Change Detection in Satellite Images Applied to the Study of Sand Dunes

Amelia Carolina Sparavigna[1]

1 – Department of Applied Science and Technology, Politecnico di Torino, Torino, Italy.

Abstract: In recent years the research on Change Detection, applied to data and images obtained by remote sensing from satellites, has collected a huge number of publications, as we can easily see using Google Scholar or Semantic Scholar engines. For this reason, any review of this large research area must be necessarily fragmented according to specific applications. Here we consider the study of the motion of sand dunes.

Keywords: Image Processing, Change Detection, Satellite Imagery, Climate Change, Sand Dunes.

The sets of time series of satellite images and data maps, which are reporting information collected by means of remote sensing technologies, are today the main datasets used in the research field of Change Detection. These sets of images and maps allow researchers to examine a given area over some specific periods of time, and determine the changes inside and investigate the related causes at the origin of variations. Besides monitoring the local environments, the trends extrapolated by the Change Detection can be used to forecast the evolution of the environmental conditions too. Not surprisingly therefore, we find, among the main subjects of the Change Detection, the analyses of deforestation, polar ice loss and all the global and local consequences of the Climate Change.

Several space agencies are contributing to provide time series of satellite images, useful for the previously mentioned problems. Images recorded on different dates can be statically compared or merged in a sequence, to obtain a multi-temporal image, by means of which we can easily observe the local changes. One of these agencies is ESA, the European Space Agency, which is running the Earth Watching Project. NASA, the National Aeronautics and Space Administration of the United States Federal Government, has service ARSET, Applied Remote Sensing Training, which offers a specific training to integrate the NASA Earth Science data into decision-making activities. Google, the American multinational technology company specialized in Internet-related products, has its service too. It is the Google Earth Timelapse, based on the time series of images in Google Earth.

The methods that we can use for a study of Change Detection can be roughly categorized into the two sets of supervised and unsupervised methods. The former set is based on supervised classification methods, which require additional information to obtain the desired features contained in the images or maps. The latter set performs change detection by means of a direct comparison of them, without incorporating any additional information [1]. As explained in [1], Change Detection by means of unsupervised methods uses the automatic analysis of change data, which are generally created as follow. First we have an image (or map) differencing. Then, this processing is followed by normalization and vector analyses [2]. Let us remember that image differencing-based algorithms accomplish the change detection by subtracting, on a pixel basis, the images acquired at two time instants to produce a new image called "difference image" [1]. The changes need to be identified in the difference image. Some methods to detect the changes in images, referenced in [1], are those given in [3-5]. Some recent works are given in [6-14].

In recent years, the research on the Change Detection collected a huge number of publications, as we can easily see using Google Scholar or Semantic Scholar engines. For this reason, any review of this large research area must be necessarily fragmented according to specific applications. Here we consider the study of the ***motion of sand dunes***.

The sand dunes are a subject which has attracted many studies from the first pioneering works made by Ralph Alger Bagnold [15]. Today, instead of local explorations as those performed by Bagnold, we can easily study the dunes by means of the time series of satellite images. We can obtain the size distribution of the dunes, their motion, collision, and evolution (see for instance, [16-18]).

Actually, sand dunes can move and, during their motion, they can be a problems for human activities. Moreover, on the motion of sand dunes the climate change can strongly act, with disastrous consequences for local communities, as shown in [19-22].

The motion of the dunes has been studied by Change Detection in [23-26]; the method of analysis is based on the difference of images (in [26], the dunes of the Kharga Oasis have been analysed; these dunes are also representing a problem for the archaeological remains of the Oasis [27]).

The method is the following [25]. Two satellite images A and B of a dune field, recorded at different times and converted in grey tones, are merged in an image C. From image A, a new image A' is obtained by inverting the grey tones of it. Reducing its opacity to 50%, A' is copied as a layer on B. A' and B gives image C, an image like that shown in the Figure 1. In C, the dunes of image A appear as bright dunes, whereas the same dunes, recorded at a different time, and given by image B, appear in dark tones. We can join the two positions of the brink of each dune by a red line, to obtain the displacement of the dune. Since we have the dates when images have been recorded, we can easily obtain the speed of the dunes.

