Aeromagnetic and radiometric data filtering at the Vesuvian Volcanic Area

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ABSTRACT In this paper we present an application of denoising techniques to the high-resolution aeromagnetic and radiometric data measured in 1999 in the Vesuvian Volcanic Area, southern Italy. The helicopter-borne survey aimed at giving new detailed insights into the distribution of the magnetization and of the main radionuclides of the area and, therefore, into the volcanological characteristics of the region. The surveyed area is characterized by the presence of towns and buildings and an extensive network of railway lines which affected the measurements and were responsible for some of the anomalies measured. In order to warrant a reliable interpretation of the data, it was therefore necessary to filter out this cultural noise. The denoising was performed by a powerful method based on the discrete wavelet transform, whose excellent space-scale localization properties lead to a very sharp and space-localized filtering. The comparison between the filtered maps and known geological sources located in the area by other geophysical and geological constraints led to the identification of some of the main magnetic and radiometric features of the Vesuvian Volcanic Area.

1. Introduction

High-resolution aeromagnetic and radiometric surveys are used increasingly for studying active volcanic areas. Both methods are in fact very effective in environmental monitoring and geological mapping. Aeromagnetic surveys have proven very useful in several applications regarding regional and near-surface investigations. These applications include mapping the basement under sedimentary basins for oil exploration, investigating water resources and studying areas characterized by environmental and land-use problems (e.g., Cordell and Grauch, 1985; Glenn and Badgery, 1998; U.S.G.S., 1999). The study of the aeromagnetic field of an active volcanic region can provide useful information about the subsurface magnetization distribution allowing significant insights into the geo-structural and volcanological characteristics of the area. Meaningful studies of the structure of volcanoes by aeromagnetic surveys have been carried out, e.g., on the Island of Hawaii (Hildenbrand *et al.*, 1993), Mt. St. Helens (Finn and Williams, 1987), Unzendake Volcano (Nakatsuka, 1994), the Campanian Volcanic Area (Florio *et al.*, 1999), the Canary Islands (Arana *et al.*, 2000), Mt. Rainier (Rystrom *et al.*, 2000; Finn *et al.*, 2001), Yellowstone National Park (Finn and Morgan, 2002) and the West Antarctic Rift System (Ferraccioli *et al.*, 2002).

Airborne gamma-ray measurements are usually presented as total activity and equivalent ground concentration of Uranium, Thorium, Potassium and other radionuclides. This kind of survey represents a quick and effective tool for mapping large areas, with many applications in environmental monitoring (Akerblom, 1995; Barnet, 1995; Damkjaer and Korbech, 1998) and in geological characterizations (Grasty and Shives, 1997; Billings, 1998; Gunn *et al.*, 1999). More specifically, it can be used to: *i*) contribute to a better understanding of the surface and the shallow subsurface geology; *ii*) define the distribution of natural and anthropogenic radionuclides; *iii*) identify regions prone to high indoor radon levels; *iv*) identify pollution of ground and wastewater from industrial and waste sites; *v*) check map radioactive fallout from nuclear accidents and contaminant plumes from power plants (Lee *et al.*, 2001).

Many active volcanic areas are located in densely populated regions and this has made the study of their structural and volcanological features by air-borne methods increasingly frequent and important in recent years. This is because of the advantages of this kind of survey with respect to ground ones; i.e. the higher speed for collecting data and the better spatial coverage, allowing the surveying of areas inaccessible to ground work. As is well known, the Vesuvian Volcanic Area is one of the most dangerous in the world because of its mainly explosive eruptions and of its location in a very densely populated area. For these reasons several studies on its structural and volcanological characteristics by both potential fields and radiometric methods were carried out recently (Capaldi *et al.*, 1982; Berrino *et al.*, 1998; Fedi *et al.*, 1998; Cella *et al.*, 2003). Somma-Vesuvius is a strato-volcano characterized by products of both explosive and effusive eruptions highly enriched in radioactive elements and Potassium (Oversby and Gast, 1968; Capaldi *et al.*, 1980, 1982). The $^{226}Ra/^{238}U$ ratios in the Vesuvius lavas are 2-4 times higher than in any other measured volcano. The Ra, U and Th enrichment trends show that these elements came largely from a region wider and geochemically different from the magmatic source of the major elements (Capaldi *et al.*, 1982). The authors therefore proposed that the Ra, U and Th could be introduced from fluids of a deep origin, rich in these elements. This complex, formed by an older volcanic center (Mt. Somma) and a more recent one (Mt. Vesuvius), is located in an area where a sedimentary, carbonate basement sinks to depths of a few thousand meters b.s.l., as shown by gravity methods (Carrara *et al.*, 1974) and seismic reflection data (Bruno *et al.*, 1998). The Trecase1 well, drilled inside the Vesuvius volcanic area, detected the sedimentary basement at about 1700 meters b.s.l. (Bernasconi *et al.*, 1981). The last eruption was in 1944 and closed a period of considerable activity begun with the violent 1631 eruption. After the 1944 eruption, which caused the conduit to remain closed, a quiescent period started. Rock magnetism measurements from Mt. Somma, Vesuvius and Trecase1 well (Cassano and La Torre, 1987) showed intense magnetization ranging from 6.8 A/m (lavas from Vesuvius) to 0.5 A/m (tuffs), with an average Koenigsberger ratio of about 8.6 and a total magnetization vector aligned in the direction of the present field.

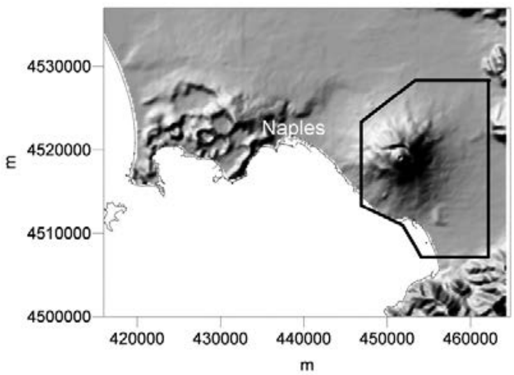
In regions characterized by a high density of urbanization like the Vesuvian area, the data quality is subject to an intense level of noise that in some cases may be of relevant amplitude, enough to mask features of geological origin. Magnetic cultural noise can be characterized by singular anomalies caused by drill platforms (Muszala *et al.*, 2001), farms (Cuss, 2003), water tanks, industrial buildings and landfills (U.S.G.S., 1999), or by linear magnetic features connected to pipelines (Gay, 1986; Cuss, 2003), railway lines (Linington, 1974; Fedi *et al.*, 2003), power-lines (U.S.G.S., 1999; Gharibi and Pedersen, 2000), roads (Cuss, 2003). In radiometric surveys, cultural noise coming from urbanization interferes with, and often masks, natural signals. For example, the use of mining wastes in construction causes manmade radiation in urbanized areas such as towns, villages and roads (Lahti *et al.*, 2001). In volcanic areas, where tuffs and other rocks highly enriched in radioactive elements are used for construction of buildings and roads, these manmade structures generate radioactivity and are clearly outlined, masking the natural signal (Pinto *et al.*, 2005).

In this paper, we apply localized filtering techniques based on a discrete wavelet transform algorithm (Fedi and Quarta, 1998) to the high-resolution aeromagnetic and radiometric data measured in the densely populated Vesuvian Volcanic Area in 1999.

