrument for global change studies, land cover monitoring and assessment, and large mapping than its forebears.

Much like GloVis, Earth Explorer provides access to millions of land-related products, including satellite images from Landsat. The program allows users to search the database using options such as address, path/row, latitude and longitude, and date.

LIMA provides virtually cloudless, seamless, and high-resolution satellite view Antarctica. It was created by the USGS, the British Antarctica Survey (BAS), and NASA through the use of funding from the National Science Foundation (NSF) and more than 1,000 Landsat ETM+ scenes. It covers the entire continent except from the South Pole at 90 degrees south to 82.5 degrees south latitude, where Landsat has no coverage because of its near-polar orbit [7]. The website allows users to view, download, and order satellite images.

[1] www.usgs.gov
[2] glovis.usgs.gov
[3] lima.usgs.gov

II. METHODOLOGY

ENVI, a software application created by ITT Visual Information Solutions, was used to determine the area of the ECSU ice shelf. Archived Images from the years: 1972, 1981, 1986, 1989, 1991, 1997, 2000, 2001, and 2003 were downloaded from United States Geological Survey Global Visualization Viewer (GLoVis) and the Landsat image mosaic of the Antarctic. Path and row identifier combinations defined by the Landsat global coverage grid locates the geographic area captured in each scene. Thus, path and row numbers define the location and area covered by a specific image. Ice shelf area was measured in each of selected pre-2003 Landsat archived images with respect to the ASAID circa-2003 grounding line vector. Ice shelf area was identified and measured as equal to the area of ice lying seaward of the grounding lone. Pixel and geographic coordinates were not well registered in Landsat images recorded prior to 2003.

The GL is based on the pixel to geographic coordinate correlation of the 2003 Landsat 7 Images used to define it. However, the 2003 Landsat 7 images do not have the same pixel-to coordinate registration as the older Landsat archived imagery. Therefore, an image-to-image registration had to be performed. Landsat 7 images from 2003 were used as reference images to accomplish this co-registration. Pixel to pixel image registration involves warping, stretching or shifting of an archived image to achieve a pixel-to-pixel geographic correspondence with one of the circa-2003 reference images. The reference image was defined as the base image and the archived image was selected for warping. Five geographic points in each image were selected as ground control points to from which to create the new (warped or co-registered) image. Once the points are selected, there is a tool on ENVI that will warp the images.

Once the new co-registered image is created, the grounding line is overlaid upon it. A vector bounding line was created to encompass the border of the ice shelf that included the GL as one component. Multiple, independent iterations of calculating the ice shelf's area were made and an average was taken. A standard deviation formula was introduced to define the variability in the data. A second round of calculations was performed using common geographic bounding points.

III. RESULTS

A spreadsheet was created to store all of the data. In the first table, to get the "Julian Day" column, the actual day was divided by three hundred and sixty-five and then added to the year. The "Instrument – Path/Row" column describes the type of instrument used to capture the image and the location of the area in the image. The "Base image…" column contains the file name of the base reference image used to create control points. The average area was calculated using 4 trials without specifying the geographic points. The standard deviation column was created to quantify the variability in the areas collected. To minimize trial variability, the area was recalculated but this time with each trial limited to an area within specified limiting geographic points, one lying to the SE of the ice shelf at 73°57'25' S and 102°16'00'' W and one lying NW of the ice shelf at 73°55'55'' S and 102°27'50' W. Line graphs were then created from the tables.

Julian Day	Instrument - Path/Row	Base image (File name)	Avg Area (km²)	Stndrd Dev.
1972.94	LM1 - 001/112	LE70031122003024EDC00	6.94	0.024
1981.95	LM3 - 251/113	LE70011132001004EDC00	6.53	0.152
1986.97	LT5 - 001/113	NLAPS_LE7002113000301	7.78	0.102
1989.97	LT4 - 001/113	NLAPS_LE7002113000301	5.35	0.429
1991.15	LT5 - 004/112	NLAPS_LE7002113000301	4.44	0.155
1997.09	LT5 - 001/113	NLAPS_LE7002113000301	3.11	0.285
2000.18	LE7 - 001/113	NLAPS_LE7002113000301	2.35	0.532
2001.01	LE7 - 001/113	NLAPS_LE7002113000301	2.52	0.114
2003.05	LE7 - 002/113	NLAPS_LE7002113000301	0	0