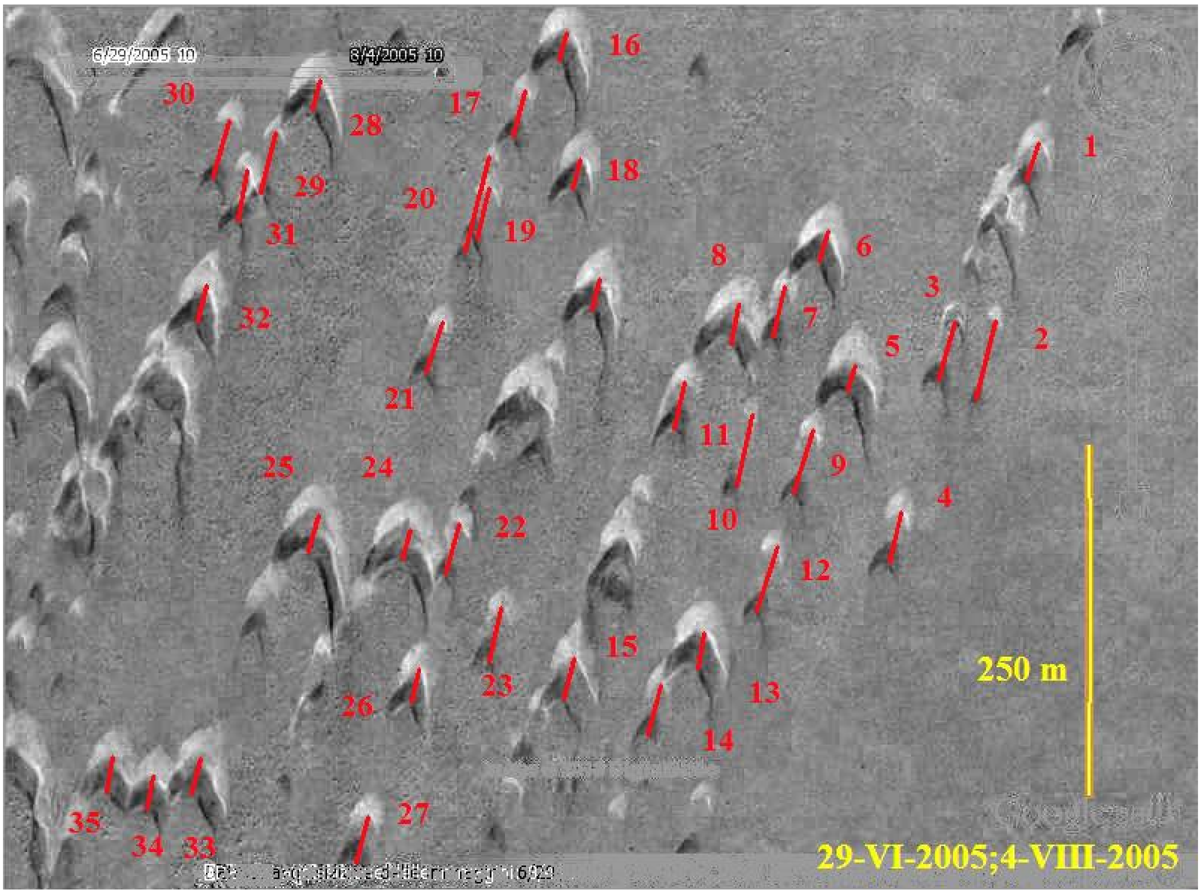

Figure 1: Dunes move, as we can see using the time series of Google Earth. See Ref.25 for more details.

Also the sedimentary patters of the dunes can be easily studied, by means of satellites [28-30] (see for instance the Figure 2). Moreover, the satellite images also show that the dunes can change their shapes, as it is happening for the barchans of the Laayoune-Sakia El Hamra region and Khenifiss National Park [31,32] (see the Figure 3). Is this a consequence of the Climate Change?