2. The aeromagnetic and radiometric data of the Vesuvian Volcanic Area

2.1. Technical and logistical characteristics of the survey

The helicopter-borne survey, carried out by the Geological Survey of Austria (Supper *et al.*, 2001), covered an area of about 15 by 21 km (Fig. 1). The profile lines, with a N-S azimuth, were spaced about 600 m apart, while the cross-track tie lines were about 2 km apart. The sample spacing along each line was about 4 m. Regarding the flight altitude, data acquisition was along a surface roughly parallel to the topography of the area (draped acquisition), with a clearance varying between 150 and 200 m. This survey layout is usually adopted in high resolution surveys and according to Bhattacharrya and Chan (1977) allows to minimize the effect of a magnetized terrain on the data. It is worthwhile mentioning that Grauch and Campbell (1984) note that the effect of a magnetized terrain is still present in the case of draped acquisition.



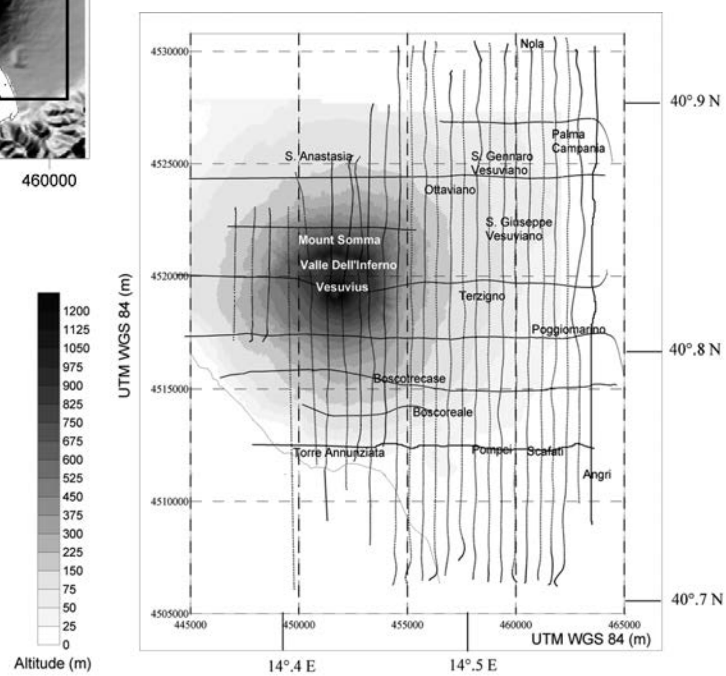


Fig. 1 - Flight lines of the draped helicopter-borne survey performed in October 1999 in the Vesuvian Volcanic Area. The profile lines (with azimuth N-S) are 600 m apart, the tie lines (with azimuth W-E) are about 2 km apart and the sample spacing along the flight lines is about 4 m. Due to the cultural noise of the area, the satellite signal used by the GPS was not detectable in the area placed west of 14°, 43 of east longitude. Coastline in black.

The equipment used for the survey was supplied by the Geological Survey of Austria and consisted of ground and flight instruments. Among the ground devices two magnetometers were used to monitor the external field activity during the flights and a GPS reference station was used for the differential correction of satellite data. The flight section consisted of: (i) a Cesium magnetometer having a precision of 0.01 nT, contained in a "bird" towed 30 meters below the helicopter; (ii) a Global Positioning System (GPS) sensor for the horizontal positioning, having a precision of ± 1 m after the differential correction; (iii) a laser-altimeter for the vertical positioning (with an accuracy of 10 cm); (iv) a NaI crystal detector to measure natural radioactivity; (v) an infrared camera to evaluate the area's thermal characteristics (temperature range: -20°C – 450°C); and (vi) a computer for data acquisition.

2.2. Data processing

The magnetic data processing allowed several data corrections and included the following steps: (i) removal of spikes and gaps in the data; (ii) flight path check and re-positioning, which consisted in the removal of wrong coordinates and double records, differential correction of the GPS data and check of the flight altitude; (iii) Earth's magnetic field diurnal variation corrections (these were also performed using the magnetic data of the Observatory of L'Aquila, Italy, as the magnetic data of the local base stations were often disturbed by the cultural noise of the area); (iv) removal of the IGRF (International Geomagnetic Reference Field); (v) statistical leveling, consisting in a minimization of the differences between values measured at the crossing points between flight lines and tie lines; (vi) decorrugation, a directional filtering to remove the directional anomalies still present along the flight lines.

The gamma-ray data processing included the same first two steps of the magnetic data processing and furthermore: (i) stripping ratios applied to correct Compton scattering; (ii) removal of the cosmic background; (iii) altitude correction, applied to reduce data to an average survey height.

2.3. The aeromagnetic map of the Vesuvian Volcanic Area

The map of the magnetic data measured in the Vesuvius area (Fig. 2), gridding the data to 300 m intervals, is dominated by a large dipolar anomaly (amplitude of about 2500 nT) clearly related to the Somma-Vesuvius complex and characterized by a roughly elliptical shape elongated towards south. Remarkable features of the area at the base of the edifice are a narrow anomaly on the western slope of the edifice (A in Fig. 2) and an irregular shape of the anomaly on the south-eastern slope of the volcano in the area of Boscotrecase and Boscoreale. Here, we observe some small anomalies (B, C and D in Fig. 2). Finally, in the area NE of the edifice, we notice an elliptical anomaly (E) and a general radial trend of the field. The presence of a double minimum in the summit area of the volcano, a bigger one placed north of Mt. Somma and a smaller one placed above Valle Dell'Inferno, seems due rather to altitude variations of the helicopter, as observed in a synthetic model reproducing the geometry of the data acquisition and the topography of the volcano.

The areas surrounding the edifice are characterized by many high-frequency anomalies, which may be partly connected to the high cultural noise in the densely inhabited Vesuvian area. This area is in fact characterized by the presence of towns and buildings and an extensive network of railway lines, which affect the magnetic field and are responsible, at least in part, for some of the measured anomalies. Previous studies (Linington, 1974) showed that the presence of electrified railway lines creates a magnetic dipole effect caused by currents flowing through the overhead voltage line and returning through the running rails. These train-induced signals, whose intensity and frequency varies with the position and number of the trains and the amount of current used by the trains (Larsen *et al.*, 1996; Buccella and Feliziani, 2003), may therefore cause intense dipolar magnetic anomalies aligned along the railway line (Iliceto and Santarato, 1999). A further magnetic disturbance is connected to the currents dispersed through the ground as a direct result of the rail-Earth connections along the railway line (Senanayake, 1990). This secondary magnetic effect is controlled by local subsoil geological features .

