Anno **2011**_Numero **181**

rapporti tecnici INGV

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Istituto Nazionale di
Geofisica e Vulcanologia

rapporti tecnici INGV

CAPTURING FULL RESOLUTION PERSPECTIVE AND STEREO VIEWS OF LARGE DEMS

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Introduction

When dealing with environmental studies, the morphology of the study area is of primary importance, and an effective visualization of the landscape under examination is crucial. Digital elevation models (DEMs) are thus key pieces of information for the rendering of geospatial data, and are the basis for the creation of effective three dimensional (3-D) views of data draped on the involved landforms [e.g. Wawrzyniec et al. 2007; Csatho et al. 2008; Zanchi et al. 2009]. This type of rendering is possible by using computer programs dedicated to environmental analysis. The recent boost in the use of virtual globes for scientific purposes underlines how 3-D data visualization over elevation models helps in geospatial data exploration and interpretation [e.g. Wright et al. 2009; Yamagishi et al. 2010].

Elevation models can be observed also in stereo mode. The basic principle is the same that human brain uses to create a 3-D perception of the world. The couple of images captured by eyes is a stereo pair which allows the reading of relative distances between observed objects. This concept brought about the classic examination of couples of aerial stereoscopic photographs in stereoscopy [e.g. Jordan and Cocquerez, 1995], and is also applied since decades to investigate remote sensing signals such as landsat images [e.g. Salvi, 1995].

A variety of programs can provide enhanced visualizations of DEMs and geospatial datasets draped on DEMs. Geographic Information System (GIS) programs (e.g. ESRI arcGIS), virtual globes (e.g. Google Earth) and remote sensing programs (e.g. ERDAS) are equipped to visualize on screen (or export to files) perspective views of landscapes with a good resolution. Nevertheless, the embedded visualization engines are not fully under the control of the user, which can freely change the viewpoint but cannot modify the view geometry (e.g. the amplitude of the angle of view). Moreover, when dealing with very large elevation datasets, the information relative to the elevation is often largely compressed, producing only a rough approximation of the input DEM. Most of the time this is not perceived as a drawback, because the target of these visualization engines is not the creation of high resolution images but to allow a fast and dynamic 3-D visualization. Nevertheless, when the purpose is the production of a full resolution perspective view of a DEM (in stereo or conventional format), for example to create a detailed layer for a custom GIS application or to derive a high resolution image for a large poster, off-the-shelf programs are inadequate, and a custom application such as the one described in the following is more appropriate.

We present here a method to capture views of images draped on DEMs from an arbitrary viewpoint, according to an arbitrary geometry (i.e. amplitude of the angle) and providing an arbitrary output image resolution. Output images can be obtained in stereo (anaglyph) format. This method is based on ViCam, a custom program acting as a virtual camera with unlimited lens and virtually limitless sensor resolution. ViCam can work in loop over an arbitrarily large dataset adequately formatted and structured, creating a single, seamless image layer of the whole input dataset, potentially keeping all the input details. This program has been extensively applied [Tarquini et al. 2007] and described in short by Tarquini et al. [2011]. In the present Technical Report we provide a complete description of the program that can be useful for researchers dealing with environmental studies and which could, in case, benefit for the use of ViCam (under request to the authors).

1. Method

The method to capture views of images draped on DEMs (or optionally anaglyph views) needs a specifically formatted input, as described in the next subsection. We used the GIS program ArcView 3.2 for the handling of geographic databases.

1.1 Input data

The principal input data is a DEM in grid format. Our method is especially devised to deal with very large elevation datasets, but works as well with ordinary-sized or small datasets. The concept of *"large size"*, when dealing with computer elaborations, depends on the performances of the available hardware/software facilities. Nowadays, considering a general purpose PC and standard software, handling a grid exceeding 20000×20000 cells may be complicated. In our method we overcame this constraint addressing large databases as a series of subsets [tiled structure, e.g. Tarquini et al. 2007]. Once the tiled structure is created, the program works on each single tile independently, and results are merged later. A relatively small DEM is handled as a single tile.