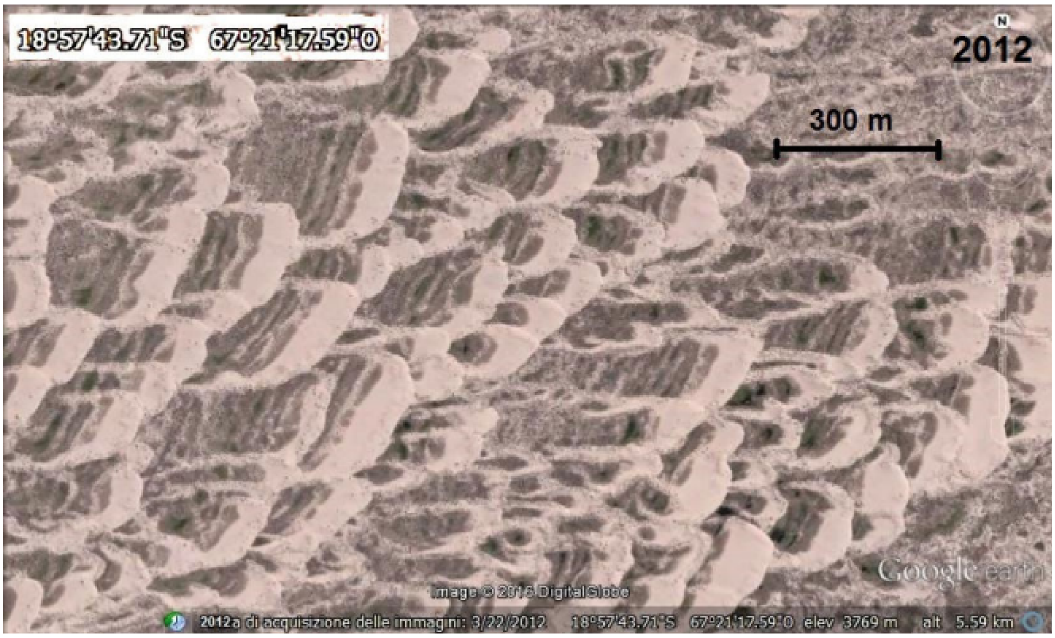

Figure 2: Sedimentary patterns of a dune field in Orinoca Canton, Bolivia. Note the “footprints” of the dunes (see [28]).

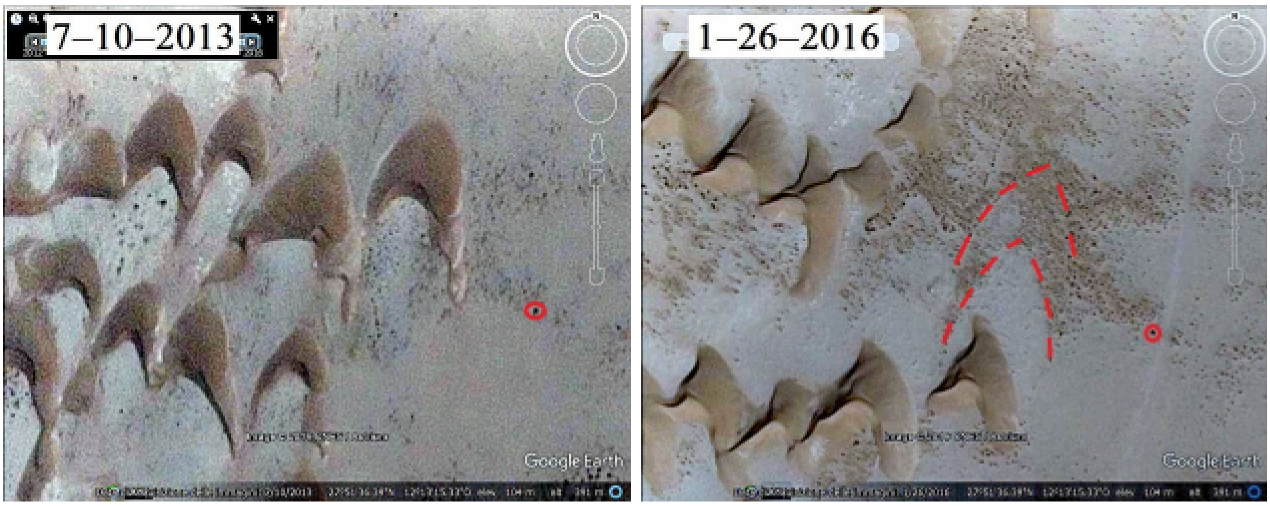

Figure 3: Barchans move and can change their shapes (the red circle is the reference point). Note the faint “ghost” shapes (marked in red) of the previous position and shape of a dune (more details in [31,32]). The change in the shape was driven by a variation of the direction of prevailing winds. Is this variation induced by the Climate Change?

The Change Detection among images can be performed by many different approaches. In [33], the images are compared by means of a Radon Transform. Features based on the Radon spectrum are used to cluster dunes of various orientations. The dunes studied are those of the Gobi desert. A GIS-based method for extraction of sand sea encroachment was used for the dunes of the Rigboland Sand Sea, Central Iran [34]. According to the authors, their proposed analysis of the remote sensing images can be an effective tool for the monitoring and prognostication of sand dune movement and sand sea change.