The surveyed area has a main and secondary railway lines (see Fig. 2), which basically differ by the number of trains running along the electrified line and for the amount of current used by the trains. These differences are responsible for a different degree of disturbances in the magnetic

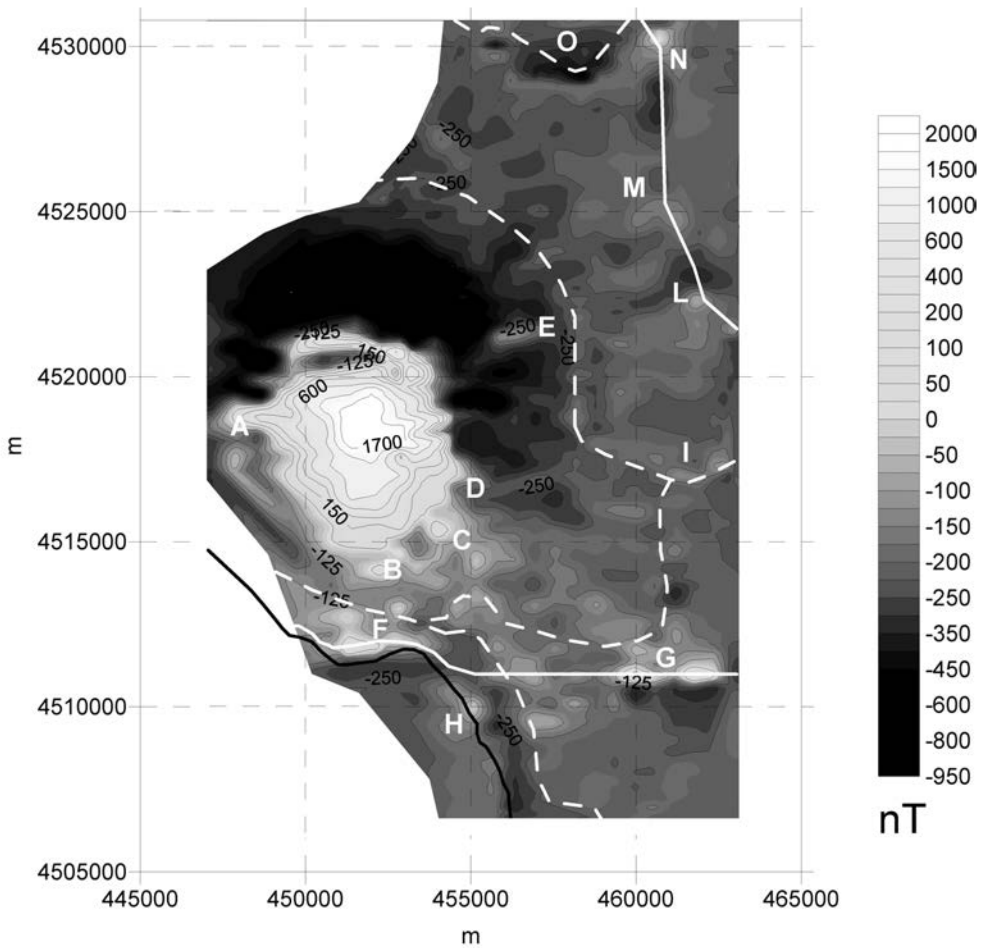


Fig. 2 - The new magnetic map of the Vesuvian Volcanic Area obtained from the aeromagnetic survey performed in October 1999. The solid white lines show the main railway lines and the dashed white lines show the secondary railway lines. Coastline in black. For location of the anomalies see Fig. 1.

field measured in correspondence to the railway lines, as can be observed in Fig. 2. The noise along the main line is characterized by a larger amplitude than one in correspondence to the secondary line.

Among the anomalies measured in the Vesuvian area in correspondence to railway lines, we notice two reversed anomalies of amplitude of about 250 nT in the Torre Annunziata and Pompei-Scafati regions (F and G in Fig. 2), which seem to be aligned along a W-E trend and are placed along the main railway line. Other anomalies in correspondence to the main railway line and characterized by an amplitude of about 100 nT (see Fig. 2) are those in the areas between San Giuseppe Vesuviano and Palma Campania (L and M) and south of Nola (N). As regards the anomalies in correspondence to the secondary railway lines, besides a number of high frequency ones, we notice the anomalies in the areas of Poggiomarino (I) and west of Nola (O).

Since these train-induced signals may mask magnetic features of geological origin, a reliable interpretation of the local magnetic features can be warranted only by a localized denoising of the data aimed at reducing the influence of the railway lines.

2.4. The radiometric maps of the Vesuvian Volcanic Area

The maps of total count, Uranium and Potassium (Figs. 3, 4, 5), are characterized by both the presence of cultural noise due to the urbanization of the densely populated Vesuvian area and by a high frequency signal due to the different lava flows of the area. Nevertheless, all the maps show a circular anomaly corresponding to the caldera rim and a sharp positive anomaly located on the top of the 1944 lava flow.

The presence of the lava flows of the area masks the signals related to the regional trends which could provide insights into the structural characteristics of the whole volcanic area. Therefore, in order to allow a better identification of the main geological features and environment implications of area we filtered this high frequency signal.

3. Wavelet analysis for the local separation of potential field anomalies and filtering of gamma-ray data

The filtering was performed by a powerful method based on discrete wavelet transform (Fedi and Quarta, 1998). Its main performance among other methods is that the analysis can be carried out with mathematical models characterized by both a frequency and a space resolution. This is important, especially when compared with Fourier methods which have good frequency resolution but no space resolution. A specific space-scale wavelet analysis, called multi-resolution analysis, allowed the decomposing of the signal with respect to a vast range of scales. The most appropriate basis was chosen by requiring the maximum compactness for the multiresolution analysis. Since such analysis is not shift-invariant, the same criterion was applied to choose the best signal shift too. In the case of potential fields, good bases are the interpolating and the triangular, which are both biorthogonal (Fedi and Quarta, 1998). In fact, their shape is rather consistent with the shape of simple anomalies. The algorithm used automatically identifies the wavelet coefficients by simply specifying the sub-area coordinates, this one having any desired shape. The excellent space–scale localization properties of the wavelet bases allowed a very sharp and space-localized filtering, leaving the field in adjacent areas unchanged.

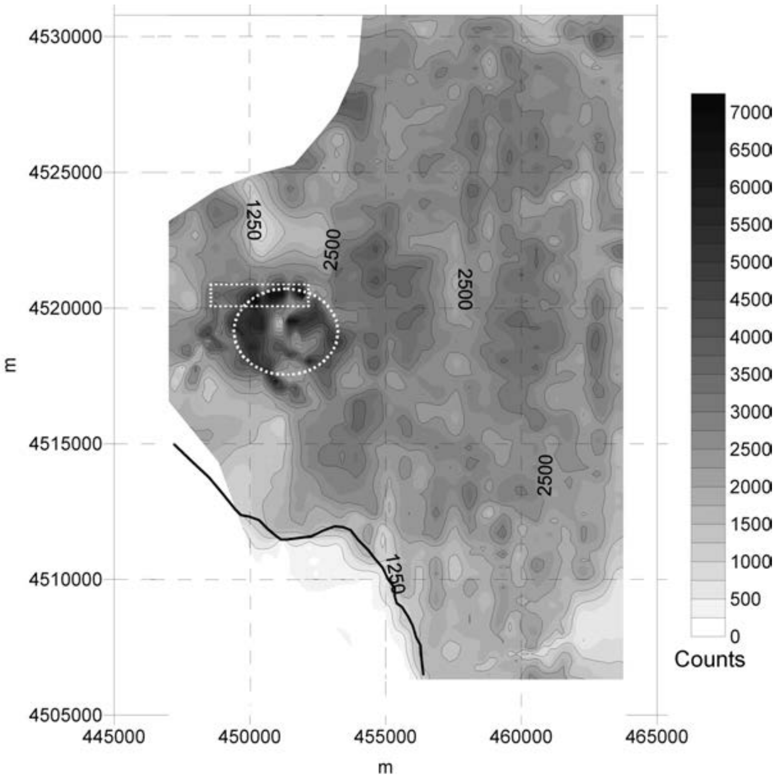


Fig. 3 - Map of distribution of total gamma emissions from Vesuvian rocks and soils. The white dots show the caldera rim and the 1944 lava flow. Coastline in black.