To run the camera, in addition to the DEM in grid format, a corresponding image is needed. The image must be collimated with the grid. This means that the grid and the image: (i) have the same cell/pixel size; (ii) are arranged in matrices of cells/pixels having the same number of rows and columns; and (iii) have the same geographic reference (at least within the tolerance of half a pixel). A straightforward example of an image collimated with a grid is a shaded relief image computed from the grid itself. In some cases GIS programs (e.g. ESRI ArcView) derive shaded relief images where pixels matrices are shifted by a half cell size along both X and Y axes with respect to the original grid. Instead of being a drawback this fact turns out to be useful when using ViCam, as explained in the following.

Considering a tiled dataset composed of a number N of tiles $t_0..t_N$, we define d_i as the DEM in grid format belonging to the t_i tile. As an example of collimated images, from each tile t_i, we derive an image h_i by applying the standard shaded relief function of ArcView 3.2. The input grid is therefore completely covered by collimated images.

1.2 Capturing images using ViCam

ViCam is a system to grab images in a virtual environment, hence it is a sort of virtual camera. To allow the projection of a vitual scene, the user must define a few geometric elements used by the program. In the reference system of the DEM, these elements are: (i) a viewpoint p_e (x_e, y_e, z_e); (ii) an observed point p_o (x_o, y_o, z_o); and (iii) a plane P orthogonal to the vector p_e-p_o, where the observed virtual scene is projected (**Figure 1**). On the P plane, we define a Cartesian coordinate system S centred on χ, which is the intersection between P and the vector p_e-p_o (**Figure 