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Evaluation and use of CBERS-2 digital data for glacier inventories

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Abstract: In this paper, we describe the glacier baseline inventory carried out for the Cordillera Tres Cruces (67°22'-67°32'W and 16°47' - 16°09'S), Bolivia, and provide information on its glacier state in 2004. A geo-rectified China-Brazil Earth Resources Satellite (CBERS-2) scene acquired on 19 May 2004 was employed for delimitation of glacier catchment areas and snow line position. To validate the results, we overlayed the resulting glacier outlines on an ASTER band-ratio image. Final results showed errors (≈ ± 40 m) due the different spatial resolutions and geo-rectification of the images. This study constitutes potential contribution to the international project Global Land Ice Measurements from Space, and towards a low-cost glacier monitoring program for the Andean region.

Keywords: CBERS-2; Glacier Inventories

1.Introduction

Andean glaciers play an important role in the hydrological and social-economical systems of many countries. For example, they are essential to supply drinking water to local communities; produce energy in hydroelectric power plants; supply water for agriculture; and as scenic values in the tourism. In La Paz (Bolivia), for instance, 70% of the water used by the population comes from glaciers. Mountain glaciers, in general, lost mass during the XX century (Dyurgerov and Meier, 2000). This is a process that can be attributed both to a general atmospheric warming and to regional climatic variability (Meier, 1984). Through of monitoring of the glacier geometry changes is helpful in global climate models, and understanding them to forecast future trend of water availability (Rignot and others, 2003).

Many glaciers are located in remote mountainous regions, where glaciological studies are difficult to be carried out. Consequently, satellite imagery has been used to glacier research, allowing the monitoring of glaciers and understanding of their responses to climate change (Dyurgerov, 2002). An example is the Global Land Ice Measurements from Space (GLIMS) project. GLIMS objectives are to monitor glaciers on the Earth using primarily satellite data. Furthermore, this project maintains a geospatial database of glacier information derived from satellite sensors.

In this study we evaluate the availability of China-Brazil Earth Resources Satellite (CBERS-2) data for glacier inventories. Our test area is located in Cordillera Tres Cruces, Bolivia (67°22' - 67°32'W and 16°47' – 16°09'S).

2. Study area

Tres Cruces is a 35 km length and 10 km width mountain range **(figure 1)** located around 150 km South of La Paz, the Bolivian Capital. This Cordillera has several peaks higher than 5000 m, where the summit is called Jachancuncollo and has an altitude of 5900 m. The mean snow line altitude of the ice masses is about 5250 m (Francou and others, 2004).The production of energy in the region is highly depending on small hydroelectric power plants located along rivers originated by glacier melt water.

Regarding the climate, the region is marked by two well distinct annual seasons (Kaser and others, 2002). In the summer, the meteorological settings are influenced by the intertropical circulation, occurring precipitation due the humid air masses coming from the Amazonia. In the winter, dry air masses coming of southwest predominate, resulting in almost no precipitation. So, the summer months determine the behavior of the glaciers, regarding mass reserve and loss.

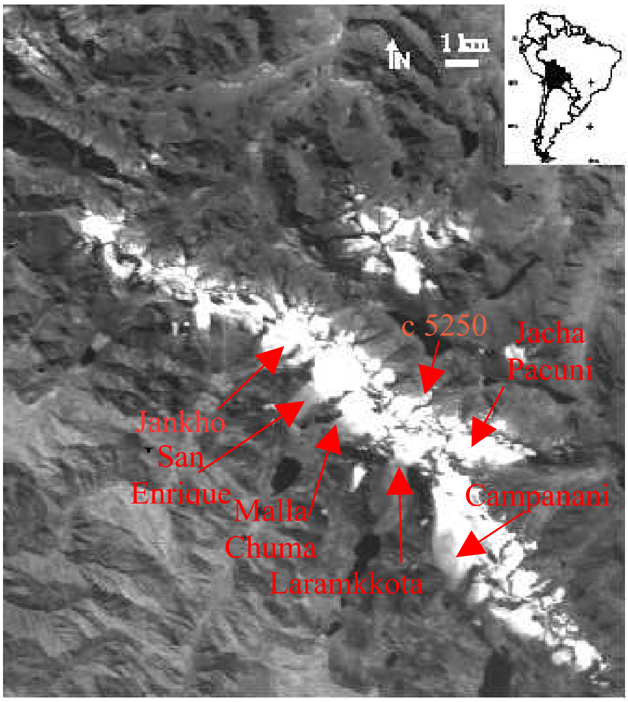

Fig. 1. Location of Cordilhera Tres Cruces. CBERS-2 CCD band 3, acquired on 19 May 2004.

