Google Earth and Ice Flows in Antarctica

Amelia Carolina Sparavigna

Department of Applied Science and Technology, Politecnico di Torino, Italy

The Google Earth imagery can give us some evidence of the ice flows of Antarctica. Here we will show, in particular, that the Google Earth time series can evidence the motion of some surface features, which are considered as the surface expression of basal crevasses. We can measure the rate of their motion too.

Keywords: Ice flow, Satellite Images, Geophysics, Climate Change, Global Warming, Crevasses, Basal Crevasses, Antarctica, Amery Ice Shelf, Larsen C Ice Shelf.

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Antarctica is a remote and hostile continent, but the study of its environment is fundamental for the role that this continent has on the Earth's climate and oceanic environment. In the last years, in particular, the Antarctic science has focused on the effects of the global warming on ice loss. Actually, a recent study has shown that West Antarctica is one the fastest-warming places on Earth [1]. And an article published in 2018 [2] has also estimated the ice loss during the period from 1992 to 2017. Most ice loss occurred in West Antarctica and the Antarctic Peninsula.
To collect more information on this continent, a constant monitoring of the status and motion of the ice is necessary. This monitoring can be achieved through satellites. By means of them, in 2011, it had been published the first map showing how the ice moves across the entire Antarctic continent [3]. The measurements were made by radar instruments on satellites between 1996 and 2009 [4,5]. The mapping show areas which are moving as quickly as a few kilometers per year. And we can also see areas where the movement is of a few centimeters per year. As evidenced by the study, the slowest moving ice is along the divides, which are separating the glacier basins.
Several studies on moving ice in different regions of Antarctica have preceded this map of entire Antarctica. We have studies, such as that proposed in [6], which are based on the results of satellite radar interferometry (SRI), and those, such as [7], where Global Positioning System (GPS) data had been collected and used. In [6], it was the Lambert Glacier Drainage Basin under investigation; in [7], GPS observation data were concerning the Amery Ice Shelf. Other observations about Antarctica are given in [8-18].
Here will show that also in Google Earth imagery we can find evidences of the ice flows in Antarctica. We will focus in particular on the motion of those surface features, which are considered as the surface expression of basal crevasses.

Moving features
As stressed in [19], NASA has the Earth Observation Program, which is monitoring Arctic and Antarctic from many years. In the framework of this program, Operation IceBridge is an ongoing program of NASA which is studying the motion of the ice [20]. From 2003 to 2009, NASA used the ICESat satellite, which was retired in 2009. This fact was leaving NASA without a satellite dedicated to ice observance. The next-generation satellite, ICESat-2, was launched in September 2018. To maintain the annual observations of ice sheets, NASA introduced the IceBridge program, in order to "bridge the gap" between the satellite missions. The program utilizes aircraft platforms. IceBridge flights began in March 2009, for an Arctic Spring campaign, followed by the first Austral Spring campaign in October 2009 [20].
Operation IceBridge has spent much of the past decade monitoring the Antarctic ice sheet for signs

of cracks and flows [19], in order to determine how and at what rate the ice sheet is changing. Actually, the method is similar to that used for the sand dunes [21-24]. In these references [21-24], we discussed the use of the time series of satellite images (in particular of Google Earth) to follow the motion of the dunes. In the case of the ice flow, instead of observing the dunes, we can observe the motion of large ice cracks, crevasses, or other features, in the time series of images. Here in the following we shows some examples, using Google Earth imagery.

Amery Ice Shelf

The Amery Ice Shelf is a broad ice shelf in Antarctica. In [25], a map of the shelf is given. In the upper part of Figure 1, we can see an area of one of the glaciers - the above mentioned Lambert Glacier is one of them - which are flowing into the Amery Ice Shelf. In the lower part of the Figure 1, we can see two images from a time series of Google Earth, one recorded on 31 December 2013, the other recorded on 31 December 2016. The visibility of a part of these satellite images was enhanced by means of the GIMP Retinex filter. In this manner we can see clearly the crevasses in the ice. They are moving. The 2013 and 2016 images are combined in the panel on the right of Fig.1, in the manner discussed in [24]: we can see that these features moved of about 180 meters during the time interval of three year, that is, they moved of about 60 meters per year.

In the Figure 2, we can see some different features on the surface of the Amery shelf. After enhancing the Google Earth images by means of GIMP Retinex, we can see the presence of lines of surface deformation. These lines are almost perpendicular of the flow direction. In [26], it seems to me that these features are considered as crevasses.