1**). Optionally, the coordinate system can be arbitrarily rotated. In practice, the S Cartesian coordinate system constitutes the virtual sensor of ViCam. A cell size s for S and a numbers of rows (n_r) and columns (n_c) for the output image are also fixed. The system is totally flexible, and by varying the relative positions of the points p_e, p_o and of the plane P with respect to the DEM, and considering also the dimension of the virtual sensor (given by n_r, n_c and s), an arbitrary angle of view is obtained. In other words, ViCam can virtually mount an endless series of lens, from an Hubble-like telescope to a fisheye, any kind of real-world physical constrains being absent in the virtual space. In particular, by setting an exceptionally large distance between the viewpoint and the target area and by setting the P plane close to the same target, the typical distortion due to the convergence of the linear light paths towards the viewpoint (which is a function of the field of view angle) can be arbitrarily reduced. This tip is useful to obtain particularly regular perspective images, where the ratio between the cell size s on the Cartesian reference system S on the P plane and the cell size of the input DEM are constant throughout the entire output image. In this case, by setting a cell size s equal (or very close) to the cell size of the input DEM, we can avoid both over-sampling and sub-sampling in the output image.
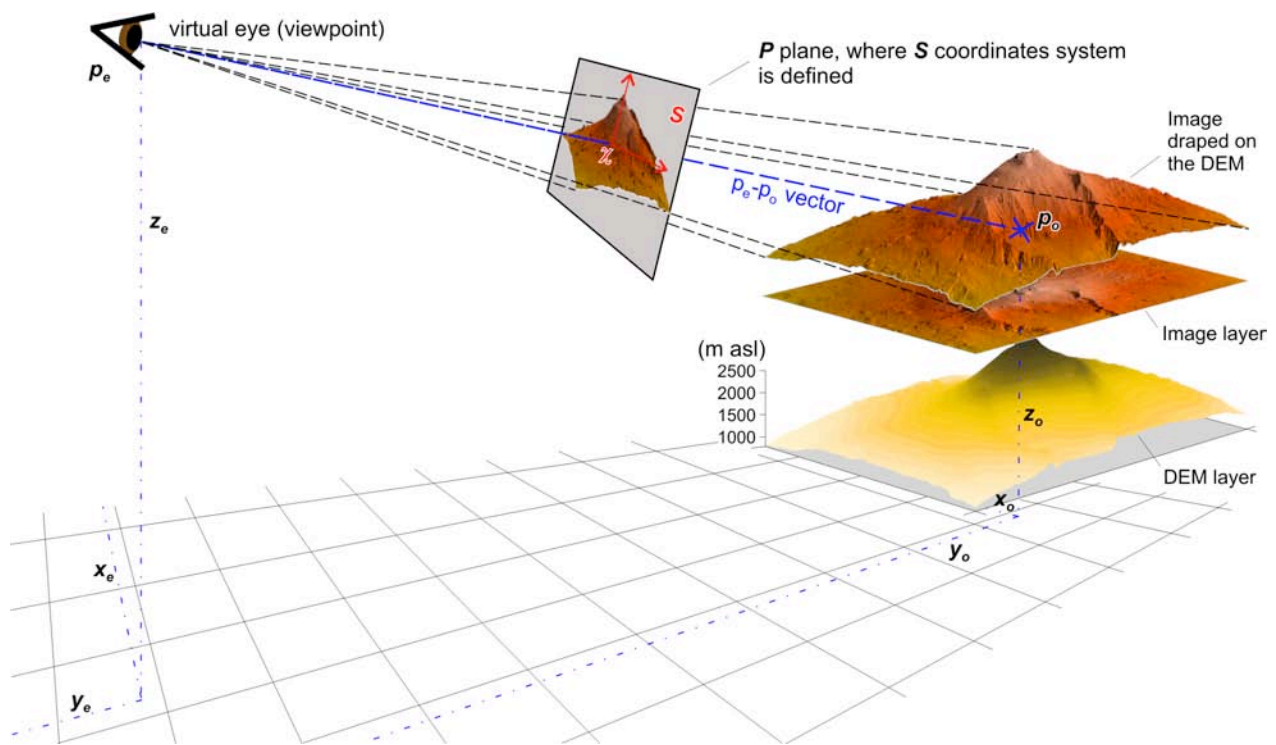
Figure 1. Sketch of the ViCam system. This example is the upper portion of Mount Etna (Sicily, Southern Italy). Data have been extracted from the TINITALY/01 database [Tarquini et al. 2007]. Vertical exaggeration is 2 ×. The grid on the bottom marks the geographic reference system of the input dataset.

