Validation of the basal stress boundary utilizing Satellite Imagery along the George VI Ice Shelf, Antarctica

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***Abstract*—Majority of ice shelves are fed by inland glaciers. Together, an ice shelf and the glaciers feeding it can form a stable system, with the forces of outflow and backpressure balanced. Warmer temperatures can destabilize this system by increasing glacier flow speed and more dramatically by disintegrating the ice shelf. Without a shelf to slow its speed, the glacier accelerates. After the 2002 Larsen B Ice Shelf disintegration, nearby glaciers in the Antarctic Peninsula accelerated up to eight times their original speed over the next 18 months. Similar losses of ice tongues in Greenland have caused speed-ups of two to three times the flow rate in just one year.**

Rapid changes occurring in regions surrounding Antarctica are causing concern in the polar science community to research changes occurring in coastal zones over time. During the research, the team completed a study on George VI Ice Shelf located on the western coast of the Antarctic Peninsula. The study included a validation of the Antarctic Snow and Ice Accumulation Discharge Basal Stress Boundary (ABSB) vs. the natural basal stress boundary (NBSB) along the George VI Ice Shelf. The ASAID BSB was created by a team of researchers headed by National Aeronautics and Space Administration Goddard Space Flight Center (NASA GSFC), with an aim of studying coastal deviations as it pertains to the mass balance of the entire continent. The point data file was aimed at creating a replica of the natural BSB. Select cloud free Landsat satellite imagery from satellites 1 through 7 was used to detect changes occurring over the span of 19 years. The last major interest in the study included documenting the deviations or incorrect placements of the ABSB vs NBSB. Changes that occurred were documented in the form of a table with the change that occurred along with the geographic coordinates.

***Index Terms*—ENVI GloVis, NBSB, ABSB, Landsat, Ice Shelf, Ice Sheet**

I. Introduction *(Heading 1)*

Large suspicions remain in the current and future involvement to sea level rise from Antarctica [2]. In West Antarctica, widespread losses along the Bellingshausen and Amundsen seas increased the ice sheet loss by 59% in 10 years [2]. Losses are concentrated along channels occupied by outlet glaciers. Changes in glacier flows have a significant, impact on ice sheet mass balance. Ice shelves are floating blocks of ice that forms where a glacier or ice sheet runs down to a basal stress boundary (BSB) and onto the ocean surface. Ice shelves are only present in Antarctica, Greenland, and Canada. After the 2002 Larsen B Ice Shelf disintegration, nearby glaciers in the Antarctic Peninsula accelerated up to eight times their original speed over the next 18 months. Similar losses are reported in Greenland and have caused speed-ups of two to three times the flow rate in just one year. This paper reports a validation of the Antarctic Surface Accumulation and Ice Discharge (ASIAD) basal stress boundary (ABSB) versus the natural basal stress boundary (NBSB) along the western side of the Antarctica Peninsula at George VI ice shelf (-69.428825, -69.124926) to (-73.053685, -72.419080). According to Hansen (2009) some of the warmest temperature increases for over a half-century are found within these boundaries [1].

The ASAID project accumulated the image-interpretation from United States Geologic Survey to map the BSB and to analyze the data (http://earthexplorer.usgs.gov). The images retrieved from earth explorer are cloud free images taken with Landsat satellites 1 – 7. The bands used while viewing these images show, which features are going to be most predominate in the satellite images. Band 2 is used for viewing the features present in Multi Spectral Scanner (MSS) images [3]. Wavelength for band 2 is (0.52 – 0.60u m) meaning it is sensitive to water turbidity differences [3]. The band 4 is used to view Enhanced Thematic Mapper (ETM), and Enhanced Thematic Mapper Plus (ETM+) image data. Wavelength for band 4 is (0.76 – 0.90u m) meaning it operates in the best spectral region to distinguish ice sheet, ABSB and NBSB characteristics [3]. Exelis Visual Information Solutions (ENVI) 5.0 is used for the analysis and comparison of satellite data, which are GeoTiff images. One feature from ENVI 5.0 allows us to superimpose the ABSB on the acquired satellite images to perform a validation of its accuracy versus the NBSB.

