Federico Vantadori's master thesis summary:

MAPPING OF GLACIERS IN THE CENTRAL AND EASTERN ITALIAN ALPS WITH ASTER SATELLITE IMAGES

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INTRODUCTION

The GLIMS (Global Land Ice Measurements from Space) is an ambitious project, partially funded by NASA and other international organizations, to develop a Geographic Information System (GIS) regarding World's ice land data extracted from the analysis of satellite images, mainly captured by the multispectral sensors ASTER and ETM+.

The images processed during this thesis work have been acquired from ASTER sensor on the 25/08/2007 over Ortles-Cevedale's glaciers.

The spectral properties of snow and ice make multispectral satellite sensor particularly useful in this field. Processing a satellite image needs a considerable effort and a good knowledge of the regional context.

The chief issue that concerns analysts of satellite images in this field is the spatial resolution of the multispectral sensors. Indeed, to map elements of such small size as glaciers a high spatial resolution is necessary. Generally, these images are acquired from instruments on board of satellites in sun-synchronous orbits around the Earth, thus they are 700 km far from glaciers. The ASTER sensor, on-board the Terra (EOS AM-1) spacecraft, has a spatial resolution of 15 meters in the visible and near-infrared part of spectrum, 30 meters in the short-wave infrared spectral ranges, and 90 meters in the thermal-infrared bands. These specifications make simple understanding that a preventive and methodical image processing is indispensable to distinguish clearly the glaciers' boundaries.

PROCESSING OF ASTER IMAGES CAPTURED ON THE 25/08/2007

The work has been focused on the Trentino's glaciers of Ortles-Cevedale mountain range, which is located on the boundaries between Lombardy and Trentino-Alto-Adige. The particular geographical collocation has brought to several difficulties during data collecting and processing of digital supports, such as orthophotos and Digital Elevation Models (DEMs).

In this context the satellite image processing starts from orthorectification, goes on to classification, and ends at outlining glaciers' boundaries.

The geometrical configuration of satellite-Earth system brings inevitably to deformations in the scenes acquired by satellite sensors. Orthorectification is an indispensable step when the aim of the analysis is to extract geometrical information or to realize reliable maps. This correction is one of the longest in time of the entire image processing and needs both analyst experience and capacity of recognizing on images elements that can be set as control point. These points, named Ground Control Points (GCPs), contain information of altitude, obtained from DEM, and of geocoding, obtained from orthophotos. For each an element clearly recognizable both on satellite image, usually represented in false colors to understand better the portion of terrain framed, altitude and coordinates values have been assigned. By setting carefully and homogeneously these GCPs, correcting geometrically the ASTER image is possible through software for image processing. These applications use GCPs and DEM together to correct satellite images on the basis of resampling methods.

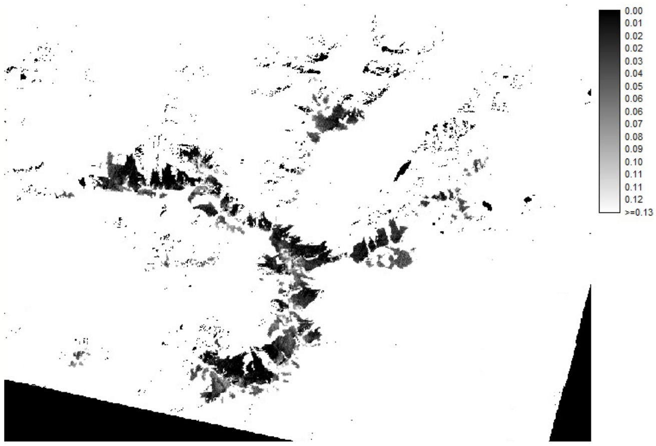

Figure 1: The Ortles-Cevedale's glaciers mask obtained from the ratio of 25/08/2007 ASTER band SWIR4 and VNIR3N.