Instead of working on a pixel basis, ViCam works on the basis of 3-D vector (polygonal) cells. A 3-D polygonal cell is obtained joining the nodes of four adjacent grid cells, each node being characterised by X-Y coordinates plus elevation (**Figure 2**). In particular, the considered polygonal cells are perfectly collimated with the pixels of the shaded relief images obtained by using ArcView, since these images are already shifted by a half cell. Any other image can be interpolated obtaining exactly the same format. Each elementary polygonal cell c_i is then spatially coherent with a single pixel of h_i and is assigned with the colour of that pixel. The projection of an elementary cell is as follows. Each vertex of c_i is projected along a linear light path to p_e; hence four vectors for each cell are used. These vectors intersect the projection plane P in four points which are the vertexes of the projected elementary cell c_{ip}. Each projected cell is also assigned with a value δ_i, which is the average distance of c_i from viewpoint p_e (the use of δ_i is explained in the next section). The same operation is repeated in loop for all the input elementary cells. Once the loop is completed, all the pixels of the S system on the P plane (**Figure 1**) covered by projected cells by at least half its area, are assigned with the colour of the c_{ip} overlying the biggest portion of that pixel. Alternatively, the values of the pixels on S can be determined by weighting all the colours of touching c_{ip} cells according to the relative portions of pixel area covered.
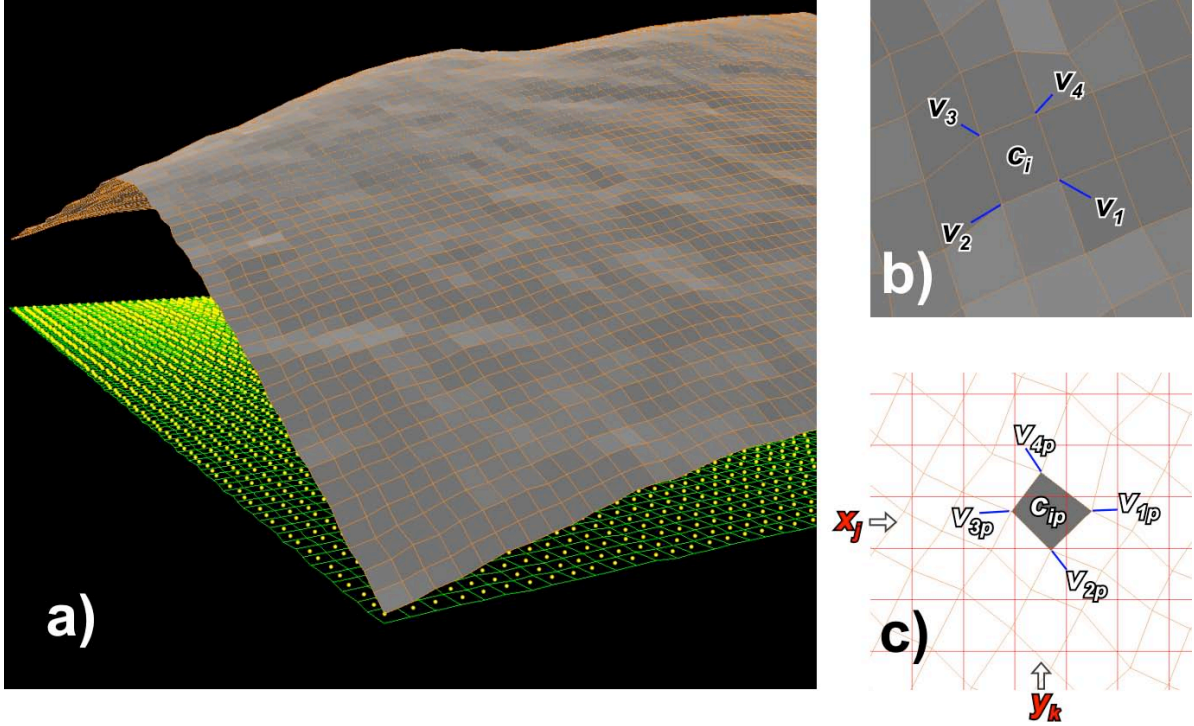
Figure 2. a) View of the vector 3-D cells used to project the image; on the bottom, yellow dots represent centroids and green lines boundaries of grid cells. 3-D cells are 3-D polygons created by joining 4 centroids of four mutually adjacent grid cells (each centroid being set at the corresponding cell elevation). The colour of each vector 3-D cell is given by the corresponding pixel of the image collimated with the grid. b) zoom on 3-D cells where the four vertexes $v_1..v_4$ of a generic c_i cell are labelled. c) the elements of b) projected on the S reference system; vertical and horizontal lines mark the pixels of the output image created by ViCam on S. Capturing an image means to assign every output pixel to a colour. If the criterion of maximum coverage is chosen, in this case the x_j-y_k pixel should be assigned to the colour of the c_{ip} cell.