One participating institution was Elizabeth City State University (ECSU) Center of Excellence in Remote Sensing Education and Research (CERSER). CERSER's participation in the Center for remote sensing of educational and research objectives. The study reported here represents research of undergraduate students at ECSU to: 1. Use Landsat images and ASAID BSB as a temporal and spatial glaciological benchmark 2. Validate the ASAID-derived able changes in the ice sheet and 3. Explore both earlier and later imagery for observable changes in the ice sheet.

II. Methodology

A. Path/row of George VI Ice Shelf

The initial step in of the analysis involved finding the path and row of the George VI Ice Shelf. The reason for establishing the path and row was so that the best possible cloud free Landsat images were chosen to cover the entire designated region.

B. Retrieving Landsat Images

The United States Geological Survey (USGS) online archives of Landsat imagery through the Global Visualization Viewer (GloVis) (http://glovis.usgs.gov/) and Earth Explorer (http://earthexplorer.usgs.gov/) browsers were used to locate pre-2003 cloud free Landsat images. The websites included images recorded by the Landsat 1 and 3 Multi-spectral Scanner (MSS); the Landsat 4 and 5 Thematic Mapper (TM); and the Landsat 7 Enhanced Thematic Mapper (ETM+).

C. BSB text file

The team then analyzed a large text file that included latitude, longitude and ENVI point data for the Antarctica Peninsula. Dr. Robert Bindschalder along with a team of researchers from around the world created the point data file to show the basal stress boundary (BSB) of the entire continent [4]. Loading the data in ENVI 5.0, a software application distributed by *Exelis Visual Information Solutions*, presented a challenge due to the size of the document. The project required an edit to truncate the 236-megabyte file to 38.4-megabytes so that the text file would load faster and only include the area of interest for the research. Viewing images of the peninsula the latitude and longitude points of the area of interest were found. Using the latitude and longitude points found, the 3,575,503 lines of records were accessed and then point data was edited to only include the points within (-1807366.800 W, 306894.810 S, 73 14' 35.35" S, 80 21' 46.70" W) and (-1971911.500 W, 1030714.100 S, 69 45' 37.64" S, 62 24' 14.49" W). The edited text points extend from Larsen D Ice Shelf to Larsen A Ice Shelf and extended around the peninsula through the extent of George VI Ice Shelf.

D. Creating vector file

The next step in the process was to create a vector file (.evf) from the text file. This process was completed using ENVI Classic (4.7) point collection feature. The points were imported into an ENVI point collection data table. Within the table properties, settings were changed to assign the point data values to the correct column. After completing the point collection process the file was saved as vector file to be overlaid over the downloaded satellite images.

E. Creating Mosaics

ENVI 5.0 was then utilized to create mosaics of the reference images (images from 2001-2003) and the older images (images from 1974-1988). Mosaics were created to overlay the images on one another to view them together displaying the George VI Ice Shelf. Creating the mosaics helped visualize the area of George VI Ice Shelf that was covered with the retrieved images. It was also used as a reference tool for the older images. Upon completion of the creation of the mosaics after the first downloaded image sets, it was determined that another image was essential to covering the entirety of the George VI Ice Shelf. The additional image was downloaded and the mosaic was recreated with the additional image included.

F. Linking images

The reference images were then linked to the older warp images using ENVI Classic (4.7), permitting the screening of superimposed geographically mutual areas. Linking the images allowed a pixel-by-pixel flickering or temporary superimposition of a small region of one image over another to make any variations between two images more recognizable.

G. Warping images

Further, the warping of each pre-2003 Band 4 (0.75-0.90 um) older image to one of four reference images to provide necessary common, geographically consistent, pixel registration was finalized. Band 4 TM images (spectrally similar to MSS Band 2 images) provided the most efficient scene contrast for ice shelf, natural basal stress boundary and sea ice discrimination.