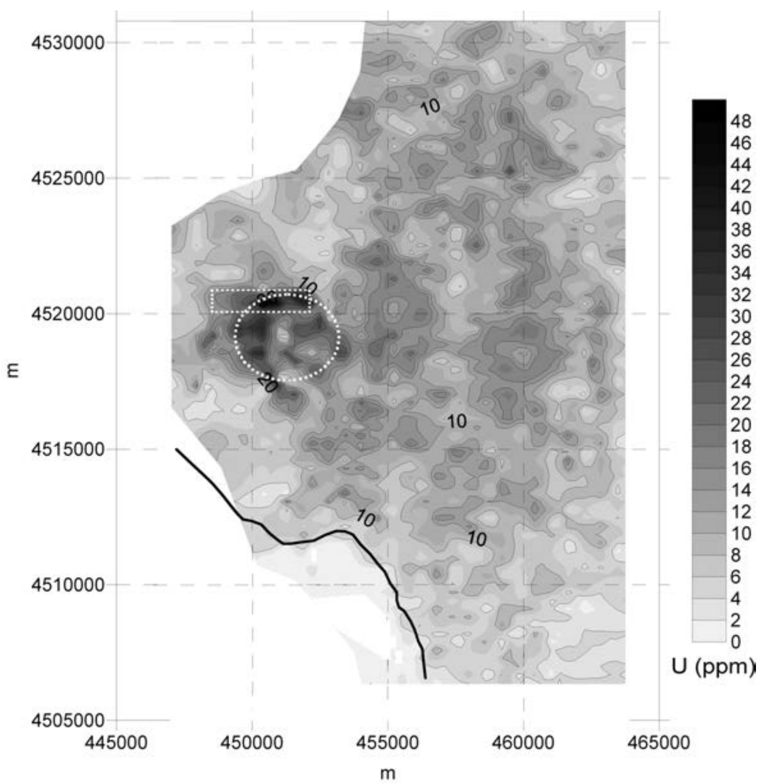


Fig. 4 - Map of distribution of equivalent Uranium from Vesuvian rocks and soils. The white dots show the caldera rim and the 1944 lava flow. Coastline in black.

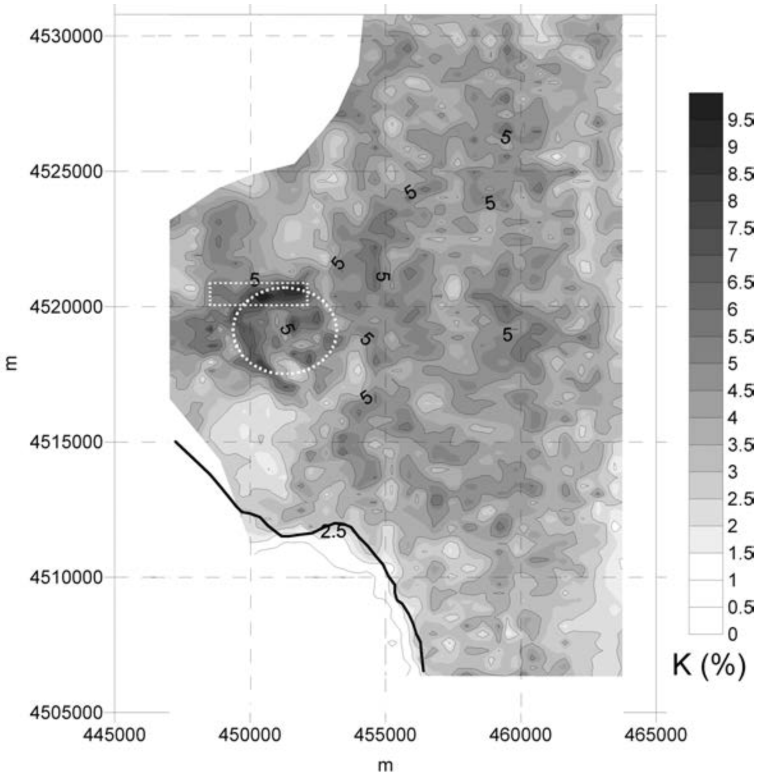


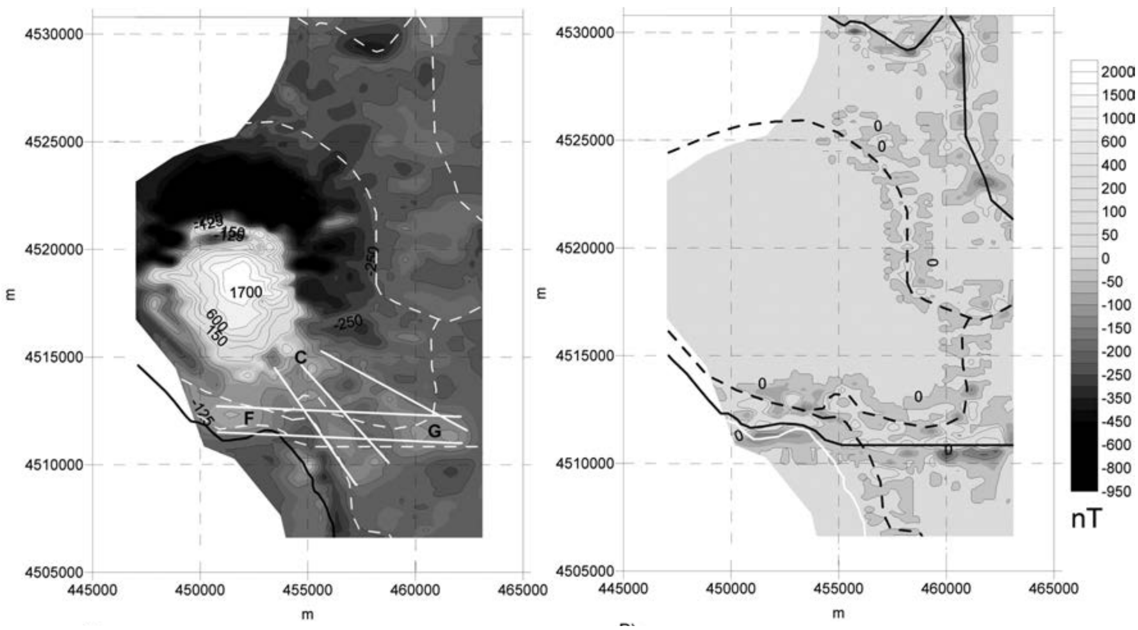
Fig. 5 - Map of distribution of Potassium from Vesuvian rocks and soils. The white dots show the caldera rim and the 1944 lava flow. Coastline in black.