Statistical parameters obtained by satellite images and wind data are used in [35], for the dunes of the Mesr Erg region. In [36], the Ubari Sand Sea (Libyan Fazzan) is studied, by means of image overlay and differencing; the Root Mean Squared Error (RMSE) was used to determine if the mapped dune patterns were significantly different.

Of course, Change Detection is not only applied to satellite images. In [37], a digital image analysis procedure was adapted to extract multispectral data from sequential colour air photos of a Lake Huron sand dune system. UAVs, Unmanned Aerial Vehicles, are also used [38-41]. In [42], by means of GIS techniques, it is the change of the elevation profile of coastal dunes, which is investigated. In fact, highly accurate and densely sampled coastal elevation data can be obtained by means of LIDAR topographic mapping (airborne Light Detection and Ranging). In [43], the coastal dunes of Cape Hatters have been investigated using this technology. In general, we can tell that the study of sand dunes and of other subjects of the Aeolian Science is today receiving a large benefit from the recent advances in Aerial and Information Technologies [44].

To conclude, let us also note that the study of the sand dunes is not limited to Earth. Dunes are also present on Mars and they move [45,46]. Then, the Change Detection can be applied also for these dunes too (Figure 4). Examples were proposed in [47,48].

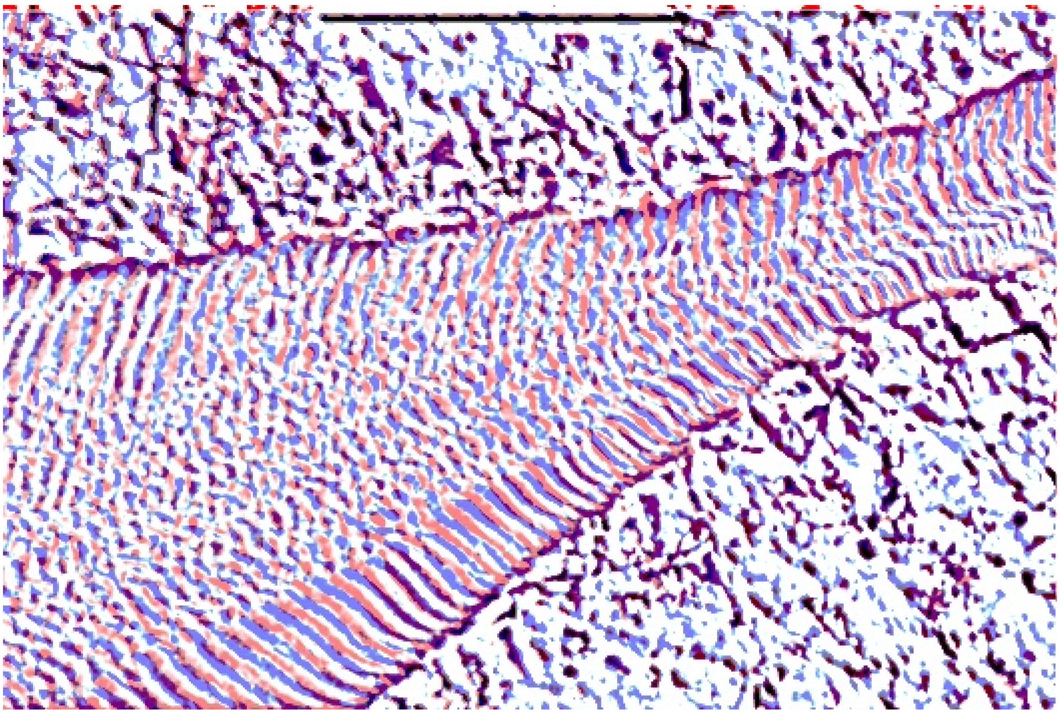

Figure 4: The red and blue pixels are showing the ripples on a dune in the Nili Patera Caldera on Mars, from two images recorded at different time by HiRISE, the High Resolution Imaging Science Experiment (Credit: NASA/JPL-Caltech/Univ. of Arizona/JHU-APL). See [25] for more details.

Mars is a sandy planet. The HiRISE camera on the Mars Reconnaissance Orbiter (MRO) is the powerful tool which is giving us detailed pictures of Martian dunes. On Mars, strong and sustained winds have been considered rare. However, in the case of the Nili Patera dune field, the dunes have unexpectedly high sand fluxes, similar to those we can find in Victoria Valley, Antarctica [49]. This fact induced the conclusion that rates of landscape modification on Mars can exist, similar to those observed on Earth.

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