In the Figure 3, we show the two panels of the Figure 2 combined, as discussed in [24], to evidence the motion of these ice surface features. The red segments point the position of the features on 31 December 2016, and the blue segments the position on 31 December 2013. We can see that these features moved of about 960 meters during the time interval of three year, that is, they moved of about 320 meters per year. Therefore, using a time series of satellite images, the motion of these features can be easily monitored.

High resolution images of basal crevasses

In [27], the study of the Larsen C ice shelf was proposed. The Larsen Ice Shelf is a long ice shelf, in the northwest part of the Weddell Sea, extending along the east coast of the Antarctic Peninsula. In particular, the Larsen Ice Shelf is a series of shelves in distinct embayments along the coast. Larsen C is the largest one. The ice shelf originally covered an area of 85,000 square kilometres, it now covers an area of 67,000 square kilometres [28]. In the Figure 4 we can see two images from Google Earth of the Larsen C Shelf. In [27], the textures are interpreted simply as crevasses. These features are the same textures that we have given in the Figure 2. In Ref.29, these features are proposed and discussed as surface expressions of basal crevasses. The Figure 5, obtained by a Google Earth time series, shows that they move.

In the case of the Larsen C Shelf, Google Earth gives us the possibility to observed the crevasse features with a high resolution. Here some of such images are given in the Figures 6 and 7. What is interesting is that these images can show the evolution of the features when they reach the edge of the shelf. We can see that the surface features become huge cracks in the ice. Further analyses by means of Google Earth are under consideration, to evidence other cases in the satellite images.

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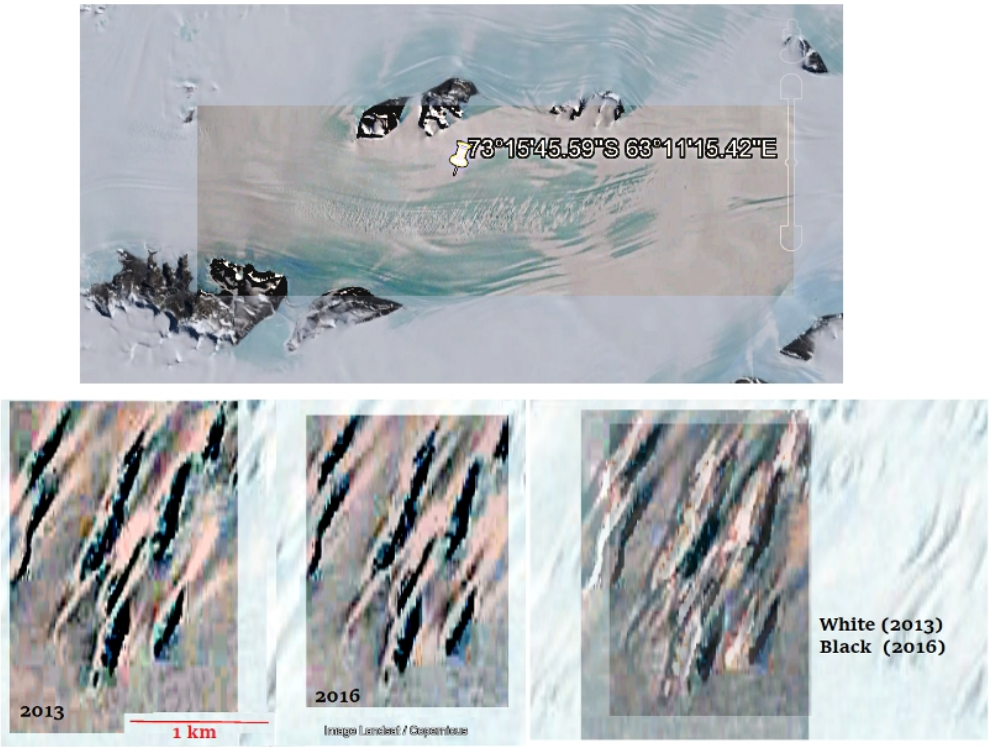

Figure 1: Ice flow of one of the glaciers flowing into the Amery Ice Shelf. The pin is at coordinates 73° 15' 45.59'' S, 63° 11' 15.42'' E. In the lower left panel, we can see an image of Google Earth, recorded on 31 December 2013; in the panel in the middle, we can see an image recorded on 31 December 2016. The visibility of a part of these satellite images was enhances by means of GIMP Retinex filter. This filter allows to improve the details in images. In this manner we can see the crevasses in the ice. They are moving. The two 2013 and 2016 images are combined in the panel on the right, in the manner discussed in [24]. In the panel, the crevasses as seen in 2016 are black, whereas the crevasses as seen in 2013 are rendered in white. We can see that these features moved of about 180 meters during a time interval of three year, that is, they moved of about 60 meters per year.