3. Data Sources

CBERS-2 data

The CBERS program was born from a paternership between Brazil and China in the space technical scientific segment. The launch of the CBERS-2 occurred on 21 October 2003. It carries three sensors: the Charge Coupled Device (CCD); the Infra-Red Multispectral Scanner (IRMSS); and the Wide Field Imager (WFI). Its orbit is helios-synchronous, at 778 km altitude, performing about 14 revolutions a day and obtaining a complete coverage of the Earth in 26 days (the site www.cbers.inpe.br presentation the main characteristics of the satellite). In this study, we used CCD and IRMSS scenes acquired on 19 May 2004. **Table 1** shows the characteristics of CCD and IRMSS images.

Camaras	Band/ Name	Range (µm)	Spatial resolution (m)	Swath (km)
CCD	2	0,52 – 0,59 µm	20	113
	3	0,63 – 0,69 µm	20	113
	4	0,77 – 0,89 µm (near infrared)	20	113
IRMSS	2	1,55 – 1,75 µm (middle infrared)	80	120

Table1.Specifications of CBERS-2 CCD/IRMSS sensors

ASTER data

The ASTER sensor was launched in 2000 aboard the Terra satellite. It has 3 instruments: a visible and near-infrared (VNIR) telescope with 4 multispectral bands (3 at nadir and 1 back-nadir) and 15 m of spatial resolution; a shortwave infrared (SWIR) telescope with 6 bands and 30 m of resolution; and a thermal infrared (TIR) with 5 bands and 90 m. In thistudy, we used an ASTER VNIR image acquired on 29 May 2004.

Topographic Map

Topographic information was obtained from a 1:70000 topographic map, produced by the Institute for Photogrammetry and Engineering Surveying and the Geographic Institute of the University of Hanover based on control points acquired on 1975 by the Instituto Geográfico Militar (IGM/SGM) from La Paz, Bolivia, in the form of UTM grid coordinates published by Jordan (1991).

4. Methodology

The CBERS-2 and ASTER scenes were acquired in the same month May 2004. The images are cloud-free, and were acquired during the dry season (fresh snow falls can obscure glacial boundaries) where the snow cover is near its annual minimum.

To compare glacier parameters and to minimize geometric distortions, the images were registered to a common base. First, the ASTER scene was geo-referenced to Universal Transverse Mercator (UTM) zone 19 world geodetic system 1984 (WGS84) using the topographic map as reference. At total, 20 ground control points (GCPs) were selected from features as lakes, mountain summits and river, which could be located precisely within the image.

The image was projected using a first-degree polynomial transformation and nearest neighbour resampling. The root-mean-square error (RMSE) obtained from the geometric correction procedure was 1.33 ASTER pixels (19.95 m). In a second step, the CBERS-2 images (CCD and IRMSS) were co-registered to the ASTER image. By using the 20 GCPs, the resulting RMS error was 2.01 CBERS CCD pixels (40.2 m) for the CCD image, and 2.11 IRMSS pixels (168.8 m). To distinguish the ice and snow facies from the surrounding land cover, we combined the IRMSS 2 (red), CCD 3 (green) and CCD 2 (blue) in a false color composite **(figure 2)**. For that, the IRMSS band was resampled to 20 m using bilinear interpolation.

The exact delineating of glacier terminus is often difficult. Glacier tongue can be covered by debris and will have a spectral reflectance similar to the surrounding terrain. In this study an oblique photograph taken of the southwest of Cordillera Tres Cruces **(figure.3)** in June of 2004 was used to validate the manual delimitation of glacier boundaries on the CBERS-2 false-color composite image. After a visual inspection, the presence of debris-covered in the glacier terminus was discarted. Thus, glacier catchment areas and transient snow line were digitized. The topographic information were used for delimitating the upper boundaries of the glaciers. The validation of the CBERS-derived glacier information was obtained by overlaying it on glacier parameters (e.g., glacier catchment areas and snow line) digitized by hand on an ASTER 3/4 band ratio image (Käab and others, 2002) **(figures 4 and 5).**