ENVI 5.0 was utilized for the warping procedure. The process required a minimum of five tie-points fixed to geographic features. Five or more broadly dispensed tie points were sought in each image duo (consisting of a reference and older image) to develop a greater efficiency of the warp. A least square bi-linear warping was performed to optimize the image-to-image correspondence relative to the selected geographic points that were established in each image duo. Each team member conducted the warping process a number of times to ultimately get a "good warp". A good warp is defined by how accurately the warp image displayed on the base image at the end of the geo-registration process. A total number of five images were warped during the procedure. The warping of each image was necessary due to the comparison of the older images to the newer images being based upon how the spatial resolutions as well as geographic coordinates correlate among each set of the satellite images [5]. Even though some images had the same spatial resolution some images are stored in the GloVis and Earth Explorer websites with varying geographic coordinate correlations. Therefore the geo-registration process was carried out on all image sets throughout the duration of this research [5].

H. Validation process

Trailed by the warping procedure, the ASAID BSB line was superimposed onto each warped image using ENVI Classic. The validation of the BSB along the George VI Ice Shelf was then conducted. The validation process involved using a standard zoom of ~x4 or greater of the ENVI Classic zoom window in order to view deviations. The deviations either positive or negative of the ASAID BSB compared to the NBSB if any were observed in the satellite imagery.

III. Results

After examining Landsat images throughout the years of 1984-2003 using a standard zoom of ~x4 or greater of the ENVI Classic zoom window, the team conducted the validation of the ASIAD BSB (ABSB) vs. the natural BSB (NBSB) along the George VI Ice Shelf as shown in Figure 1. The team also concluded that the location of the BSB has been stable over the approximately 20-year study period. Dynamics that may change the position of the BSB are all slow processes such as sea level rise. These slow procedures are unlikely to change the placement of the BSB at the Landsat-pixel scale over the twenty years of observations suggesting that this is a reasonable assumption. Supporting the assumption of the BSB stability is the teams' observation that all images display essentially the same geographic features along the coastline of George VI Ice Shelf.

IV. Future Work

Furthering this research, areas south of the George VI Ice Shelf and the Antarctic Peninsula should be examined to validate the grounding line. Looking at maps related to Antarctic Peninsula, the Ross Ice Shelf would be the next area of interest. This area was picked because it is the largest ice shelf on the entire continent. The Ross Ice Shelf is estimated to be the size of France. While looking at the BSB along Ross Ice Shelf, there should be a survey of the coastline area for ice shelf loss. While continuing this research methods to keep ENVI 4.7 and 5.0 from crashing due to uploading large files should be researched. A possible fix to the crashing problem would be to split up the BSB text file into different sections. The sections would be based off the latitude and longitude points of certain areas; the areas would be the major ice shelves around the continent. Splitting the original .txt document into the different sections would make it easier to determine what points are needed for different research project areas without looking at three million lines of data.

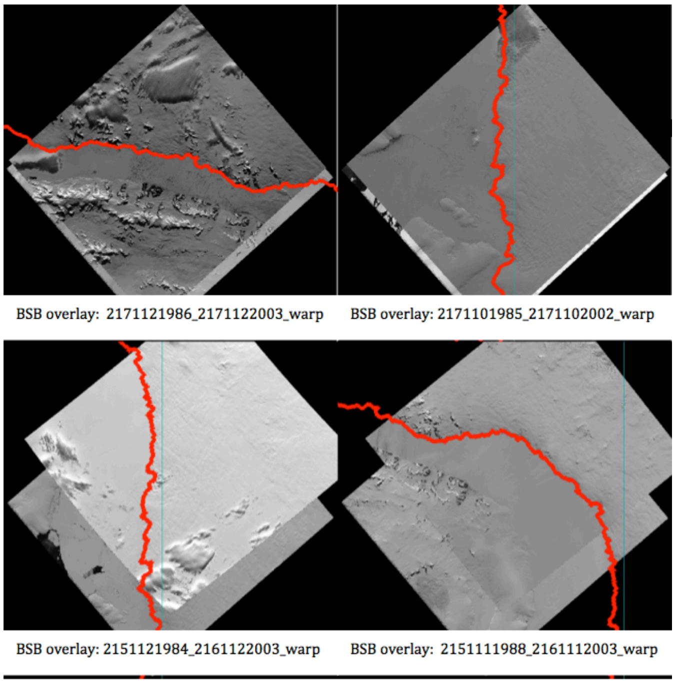

Fig. 1. Cropped, Landsat images displaying the BSB validation.

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