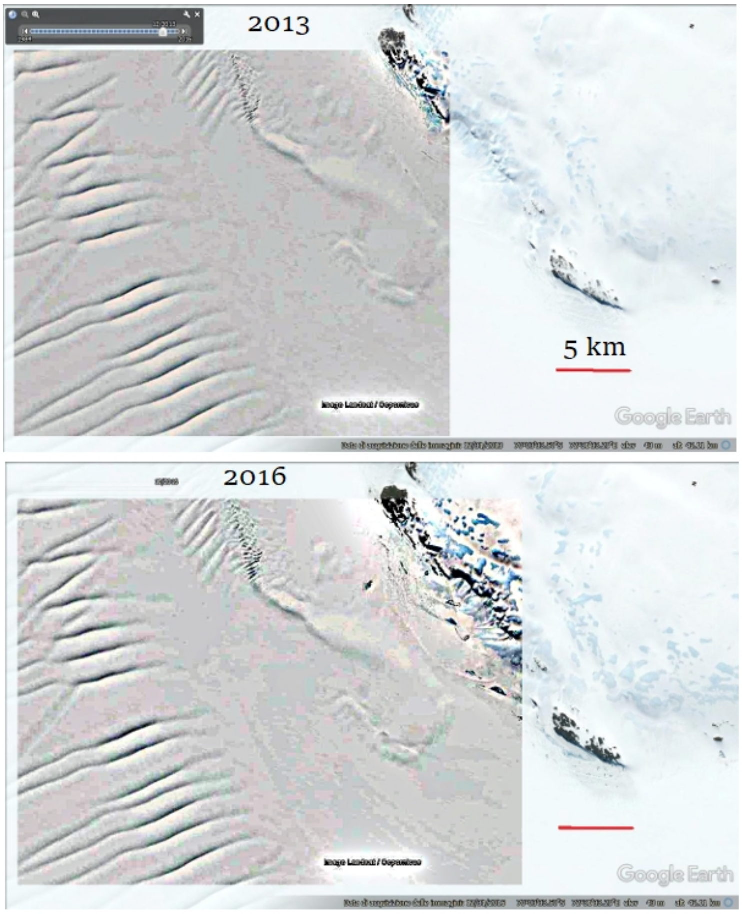

Figure 2: The upper panel shows an image recorded on 31 December 2013, the lower panel that recorded on 31 December 2016. The visibility of a part of the satellite images was enhances by means of GIMP Retinex filter. In this manner, we can see the surface features of the shelf. They are moving.

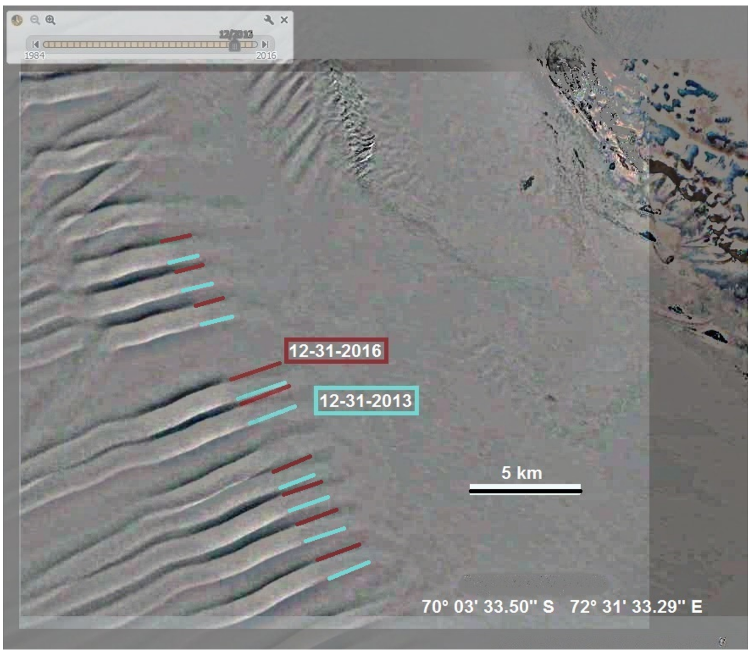

Figure 3: The image shows the two panels of Figure 2 combined, as discussed in [24], to see the motion of the ice surface features. The red segments point the position of the features on 31 December 2016, and the blue segments the position on 31 December 2013. We can see that these features moved of about 960 meters during the time interval of three year, that is, they moved of about 320 meters per year.