1.2.1 z-buffering

So far, we have addressed the problem of the colour of individual pixels. But when dealing with the rendering of a perspective 3-D scene, the visibility problem is fundamental. The latter is the problem of deciding which elements of a rendered scene are visible, and which are hidden. We solved this problem by using the z-buffering algorithm (**Figure 3**). To assign a pixel in the output image (on the P plane), we check if that pixel has more than one attribution from several 3D cells (such as exemplified in **Figure 3**), and this pixel will be assigned with the colour carried by the cell having the smallest δ_i.

1.3 Tiled database: merging several projected images

By using the same geometry (i.e. a fixed viewpoint, plus all the ViCam parameters fixed), an arbitrary number of tiles of the input database can be processed, obtaining a projected image for each element in the same S reference system of the P plane. The same visibility problem described earlier for a single tile exists when projections of several tiles are combined together in a single image layer (**Figure 3**). To solve this ambiguity, the distances δ_i calculated by the z-buffering algorithm for each tile are stored in a dedicated grid $g_{\delta i}$ collimated with h_{pi}, and during the tiles merging procedure the z-buffering algorithm is applied again across overlapping projected tiles to solve the problem. The final result is a seamless layer representing the perspective view of all the h images draped on the input DEM.
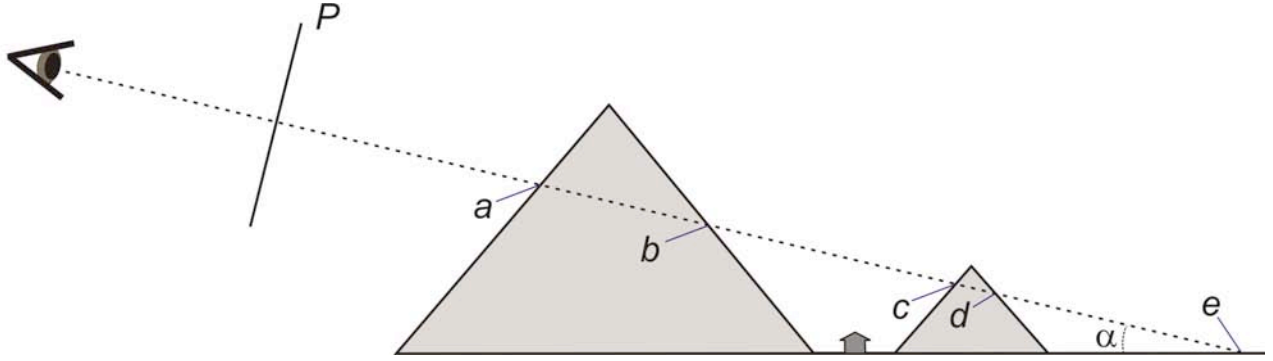
Figure 3. Simplified 2-D sketch of the z-buffering issue. Several points of the scene are intercepted by the light path (dotted line), but, if the observed scene is made of opaque bodies, only the first (i.e. nearest) point is actually visible, and hence recorded in the captured image. The first point has the shortest distance from the viewpoint (point *a*). If we hypothesize that the house drafted in the middle of the landscape is the boundary between two tiles, the merge of the two projections requires a further application of the z-buffering procedure. In this case the point *a* mask out the point *c* which was visible when the tiles where projected separately. The α angle is the elevation angle of the viewpoint.

1.4 Creating stereo images

We can use ViCam to capture two views targeting the same point p_o from two different eye positions p_{e1} and p_{e2}. A stereo-couple of images is obtained if the following conditions are satisfied: (i) the distance p_{e1}-p_o is equal to the distance p_{e2}-p_o; (ii) the angle p_{e1}-p_o-p_{e2} is in the range from a few degrees to tens of degrees; and (iii) all the others ViCam parameters are fixed to the same values. If an observer looks at a stereo-couple by seeing the right image with the right eye only and the left image with the left eye only, his brain perceives a 3D view of the captured scene.

The easiest and cheapest way to set up a stereo visualization is by creating an anaglyph. The latter was a pioneering technique in the second half of the 19th century, and it has been widely used in a very large spectrum of sciences since then, including Earth and planetary sciences [e.g. Stauffer and Haas, 1964; Keszthelyi et al. 2008]. In an anaglyph two images constituting a stereo pair are set in separate channel(s) of the output image (the anaglyph). If the anaglyph is observed wearing glasses filtering out the channel(s) representing one of the input stereo-pair for each eye, the observer's brain perceive the image in 3-D. The creation of an anaglyph is straightforward when the stereo-couple of images is in 8 bits grey-level format, because these images can be merged in a standard 24 bits RGB image by setting the left image in the R (red) channel, and the right image in the G (green) and B (blue) channels (or vice versa). To see an anaglyph in 3D, specific anaglyph glasses are necessary (easily available through the web searching for "*anaglyph 3d glasses*"). 8 bits, grey-levels, shaded relief images of a DEM are ideal to create an anaglyph image by using ViCam.