Since the ASTER image has been geometrically corrected, an image classification through algorithms based on bands ratio SWIR4/VNIR3N has been performed. As reported in literature, the most reliable ratio of spectral bands in this field is near-infrared to visible (red). This method funds its principles on spectral response of snow, ice, and soil. On the basis of this reclassified image (figure 1), the digitalization of glaciers' boundaries at the end of the summer of 2007 has been done.

To obtain accurate glacier' limits, a continuous comparison among glaciers' mask, glaciers' boundaries defined by Provincia Autonoma di Trento (PAT) at 2003, and orthophotos acquired on 2006 has been realized. This outlining, based on the overlap of multiple media, has allowed to avoid misclassification errors caused by snow- or debris-cover of glaciers.

TOWARDS A SATELLITE ATLAS OF ITALIAN GLACIERS

Glaciers' boundaries are necessary to cut DEM and consequently compute the parameters that characterize a particular ice body. These computations have been performed through codes written in Fortran and provided by Prof. Ranzi (Ranzi and Rosso, 1995).

Before computing parameters, a comparison among the numerous inventories of glaciers has been realized. Each organization interested in glacier monitoring uses its own standard. Despite this work is framed into the GLIMS project, an additional set of parameters has been proposed in view of the development of the Satellite Atlas of Italian glaciers, a project that involves University of Brescia, Comitato Glaciologico Italiano, and CNR-IREA of Milan. To this regard, in addition to the basic parameters required by GLIMS (Paul et al., 2010) for its own GIS (Raup et al., 2007) other glaciers' specifics have been computed (Comitato Glaciologico Italiano, 1961-1962) (Desio et al., 1967). The parameters selection has brought to the development of detailed and innovative tables for each glaciers of Trentino held by Ortles-Cevedale mountain range.

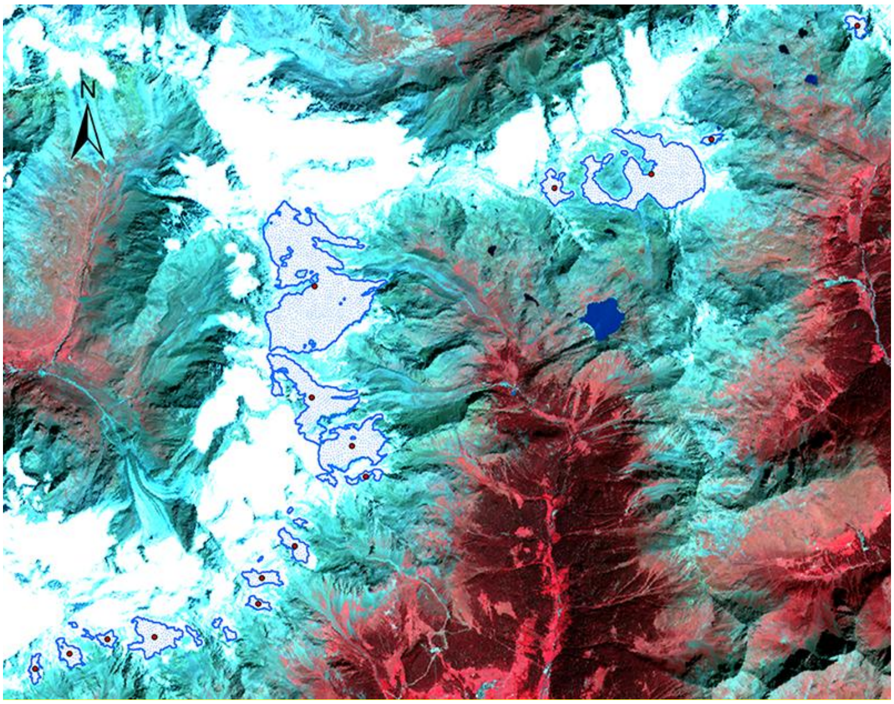

Figure 2: The glaciers' boundaries of Trentino held by Ortles-Cevedale mountain range on the ASTER image captured on 2012/08/25 represented in false colors RGB=321

The glaciers' boundaries have been exported, together with the relative database, to a file in shp (shapefile) format. This file has represented the basis to compare the glacier's variation between 2003 and 2007 through the official data provided by PAT. Latter ones have been extracted from high level measurements performed in 2003 by a low altitude flight. Other consideration has been done on the basis of World Glacier Monitoring Service (WGMS) data, measured in 1980.