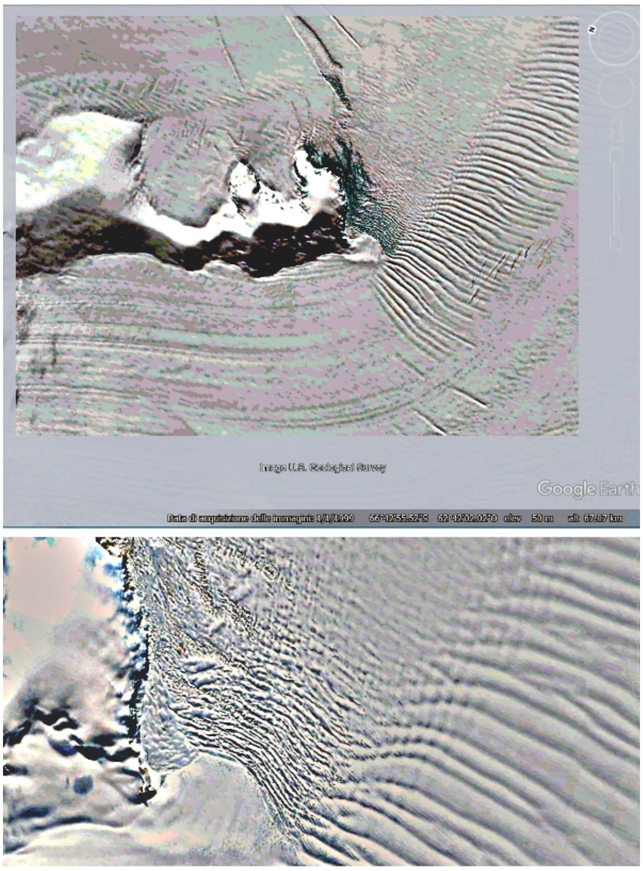

Figure 4: Images from Google Earth, enhanced by means of GIMP Retinex of the Larsen C Ice Shelf. We can see in the upper panel longitudinal and transverse surface features. A detail is given in the lower part. The transverse textures are interpreted as crevasses in [27] and basal crevasses [29].