Figure 2. Average of four trials with unspecified limiting geographic points

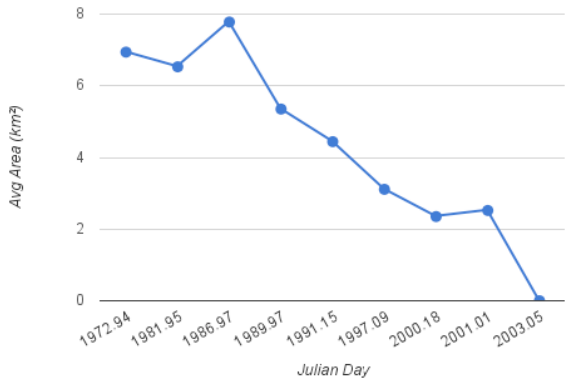


Figure 3. Average of four trials with unspecified limiting geographic points

Julian Day	Instrument - Path/Row	Base image (File name)	Avg Area (km²)	Stndrd Dev.
1972.94	LM1 - 001/112	LE70031122003024EDC00	6.18	0.052
1981.95	LM3 - 251/113	LE70011132001004EDC00	6.21	0.105
1986.97	LT5 - 001/113	NLAPS_LE7002113000301	7.43	0.095
1989.97	LT4 - 001/113	NLAPS_LE7002113000301	5.12	0.075
1991.15	LT5 - 004/112	NLAPS_LE7002113000301	4.22	0.165
1997.09	LT5 - 001/113	NLAPS_LE7002113000301	3.22	0.257
2000.18	LE7 - 001/113	NLAPS_LE7002113000301	1.96	0.256
2001.01	LE7 - 001/113	NLAPS_LE7002113000301	2.37	0.106
2003.05	LE7 - 002/113	NLAPS_LE7002113000301	0	0.000

Figure 4. Average of four trials with specified limiting geographic points

Figure 5. Average of four trials with specified limiting

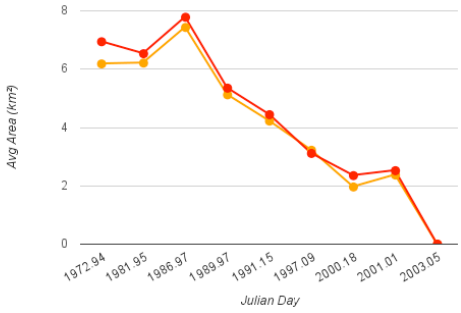


Figure 6. Overlay of graphs

Year	Instrument - Path/Row	Seasonal Ice (Y/N)
1972	LM1 - 001/112	Yes
1981	LM3 - 251/113	Yes
1986	LT5 - 001/113	Yes
1989	LT4 - 001/113	Yes
1991	LT5 - 004/112	No
1997	LT5 - 001/113	No
2000	LE7 - 001/113	Yes
2001	LE7 - 001/113	Yes
2003	LE7 - 002/113	No
2005	LE7 - 001/113	Yes
2007	LE7 - 001/113	Yes
2009	LE7 - 001/113	Yes
2010	LE7 - 001/113	No
2011	LE7 - 001/113	No

Figure 7. Chart of seasonal ice conditions during the selected year

IV. Conclusion

The area of the ECSU Ice Shelf was calculated over the period of 1972 to 2003 using selected LANDSAT images. The small shelf's area was apparently decreasing between1972 to about1981, but then appears to have increased in area between1981 until sometime before1986; around which time it began to decline in area until its disappearance around 2003. Spring and summer open ocean conditions appear to have been episodic prior to and after the ice shelf's 2003 disappearance. It appears the bay is subject to being covered by seasonal ice.

Secondly, the actual location of the grounding line was validated; it does appear to conform fairly well to the current land-water interface in the Pine Island Glacier.

V. Future Research

Future research should include investigation of the remaining Pine Island glacier and Larsen ice shelf areas. Also, there should be a continuation of grounding line validation and continued surveying the coastline for other instances of ice shelf disappearance and their associated area-history examined calculation, using NASA Goddard software and as many data sets as possible. To fill in data gaps, there should be an incorporation of other satellite image data from other satellites including but not limited to SPOT-image, IKONOS, and AQUA & TERRA (MODIS) although the MODIS instruments may not be as useful, due to their lower spatial resolution.