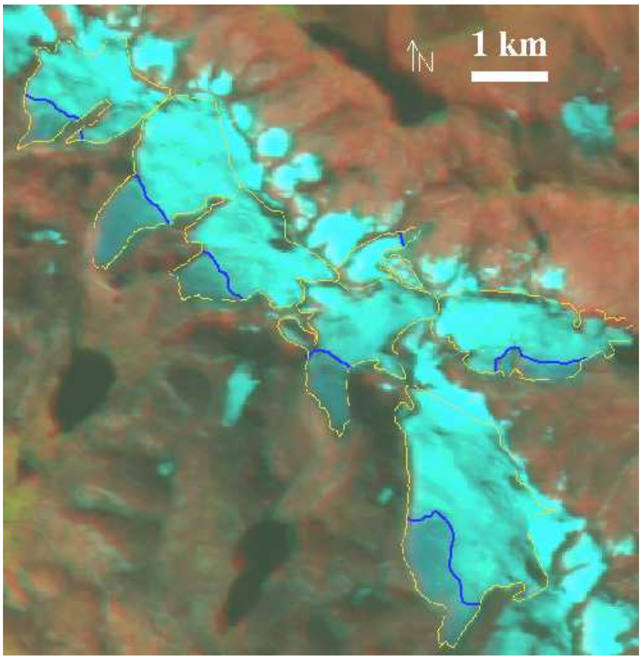

Fig. 2. CBERS–2 false color composite IRMSS 2 (red), CCD 3 (green) and CCD 2 (blue), glacier outlines in yellow and transient snow line in blue.

Fig.3. Oblique photograph taken of the southwest of Cordillera Tres Cruces. Scale bar approximated to the topographic map. By Sarah Griffin in June of 2004.

Theoretically, in the central Andes the equilibrium line altitude (ELA) coincides with the transient snow line at the end of the hydrologic year. The ELA is the place on a glacier where annual accumulation is equal to annual ablation. When the annual mass balance is negative, the ELA rise, and when positive falls is, therefore can be used as an indicator of glacier response to climate change. Klein and others (1999) demonstrated that it can be determined with satellite images, being the boundary between the white snow cover and the glacier ice. However, fresh fallen snow during the dry season can make difficult the delimitation of the ELA by remote sensing sensors (Francou and others, 2004).

In this study, we used the snow line as a rough estimative in the identification of the ELA. Furthermore, we used the snow line to calculate the proportion between the surface of the accumulation area and the total glacier area (i.e., accumulation area ratio – AAR).

5. Resulsts and Discussion

Seven glaciers of the Cordillera Tres Cruces were analyzed. The high reflectance of snow that characterize the accumulation zone, is separate of the zone of lower-reflectance where bare ice is exposed (ablation zone) by the transient snowline. To precise the measuring glacier termini we estimate the uncertainty by using the method from Hall and others (2003):

Termini error = [(pixel resolution ASTER image)^2 + (pixel resolution CCD image)^2]½ + registration error

We have:

$$[(15)^2 + (20)^2]^{½} + 40 = \pm 75 \text{ m}$$

For estimation of uncertainty for area values, we used the method proposed by Hall and others (2003):

Areal uncertainty = (pixel resolution) ^{2} *(2 * uncertainty / pixel resolution)

We have:

$a = 20^2 * (2*75/ 20)$
$a = \pm 0{,}0030 \text{ km}^2$

The calculation of AAR was done by using the equation (Benn and others, 2004):

$$\mathbf{AAR} = \frac{Ac}{Ac + Ab}$$

Where Ac is the area of the accumulation area and Ab corresponds to the ablation area. On Zongo glacier in the Cordillera Real, Bolivia, (approximately 120 km of the study area) during the 93-94 hydrologic year, the altitude of the transient snowline near the end of the ablation season occurred at approximately the same altitude as equilibrium line (Klein and others, 1999). Table 2 shows the results of the glacier inventory.