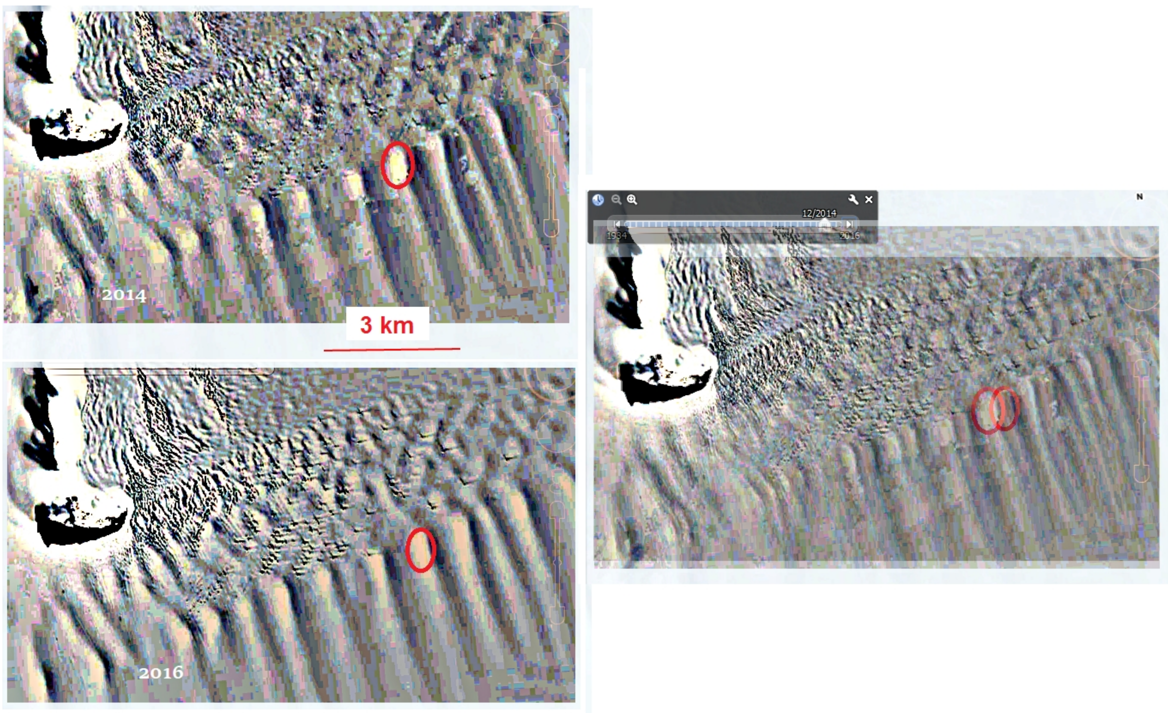

Figure 5: Two images of the time series of Google Earth (2014 and 2016) show the motion of the crevasses.

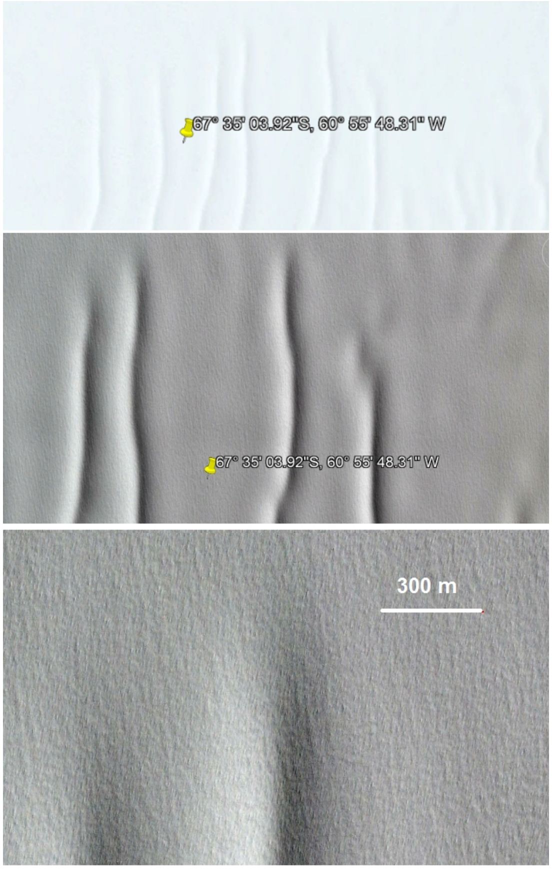

Figure 6: Images from Google Earth, enhanced by means of GIMP Retinex (coordinates 67°35’3.92’’S, 60°55’48.31’’W).

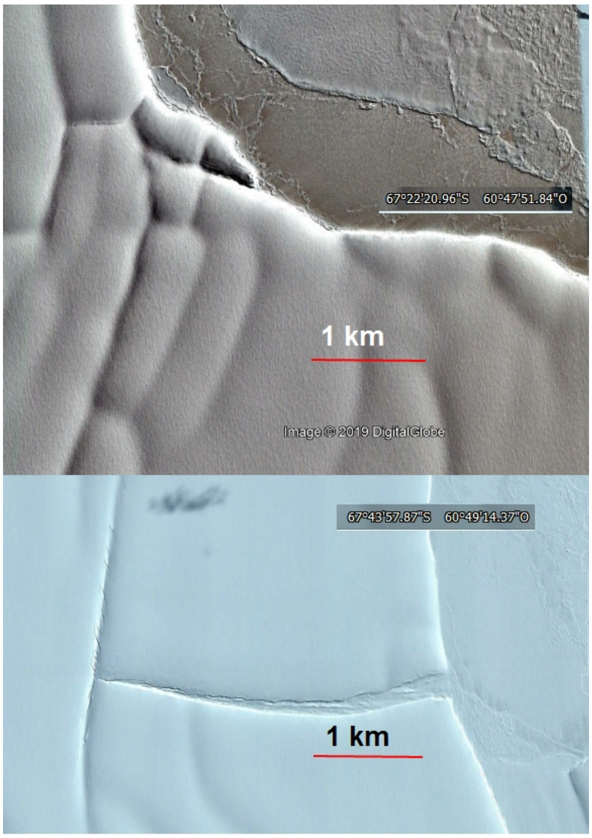

Figure 7: Thanks to Google Earth, we can see what happens to the features, shown in Fig.5, when they reach the edge of the shelf. Textures are interpreted as crevasses [27] and basal crevasses [29]. Upper panel: coordinates 67°22’20.96’’S, 60°47’51.84’’W. Lower panel: 67°43’57.87’’S, 60°49’14.37’’W.