These comparisons have mainly interested total area and altitudes of glaciers. Obviously, the results of this comparison show how much glaciers are worryingly retreating. However, some of these maintain a considerable size, due to their high altitudes and conditions of exposure.

By summing all the values of area per year a synthetic and impressive conclusion can be extracted: the total area of glacier of this zone has retreated by more than 30% between 1980-2003 and by more than 25% between 2003-2007. The total area of ice was equal to 17.180 km^2 in 1980, to 11.729 km^2 in 2003, and finally in 2007 it has decreased to 8.778 km^2.

To further assess the accuracy of data obtained from the processing of ASTER image acquired on the 2007/08/25, a comparison with altitudes (minimum, maximum and mean) measured in 2003 by PAT has been done.

It is necessary to keep in mind that values provided by PAT have been measured through high level instruments (laser scanner) on board a low-altitude flight over the glaciers, while values of 2007 have been extracted from a combination of satellite images (acquired 700 km far from Earth) and 10 m resolution DEM realized in 2000. In summary, between 2003 and 2007 the values of altitudes of the glaciers studied have changed as follows: the minimum altitude has raised on average of 104 m, the maximum has decreased on average of 36 m, and the mean has increased on average of 47 m. It clear that glaciers are retreating at higher altitudes.

CONCLUSIONS

In view of the results obtained from image processing several considerations can be extracted.

Image processing for the mapping of glaciers requires a long time. However, remote sensing allows to produce surveys with high time frequency and costs connected only to work of the analysts, which can perform the analysis minimizing expensive field surveys.

The great advantage that this method has is the possibility of frequent and repeated monitoring of glaciers. Indeed, the availability of data measured few years away allow an accurate definition of the changing trend of the glaciers key parameters, first of all geometric and altitude values. Another advantage of this method is the possibility of reviewing. The presence of snow or debris on glaciers can lead to misclassification errors. The experience of a glaciologist that reviews the glaciers' boundaries outlined or the computed data is fundamental to correct possible errors before any result is published. The reliability of measurements obtained suggests we should substitute expensive ad hoc flights with cheaper satellite image processing.

The factors that can increase the quality of data extracted from satellite image processing are: increase the spatial resolution of satellite images from which the glaciers mask is extracted; increase the resolution of DEM used for these computations;

As GLIMS project recommends (Raup and Khalsa, 2010), image analysis performed using DEM would be more appropriate, with the same resolution of satellite image (between 15 and 30 m). However, due to low reliability of GDEM realized by ASTER sensor, GLIMS analyst are more likely to use DEM produced by regions or provinces of the country in which the studied glaciers are located. These inhomogeneities in elevation models inevitably lead to inhomogeneity in data produced.

Additionally, other two subjective factors influence the inhomogeneity in results: the algorithm used to create the glaciers mask, and the method used to outline the glaciers' boundaries. The GLIMS project does not imposed any algorithms to calculate the spectral band ratio. The analyst chooses from time to time individually which is the most appropriate algorithm to process the image. This lack of standards has its reasons in the different conditions in which the glaciers are. In fact, the different combinations used for band ratios are chosen on the basis of: presence of shadows or debris over the glaciers; cloud coverage levels on the satellite scene; the proximity to water bodies that can disturb the classification.

This method is affected by some limits, including: the inability to determine the thickness of the ice sheet, a very significant parameter for understanding the glaciological unit's health, and the retreat of the front. Both of these parameters still require in-situ measurements.

A desirable increase of satellite image spatial resolution may lead to more accurate and reliable measurements. An increase of the accuracy level could make on-field measurements no longer needed.

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