2. Case studies

In this section we show two applications of the described system. In the first one, we capture a single view of a high resolution lava flow hazard map for the Mount Etna [Italy, Favalli et al. 2009a] draped on the relative DEM. Being this database relatively small, there is not need of tiling, but the flexibility of ViCam allows capturing images with enhanced characteristics with respect to some conventional programs. In the second case, instead, we just recall the application of ViCam over the very large TINITALY/01 DEM arranged in tiles [Tarquini et al. 2007], already presented by Tarquini et al. [2011].

2.1 Hazard map for Mount Etna

Favalli et al. [2009a] published a new high resolution lava flow hazard map for the whole Mount Etna based on the DOWNFLOW simulation code [Favalli et al. 2005]. As pre-emplacement topography a 10 m-resolution DEM dating back to 2005 was used [Favalli et al. 2009b], obtaining a 10 m-resolution hazard

map. We apply the described procedure to capture an image of the hazard map viewed from the South draped on the DEM (**Figure 4a**). We set a viewpoint at a very large distance and given the relatively small captured field (about 20 km wide), this means that the ViCam system is set to an extreme telephoto lens and the viewed scene is uniformly affected by the same perspective distortion. That way, points on the foreground and in the background of the projected image have the same scale. Our system does not compress the DEM, and we can capture the landscape morphology recorded by the DEM at any desired resolution. The optimum resolution is obtained if we set the projection P plane just above the ground surface and the size of the pixel on the S reference system (hence for the output image) equal to the size of the pixel in the input image and DEM (i.e. 10 m, in this case).

The obtained result is compared with an image of the same map captured by using the freeware Google Earth (GE, **Figure 4b**). The hazard map was loaded on GE as explained in Tarquini et al. [2008]. The GE viewpoint is moved to capture roughly the same area from approximately the same direction used above. Nevertheless, it is impossible to modify the settings of the GE virtual camera to zoom towards a target scene from a higher distance (to obtain a smaller angle of view). The result is that the obtained image is affected by a relevan distortion due to the wide angle of the field of view. The distance from the target scene in GE is fixed by the default onboard camera settings. In the case of **Figure 4b**, the distance between the viewpoint and the target scene is about 5000 times smaller than the one used in **Figure 4a** by ViCam.