3.1. Local separation of potential field anomalies

The overlapping of both antropic and geology-related magnetic effects in the surveyed area and the high variability of the train-induced signals present in the surveyed area, along both kinds of electrified lines, makes it difficult to distinguish between anomalies certainly due to noise and anomalies related to geology. In particular, while in some areas we cannot see any direct correlation between the anomalies and the presence of railway lines, in other cases some anomalies of interest are just in correspondence to the railway lines. The variable characteristics of the train-induced signals and the complex geological features of the area, causing a variable dispersion of the currents through the ground, may explain why the data measured in the Vesuvian area do not show a clear and constant presence of magnetic anomalies aligned along the railway lines. However, as it will be shown further on, the evidence of other related geophysical and geochemical anomalies in the same zone can help to furnish some indication about the presence of geology-related magnetic sources in the area. Nevertheless, working on the hypothesis that some of the anomalies along the railway lines are mainly connected to train-induced noise, we aim to show the effectiveness of the discrete wavelet transform in localized noise removal.

The filtering, performed by using a triangular base wavelet, was carried out specifying a closed region straddling the railway lines and considering the two smallest scales in the case of the main railway lines and only the smallest scale in the case of the secondary railway lines. The parameters used in this filtering were chosen on the basis of some studies on the anomalies induced by the railway lines (see Senanayake, 1990; Palangio *et al.*, 1991; Santarato *et al.*, 1994; Iliceto and Santarato, 1999). According to these studies the train-induced magnetic field decreases as the square of the distance from the line, and can vary from 5 to 35 nT at a distance of 1-2 km from the line. The thickness of the region straddling the railway line (about 5 km), as well as the choice of the scales to be filtered, were also chosen on the basis of a previous denoising successfully applied to the nearby northern Phlegrean area (see Fedi *et al.*, 2003; Paoletti *et al.*, 2004). The survey carried out in the Phlegrean area was, in fact, logistically similar to the survey in the Vesuvian region and highlighted some anomalies that are unequivocally train-induced.

Fig. 6a shows the magnetic map of the Vesuvian area obtained after a localized filtering along both the main and the secondary railway lines, while in Fig. 6b we see the anomalies removed by this localized filtering process. The use of this tool allowed a very space-localized filtering leaving the remaining parts of the measured signal unchanged. As we can notice, the application of this filtering procedure to our case did not completely remove the most important anomalies in correspondence to the railway lines (see, e.g., F and G in Fig. 6a). This fact, together with the evidence of other geophysical and geochemical anomalies of geological origin in the same zones, described below, suggests a superimposition in the measured data of geological and antropic effects, at least in some of the investigated areas. More specifically, a remarkable feature of the map obtained after the localized filtering process (Fig. 6a) is a group of anomalies trending NW-SE running parallel to the coastline from the Vesuvius edifice to the Pompei-Scafati area (marked with G), through Boscotrecase and Boscoreale (marked with C). This trend is, possibly, consistent with a lineament shown by gravity (Fedi *et al.*, 2004) and reflection seismic (Bruno *et al.*, 1998)



a) b)

Fig. 6 - a) Aeromagnetic map of the Vesuvian area obtained after the localized filtering along the railway lines (dashed white lines). The solid white lines show the magnetic trends highlighted by the filtering process; for location of the anomalies see Fig. 1. Coastline in black. b) Anomalies removed by the localized filtering process along the main (solid black) and secondary (dashed black) railway lines. Coastline in white.

studies. Another feature that can be observed is the presence of two anomalies in the Torre Annunziata and Pompei-Scafati regions (F and G in Fig. 6a), which seems to be aligned along a W-E trend. This W-E trend, which appears to be cut by the NW-SE lineament, is likely consistent with a structure highlighted by gravity studies (Florio *et al.*, 1999; Fedi *et al.*, 2004) and with geochemical studies which measured a CO_2 emission in the same areas (Caliro *et al.*, 1998). This evidence allowed us to take into consideration the possibility that the sources of some the anomalies south of the Somma-Vesuvius edifice (C, F and G in Fig. 6a) are connected mainly to geology. Further details about the sources of these anomalies are discussed in Paoletti *et al.* (2005).

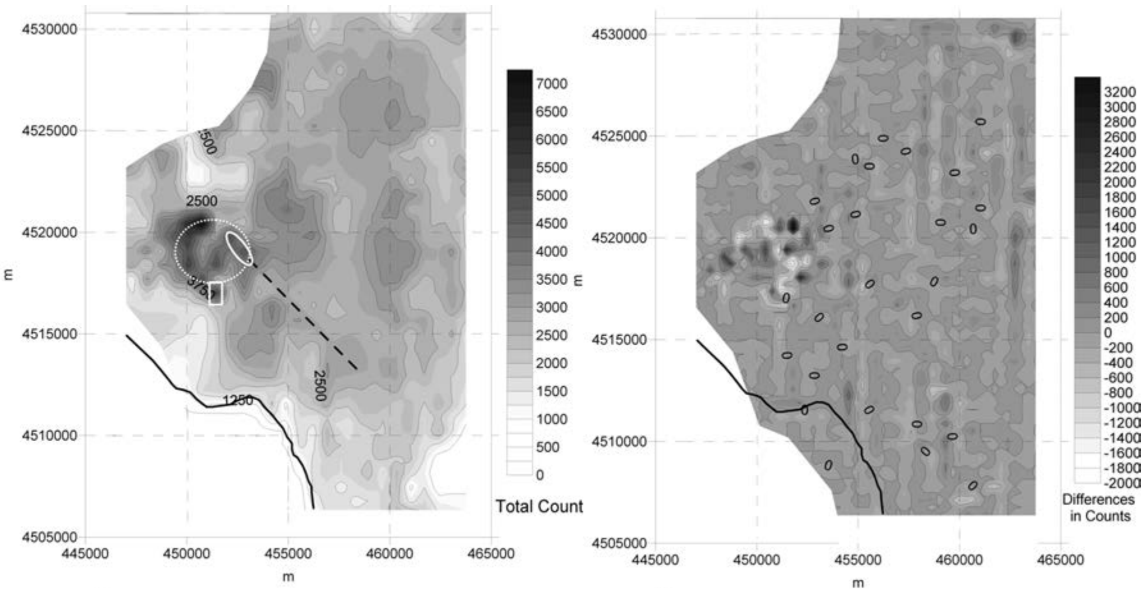
3.2. High frequency filtering of gamma-ray data

Regarding the radiometric measurements, a part of the measured signal is the residual of local contribution from rocks and soils and a part of it is generated by the urbanization itself. There is a close overlapping of the energy windows of both the signals and it is virtually impossible to distinguish between each contribution.

The filtering of the high frequency signal, due mainly to the overlapping of different lava flows and other volcanic products in the area, was performed by the method quoted based on the discrete wavelet transform, considering only the smallest scale. Part of the high frequency content was also due to the altitude correction performed during the processing phases (see Fig. 3). In this case, a directional filtering was applied to the data.