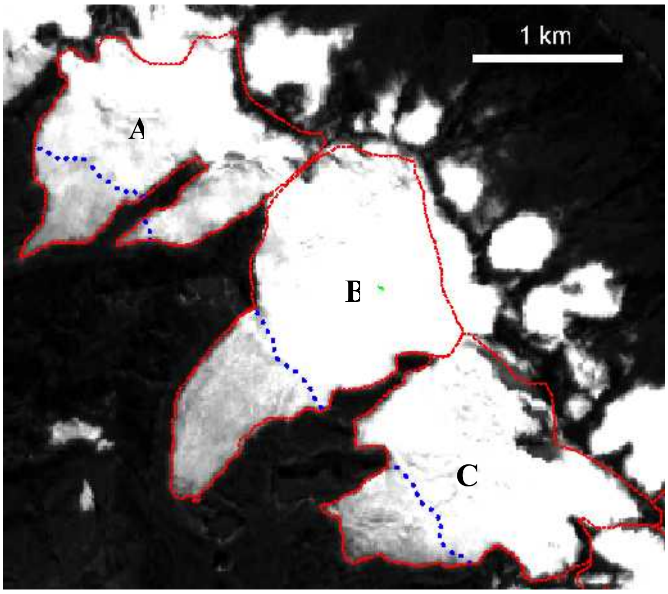

Fig. 4. Overlay of glacier outlines (red and blue) from CBERS-2 on the ASTER ratio bands in background showing Jonko loma (A), San Enrique (B) and Malla Chuma (C).

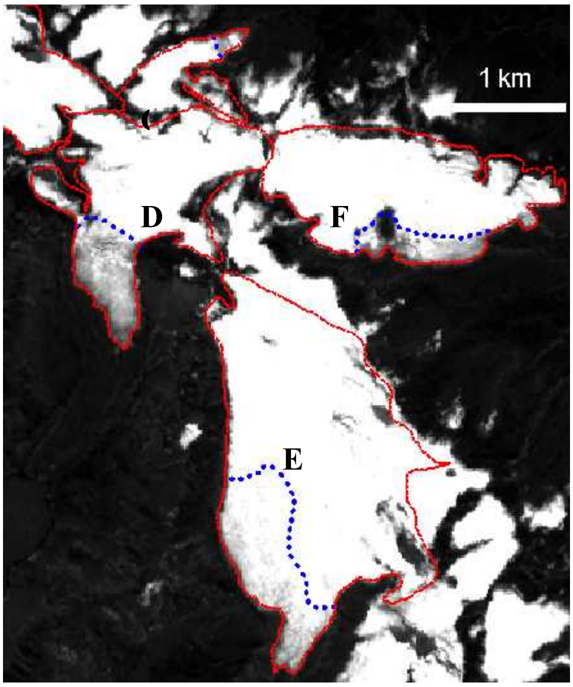

Fig. 5. Overlay of glacier outlines (red and blue) from CBERS-2 on the ASTER ratio bands in background showing Laramkkota (D),Campanani (E) Jacha Pacuni (F) and c5250 (G)

Glacier name	Location	Total area (km²)	Accumulation area (km²)	Ablation area (km²)	Acumulation area ratio (%)	Glaciar length (km)
Jankho Loma	67°41'W 16°92'S	1,5	1,1	0,4	73	1,85
San Enrique	67°39'W 16°93'S	2,0	1,5	0,5	75	2,16
Malla Chuma	67°39'W 16°94'S	1,7	1,3	0,4	76	1,30
Laramkkota	67°37'W 16°95'S	1,8	1,4	0,4	77	1,88
Campanani	67°36'W 16°17'S	3,7	2,9	0,8	78	2,89
Jacha Pacuni	67°35'W 16°95'S	1,9	1,5	0,4	78	1,15
c 5250	67°37'W 16°94'W	0,46	0,42	0,04	91	1,06

Table 2. Glacier inventory data

6. Conclusion

The combination of bands IRMSS 2 (red), CCD 3 (green) and CCD 2 (blue) permits a good delineation of snow and ice, making possible to separate accumation zone from ablation zone (determination of snow line) on glaciers and the glacier terminus position. Results suggested that both the transient snowline and glacier catchment areas can be determined using CBERS-2 data. Errors can be regarded to inherent mistakes of the spatial resolution of the data compared with the spatial resolution of ASTER products.

Changes in the ice fronts as part of the international research initiative GLIMS are being investigated using ASTER and Landsat data. Hereby, CBERS-2 appears as an alternative for monitoring of glacier frontal position and snow line altitude.

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