By looking at specific features in the two scenes (**Figure 4**), it is evident that while the GE graphic engine uses a very compressed DEM which largely flattens the actual landforms, ViCam adequately renders the details of local morphology recorded in the input DEM. So far, the terrain model used by GE is the SRTM DEM [e.g. Crippen et al. 2007], which has a much lower resolution and accuracy than the DEM used by Favalli et al. [2009b]. Nevertheless, the effect of the compression forced by GE is evident.
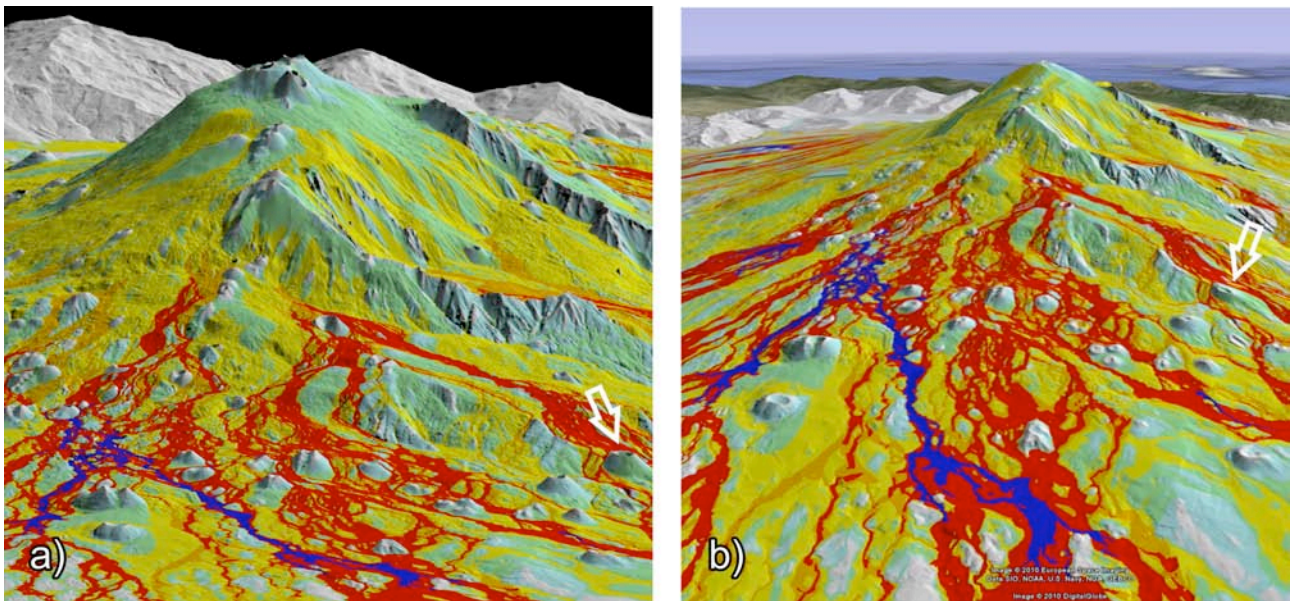

Figure 4. Two images obtained by capturing a perpsective view of the lava flow hazard map for Mount Etna [Favalli et al. 2009]: a) an image captured by using ViCam, b) an image captured by using Google Earth. The two images have been acquired from two viewpoints approximately set along the same direction, but the strikingly different angles of view originate fairly different results. White arrows point to Mount Ilice. It is evident that while the fast graphic engine onboard of Google Earth has completely flattened the actual topography, ViCam perfectly renders the shape of the cone. The black background in a) is because the computational domain is restricted to the volcano edifice (no-data values outside). As for the legend of the hazard map, the darker the colour the higher the probability of inundation by future lava flows.

2.2 The TINITALY/01 DEM

TINITALY/01 is a DEM in Triangular Irregular Network format (TIN) obtained for the whole Italian territory in the UTM 32 WGS 84 coordinate system [Tarquini et al. 2007]. The irregular mesh of the TIN

format is intrinsically adaptive and preserves input details. The standard Delaunay TIN format was refined applying the DEST algorithm [Favalli and Pareschi, 2004]. The final DEM was obtained by painstakingly cleaning-up a heterogeneous input dataset as described in Tarquini et al. [2007].