The application of the filtering to the three data sets leads to the suppression of the high frequency and directional noise which shield the main contribution due to geological-regional structures and to the most recent lava flows. These products overlay the volcanic field and are more enriched in radioactivity because they are 'young' (Capaldi *et al.*, 1980, 1982). The removal of the disturbance (see Figs. 7a, 8a and 9a) allowed us to highlight the shape of some features in the area which are comparable with geological structures detected by other studies (see, e.g., Principe *et al.*, 1987; Bianco *et al.*, 1998). In particular, some NW-SE trends, not visible in the original maps (see Figs. 3, 4, 5) and also highlighted in the aeromagnetic filtered map (see Fig. 6a) are shown in the filtered maps (Figs. 7a, 8a and 9a). These lineaments were already detected by studies of seismic reflection (Bruno *et al.*, 1998). Furthermore, the filtered maps show NE-SW trends, also highlighted by Principe *et al.* (1987).

Regarding the area of the Somma caldera, the filtered maps relative to the Potassium and total count (Figs. 7a and 9a) show good radiometric signatures of some of the most recent volcanic products of the area. In particular, the geometry of the 1944 lava flow is now well outlined in both maps. In Fig. 7a, we can notice parts of the 1944 lava flow which were not clearly detectable in the original map and some trends comparable with known tectonic structures (Principe *et al.*, 1987). In Fig. 9a, some other portions of this lava flow can be observed together with the south-western part of the caldera rim (Principe *et al.*, 1987). The Uranium map obtained after the processing (Fig. 8a) shows positive anomalies in the towns of Ottaviano, San Gennaro Vesuviano, San Giuseppe Vesuviano, Terzigno and Boscotrecase (A, B, C, D and E respectively in Fig. 8a), indicating a tendency towards high levels of indoor radon and consequently a possible risk for public health for these areas (Lahti *et al*., 2001; Lee *et al.*, 2001). The gamma-ray anomalies removed by the high frequency filtering process are shown in Figs. 7b, 8b and 9b.



a) b)

Fig. 7 - a) Map of total gamma emissions obtained after the high frequency wavelet filtering. The structures highlighted by the filtering process are shown: a NW-SE trend (dashed black line), the caldera rim (white dots) and some portions of the 1944 lava flow (solid white lines). b) Anomalies removed by the filtering process. Coastline in black.

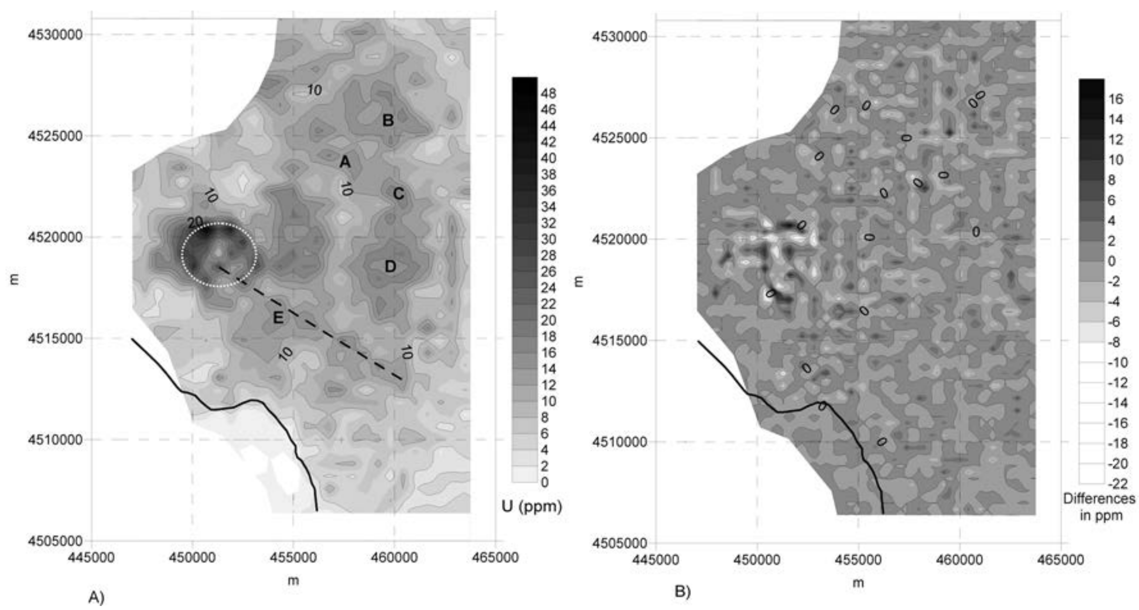


Fig. 8 - a) Map of equivalent Uranium obtained after the high frequency wavelet filtering. The black dashed line shows the trend highlighted by the filtering process, while the white dots show the caldera rim. Coastline in black. b) Anomalies removed by the filtering process.

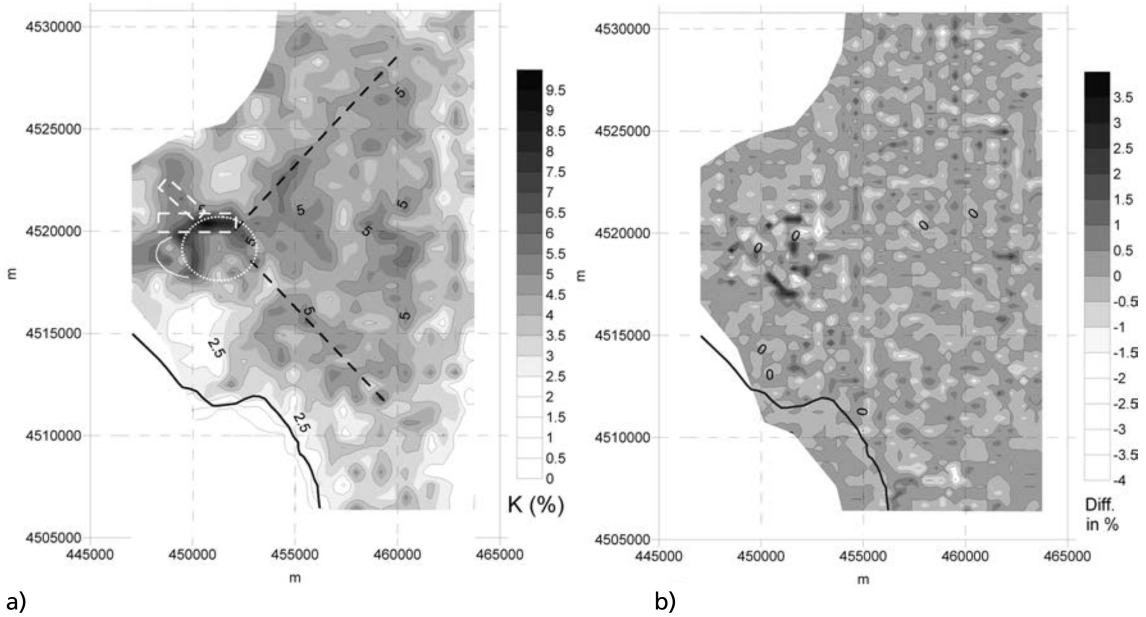


Fig. 9 - a) Map of distribution of Potassium obtained after the wavelet filtering. The structures highlighted after the filtering process are shown: the NW-SE and NE-SW trends (dashed black lines), the caldera rim (white dots), some portions of the 1944 lava flow (dashed white lines) and the south-western portion of the caldera rim (solid white line). Coastline in black. b) Anomalies removed by the filtering process.