References

[1] R. Bindschadler, H. Choi, A. Wichlacz, R. Bingham, J. Bohlander, Kelly Brunt, et al, "Getting around antartica: new high-resolution mappings of the grounded and freely-floating boundaries of the Antarcic ice sheet created for the International Polar Year," in press

[2] "Ice shelves disappearing on Antarctic Peninsula," February 2010, http://www.usgs.gov/newsroom/article.asp?ID=2409.

[3] G. Casassa, W. Krabill, P. Gogineni, E. Rignot, A. Rivera, and R. Thomas, "Accelerated ice discharge from the Antarctic Peninsula following the Collapse of Larsen B ice shelf," Geophysical Research letters, Vol. 31, L18401, doi: 10.1029/2004GL020697, 2004.

[4] "About USGS," http://www.usgs.gov/aboutusgs/.

[5] "Global Visualization (Glovis) viewer," October 2005, http: pubs.er.usgs.gov/djvu/FS/2005_3118.pdf.

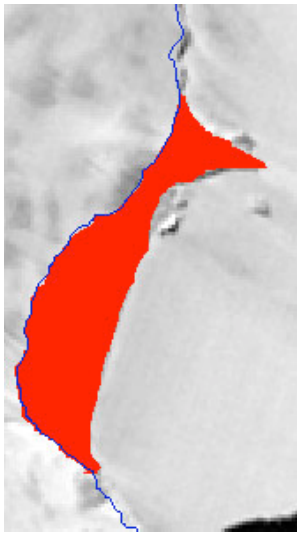
[6] "The Landsat Program," http://landsat.gsfc.nasa.gov/.

[7] "Landsat Image Mosaic of Antarctica," http://lima.usgs.gov.

APPENDIX A

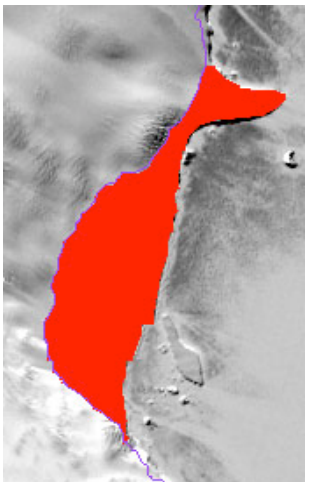
Images of the calculated area using “Region of Interest (ROI)” tool in ENVI

1972

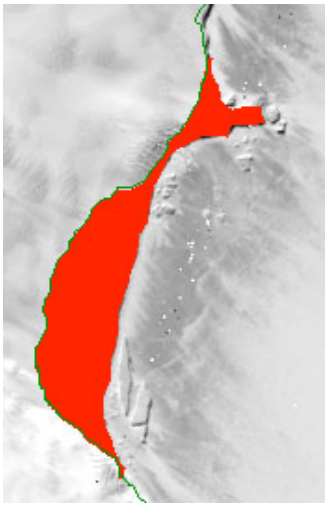


1981

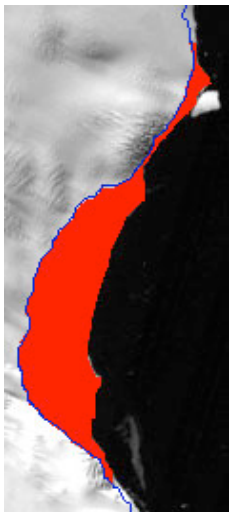
1986



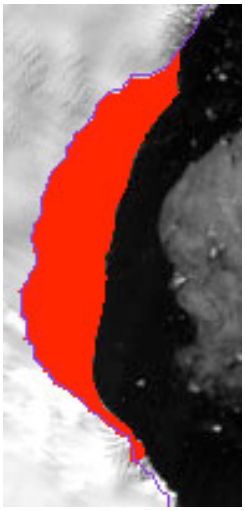
1989



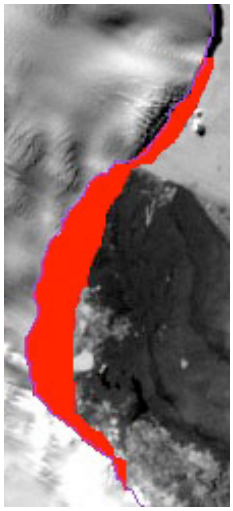
1991



1997



2000



2001