The preparation of the TINITALY/01 DEM in the suitable tiled format and the following application of the ViCam software to obtain stereo views of the whole Italian territory (**Figure 5**) have been already described by Tarquini et al. [2011]. Here we just recall that the thorough DEM database in 5 m-cell size grid format occupy about 50 Gb of disk memory, resulting a perfect test case to verify the performance of our method. The obtained results can be viewed online at http://webgis.pi.ingv.it/.
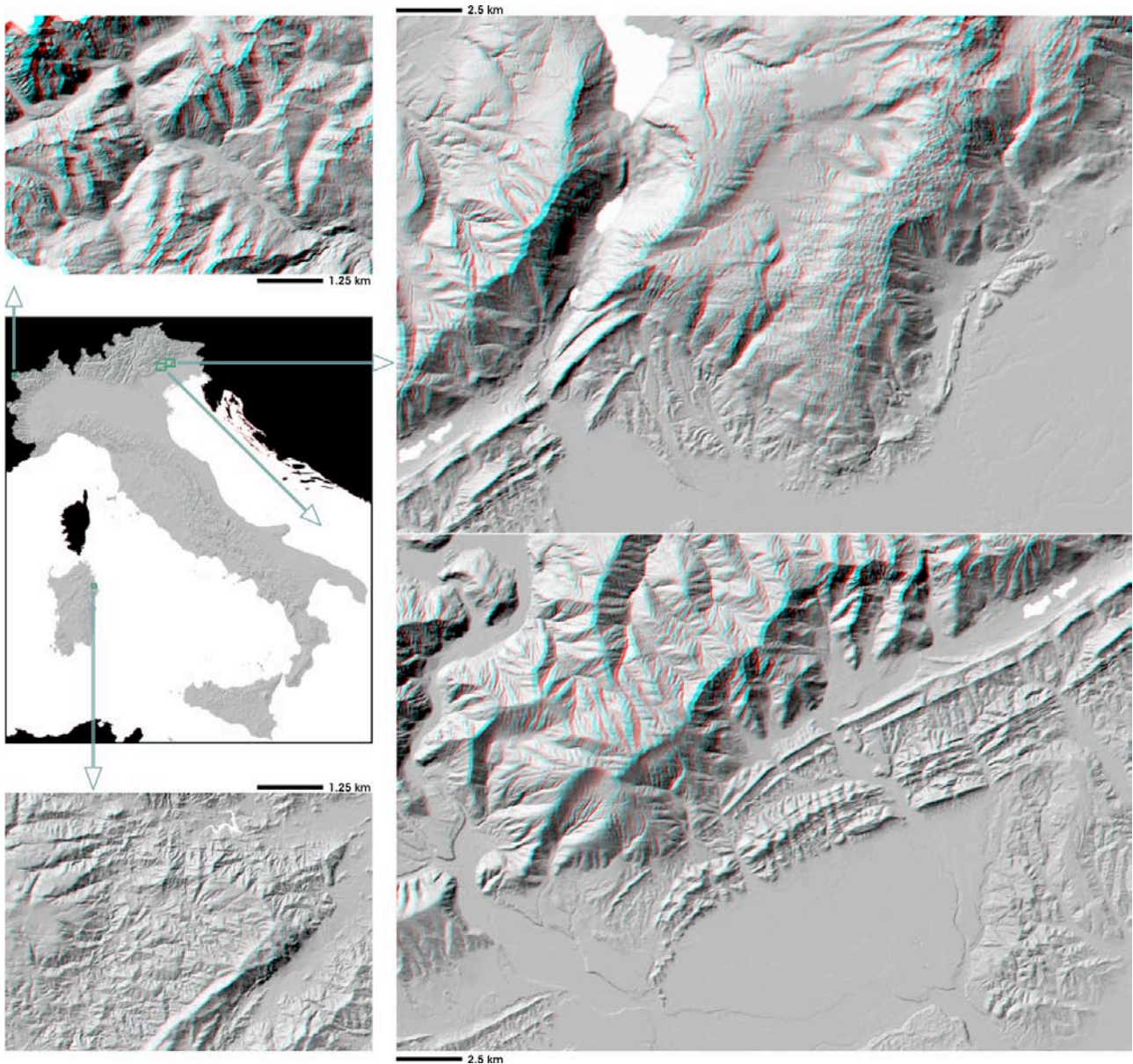

Figure 5. Anaglyph images obtained by viewing the TINITALY/01 DEM from an almost nadiral viewpoint.

3. Concluding remarks

The rapid development of Earth observation technologies and the availability of increasingly large amount of raster and elevation datasets [e.g. Hayakawa et al. 2008] boosted the development of a large spectrum of software focusing on dynamic and static 3-D visualizations of large DEMs and corresponding images. The result is the breakthrough of visualization engines which mostly uses compressed versions of the elevation datasets.

The program here presented can be used when both extremely zoomed views (i.e. low distortion) and full resolution visualization of very large raster databases draped over DEMs are needed. The presented method is an alternative when the rendering of a DEM with related geospatial information must display all the details of the input dataset.

Acknowledgements

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