4. Conclusions

We presented and discussed an application of denoising techniques to high-resolution aeromagnetic and radiometric data. The data were recently measured in helicopter-borne surveys in the Somma-Vesuvius Volcanic Area, southern Italy, with the aim of giving new detailed insights into the distribution of the magnetization and of the main radionuclides of the area and, therefore, into the volcanological characteristics of the region. The measured data were affected by cultural noise connected to the presence of towns, buildings and railway lines, which were responsible for some of the anomalies. In this paper, we showed the effectiveness of the discrete wavelet transform in localized noise removal.

The filtering tool based on the discrete wavelet transform used in this paper has excellent space-scale localization properties allowing a very sharp filtering. The application of this method to the magnetic data affected by noise connected to the presence of electrified railway lines led to a very space-localized filtering of the railway effect leaving the remaining parts of the measured signal practically unchanged. However, the application of this filtering procedure to our case did not completely remove the most important anomalies in correspondence to the railway lines. This evidence, together with the presence of known geological sources detected in the same zones by other geophysical and by geochemical methods (see Bruno *et al.*, 1998; Caliro *et al.*, 1998; Florio *et al.*, 1999; Fedi *et al.*, 2004), suggests a superimposition of geological and antropic effects in some of the investigated areas. In particular, the map obtained after the filtering shows a NW-SE magnetic lineament, possibly consistent with a lineament shown by gravity and reflection seismic studies, and a W-E magnetic trend, whose presence is also confirmed by gravity and geochemical studies.

The high frequency and directional wavelet filtering of the gamma-ray data allowed the identification of some features in the area which are comparable with geological structures detected by other geological and geophysical studies (see Principe *et al.*, 1987; Bianco *et al.*, 1998; Bruno *et al.*, 1998). In particular, some NW-SE and NE-SW lineaments, possibly related to recent lava flows, were shown. In the region of the Somma caldera, the filtered maps show good radiometric signatures of some of the most recent volcanic products of the area. The filtering then led to the individuation of regions prone to high levels of indoor radon with important environmental and public health implications.

The results obtained demonstrated the utility of the wavelet filtering for localized, directional and high-frequency filtering. The use of such filtering is in fact usually necessary when applying enhancing techniques, like high-order derivatives, to the data to warrant a reliable interpretation of the data.

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REFERENCES

Akerblom G.; 1995: *The use of airborne radiometric and exploration survey data and technique in radon risk mapping in Sweden*. In: Meeting ‘Application of Uranium Exploration Data and Techniques in Environmental Studies’, IAEA-TECDOC-827, IAEA, Vienna, pp. 159–180.

Arana V., Camacho A.G., Garcia A., Montesinos F.G., Blanco I., Vieira R. and Felpato A.; 2000: *Internal structure of Tenerife (Canary Islands) based on gravity, aeromagnetic and volcanological data*. Journal of Volcanology and Geothermal Research, **103**, 43–64.

Barnet I.; 1995: *The role of airborne gamma spectrometric data in the radon programme of the Czech Republic*. In: Meeting ‘Application of Uranium Exploration Data and Techniques in Environmental Studies’, IAEA-TECDOC-827, IAEA, Vienna, pp. 151–158.

Bernasconi A., Bruni P., Gorla L., Principe C. and Sbrana A.; 1981: *Risultati preliminari dell’esplorazione geotermica profonda nell’area vulcanica del Somma-Vesuvio*. Rend. Soc. Geol. Ital., **4**, 237-240.

Berrino G, Corrado G. and Ricciardi U.; 1998*: Sea gravity data in the Gulf of Naples: a contribution to delineating the structural pattern of the Vesuvian area*. Journal of Volcanology and Geothermal Research, **82**, 139-150.

Bhattacharrya B.K. and Chan K.C.; 1977: *Reduction of magnetic and gravity data on an arbitrary surface acquired in a region of high topographic relief.* Geophysics, **42**, 1411–1430.

Bianco F., Castellano M., Milano G., Ventura G. and Vilardo G.; 1998: *The Somma-Vesuvius stressfield induced by regional tectonics: evidences from seismilogical and mesostructural data*. Journal of Volcanology and Geothermal Research, **82**, 199-218.

Billings S.; 1998: *Geophysical aspects of soil mapping using airborne gamma-ray spectrometry*. PhD Thesis, University of Sydney, 218 pp.

Bruno P.P.G., Cippitelli G. and Rapolla A.; 1998: *Seismic study of Mesozoic carbonate basement around Mt. Somma-Vesuvius, Italy*. Journal of Volcanology and Geothermal Research, **84**, 311-322.

Buccella C. and Feliziani M.; 2003: *Calcolo e misura del campo magnetico all’interno di un treno ad alta velocità con elettrificazione in corrente alternata*. In: Meeting ‘Strumenti e tecniche di misura per la protezione dell’uomo e dell’ambiente dai campi elettromagnetici’, Sesto Fiorentino (FI), Area di Ricerca CNR di Firenze, May, 28–29 2003.

Caliro S., Panichi C. and Stanzione D.; 1998: *Vaseline study of the isotopic and chemical composition of waters associated with the Somma-Vesuvio volcanic system*. Acta Vulcanologica, **10**, 19-25.

Capaldi G., Civetta L., Orsi G. and Pece R.; 1980*: U and Th distribution in sedimentary rocks from the Campanian Appennines. An evidence against external source for the Ra excesses of Vesuvius lavas*. Periodico di Mineralogia, **49**, 45-55.

Capaldi G., Cortini M. and Pece R.; 1982: *Th isotopes at Vesuvius: evidence for open-system behaviour of magma-forming processes*. Journal of Volcanology and Geothermal Research, **14**, 247-260.

Carrara E., Iacobucci F., Pinna E. and Rapolla A.; 1974: *Interpretation of gravity and magnetic anomalies near Naples, Italy, using computer techniques*. Bull. Volcanol., **XXXVIII**, 1-10.

Cassano E. and La Torre P.; 1987: *Geophysics*. In: Santacroce R. (ed), Somma-Vesuvius, CNR Quad. Ric. Sci., **114**, pp. 175-183.

Cella F., Fedi M., Florio G., Grimaldi M., Paoletti V. and Rapolla A.; 2003: *Deep and shallow structure of Somma-Vesuvius volcano from potential field data interpretation*. In: Workshop 'Vesuvius: Inside the Volcano', Ercolano (Italy), May 8-10, 2003, Abstract Volume, pp.11.

Cordell L. and Grauch V.J.S.; 1985: *Mapping basement magnetization zones from aeromagnetic data in the San Juan basin, New Mexico*. In: Hinze W.J. (ed.), The utility of regional gravity and magnetic anomaly maps, Society of Exploration Geophysics, pp. 181-197.

Cuss R.J.; 2003: *Manual approaches to the removal of cultural noise from high-resolution aeromagnetic data acquired over highly developed areas*. First Break, **21**, 43-49.

Damkjaer A. and Korbech U.; 1998: *A search for correlation between local geology and indoor radon concentration*. Radiation Protection Dosimetry, **24**, 51-54.

Fedi M. and Quarta T.; 1998: *Wavelet analysis for the regional-residual and local separation of potential field anomalies*. Geophysical Prospecting, **46**, 507-525.

Fedi M., Florio G. and Rapolla A.; 1998: *2.5D modeling of Somma-Vesuvius structure by aeromagnetic data*. Journal of Volcanology and Geothermal Research, **82**, 239-247.

Fedi M., Florio G., Paoletti V., Rapolla A. and Supper R.; 2003: *Analysis and interpretation of aeromagnetic data affected by intense cultural noise*. In: 65th EAGE Conference, Stavanger, Norway, Extended Abstracts, E-33.

Fedi M., Florio G., Italiano F. and Milia A.; 2004: *Campanian Plain, Southern Italy: correlation between geological structures and Gravity Gradient Tensor (GGT) components*. In: SEG Special Volume Gravity Gradient Tensor, submitted.

Ferraccioli F., Bozzo E. and Damaske D.; 2002*: Aeromagnetic signatures over western Marie Byrd Land provide insight into magmatic arc basement, mafic magmatism and structure of the Eastern Ross Sea Rift flank*. Tectonophysics, **347**, 139-165.

Finn C.A. and Williams D.L.; 1987: *An aeromagnetic study of Mount St. Helens*. Journal of Volcanology and Geothermal Research, **92**, 10194-10206.

Finn C.A., Sisson T.W. and Deszcz-pan M.; 2001: *Aerogeophysical measurements of collapse-prone hydrothermally altered zones at Mount Rainier volcano*. Nature, **409**, 600-603.

Finn C.A. and Morgan L.A.; 2002: *High-resolution aeromagnetic mapping of volcanic terrain, Yellowstone National Park*. Journal of Volcanology and Geothermal Research, **115**, 207-231.

Florio G., Fedi M., Cella F. and Rapolla A.; 1999: *The Campanian Plain and Phlegrean Fields: structural setting from potential field data*. Journal of Volcanology and Geothermal Research, **91**, 361-379.

Gay S.P.Jr.; 1986: *The effects of cathodically protected pipelines on aeromagnetic surveys*. Geophysics, **51**, 1671-1684.

Gharibi M. and Pedersen L.B.; 2000: *Removal of DC power-line magnetic-field effects from airborne total magnetic-field measurements*. Geophysical Prospecting, **48**, 617-627.

Glenn W.E. and Badgery R.A.; 1998: *High resolution aeromagnetic surveys for hydrocarbon exploration: prospect scale interpretation*. In: Pierce J.W., Glenn W.E. and Brown K.C. (eds), High Resolution Aeromagnetic for Hydrocarbon Exploration, Canadian Journal of Exploration Geophysics, **34**, pp. 97-102.

Grasty R.L. and Shives R.B.K.; 1997: *Applications of gamma ray spectrometry to mineral exploration and geological mapping*. In: Proceedings of the Fourth Decennial Conference on Mineral Exploration, Geophysics and Geochemistry at the Millenium. 14-18 September 1997, Toronto, Canada.

Grauch V.J.S. and Campbell D.L.; 1984: *Does draping aeromagnetic data reduce terrain-induced effects?* Geophysics, **49**, 75-80.

Gunn P.J., Mackey T. and Meixner A.; 1999: *Airborne geophysical signatures of localities of epithermal gold deposit in Fiji*. Australian Geological Survey Organization (AGSO). <http://www.aseg.org.au/publications/fiji/fijisurvey.htm>

Hildenbrand T.G., Rosenbaum J.G. and Kauahikaua J.P.; 1993: *Aeromagnetic study of the island of Hawaii*. Journal of Volcanology and Geothermal Research, **98**, 4099-4119.

Iliceto V. and Santarato G.; 1999: *On the interference of man-made EM fields in the magnetotelluric 'dead band'*. Geophysical Prospecting, **47**, 707-719.

Lahti M., Jones D.G., Multala J. and Rainey M.P.; 2001: *Environmental applications of airborne radiometric surveys.* In: EAGE extended abstract, Amsterdam.

Larsen J.C., Mackie R.L., Manzella A., Fiordelisi A. and Rieven S.; 1996: *Robust smooth magnetotelluric tranfer functions*. Geophys. J. Int., **124**, 801-819.

Lee M.K., Peart R.J., Cuss R.J., Jones D.G., Beamish D. and Vironmaki J.; 2001: *Application and challenges for high resolution airborne surveys in populated areas*. In: EAGE extended abstract, Amsterdam.

Linington R.E.; 1974: *The magnetic disturbances caused by DC electric railways*. Prospezioni Archeologiche, **9**, 9-20.

Muszala S., Stoffaz P.L. and Lawverz L.A.; 2001: *An application for removing cultural noise from aeromagnetic data*. Geophysics, **66**, 213-219.

Nakatsuka T.; 1994: *Aeromagnetic anomalies over the area of Unzendake volcano*. J. Geomag. Geoelectr., **46**, 529-540.

Oversby V.M. and Gast P.W.; 1968: *Lead isotope composition and Uranium decay series disequilibrium in recent volcanic rocks*. Earth Plan. Sci. Lett., **5**, 199-206.

Palangio P., Marchetti M. and Di Diego L.; 1991: *Rumore elettromagnetico prodotto dalle ferrovie elettrificate. Effetti sulle misure magnetotelluriche e geomagnetiche*. In: Atti del X Convegno Annuale del Gruppo Nazionale di Geofisica della Terra Solida, Esagrafica Rome, pp. 745-762.

Paoletti V., Fedi M., Florio G., Supper R. and Rapolla A.; 2004: *The new integrated aeromagnetic map of the Phlegrean Fields Volcano and surrounding areas*. Annals of Geophysics, **47**, 1569-1580.

Paoletti V., Supper R., Chiappini M., Fedi M., Florio G. and Rapolla A.; 2005: *Aeromagnetic Survey of the Somma-Vesuvius Volcanic Area*. Annals of Geophysics, in press.

Pinto A., Capaldi G., Fedi M. and Pece R.; 2005: *Radioactivity of Campanian volcanic rocks and soils by airborne gamma-ray spectrometry (southern Italy)*. IAEA, Vienna, TECDOC, in press.

Principe C., Rosi M., Santacroce R. and Sbrana A.; 1987: *Explanatory notes to the Geological map*. In: Santacroce R. (ed.), Somma-Vesuvius, CNR Quad. Ric. Sci. **114**, pp. 11-46.

Rystrom V.L., Finn C. and Descsz-Pan M.; 2000: *High Resolution, Low Altitude Aeromagnetic and Electromagnetic Survey of Mt Rainier*. U.S.G.S. Open-File-Report 00-027.

Santarato G., Spagnolini U. and Iliceto V.; 1994: *Caratterizzazione del rumore elettromagnetico prodotto dalle ferrovie elettrificate*. In: Atti del XIII Convegno Annuale del Gruppo Nazionale di Geofisica della Terra Solida, Esagrafica Rome, pp. 635-638.

Senanayake W.E.; 1990: *An investigation of magnetic effects associated with DC electrified trains*. Boll. Geof. Teor. Appl., **32**, 275-283.

Supper R., Motschka K., Seiberl W. and Fedi M.; 2001: Geophysical investigations in Southern Italian active volcanic regions. Bulletin of the Geological Survey of Japan, **52**, 89-99.

U.S.G.S.; 1999: *New Mexico, Middle Rio Grande Basin Study*. U.S. Geological Survey, U.S. Department of the Interior. USGS Fact Sheet 032-99.

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