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The marine digital terrain model of the Panarea caldera (Aeolian Islands, Southern Italy)

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Abstract
A Marine Digital Elevation Model (MDEM) of the still active volcanic area of Panarea caldera is presented in this paper. A fast and accurate survey was performed by means of the Differential Global Positioning System (DGPS) geodetic technique coupled with an echo-sounding gear and a real time navigation software. The instrumentation was installed on board of a low draught boat in order to collect data starting from the bathymeter of one meter. Planar positions and depths were obtained with average accuracies of ± 30 cm and ± 10 cm respectively providing a 3D map of the seafloor useful for geomorphological, geophysical and volcanic hazard applications.

Key words *bathymetry – DGPS – marine DTM – Panarea caldera*

1. Introduction

Nowadays Digital Terrain Models (DTMs) constitute a fundamental element of most 2D and 3D spatial databases and are employed for a wide range of land planning, engineering and geophysical applications (Bitelli *et al.*, 1996). During recent years aerial photography and contour lines for terrestrial DTM generation were widely used and successfully applied to active volcanoes and local tectonic areas, in order to provide a powerful database for morphology and tectonic studies (Achilli *et al.*, 1997). In coastal areas, subjected to volcanic and tectonic activity, it becomes relevant to produce Marine Digital Terrain Models (MDTMs) of the sea bottom to determine seafloor morphology and the extension and shape of the tectonic structures.

A powerful methodology for the production of high accuracy DTMs of the sea bottom in coastal areas can be achieved by means of the Differential Global Positioning System (DGPS) technique applied in marine areas (Hein *et al.*, 1992) when coupled with echo sound gears and navigation softwares. The DGPS can provide 3D coordinates at a few centimetres accuracy while modern echo sounds are able to measure depths at centimetre level, allowing us to produce rapid and accurate surveys of marine areas.

This technique was applied to the Panarea complex marine caldera to obtain a MDTM of the seafloor of this active volcanic area belonging to the Aeolian arc (Southern Tyrrhenian Sea) where recent geological and geophysical data evidenced its complex evolution (Barberi *et al.*, 1974; Gasparini *et al.*, 1982; Locardi, 1985; Rossi *et al.*, 1986; Gabbianelli *et al.*, 1990, 1993; Amato *et al.*, 1993). Panarea, together with the neighborough small islands of

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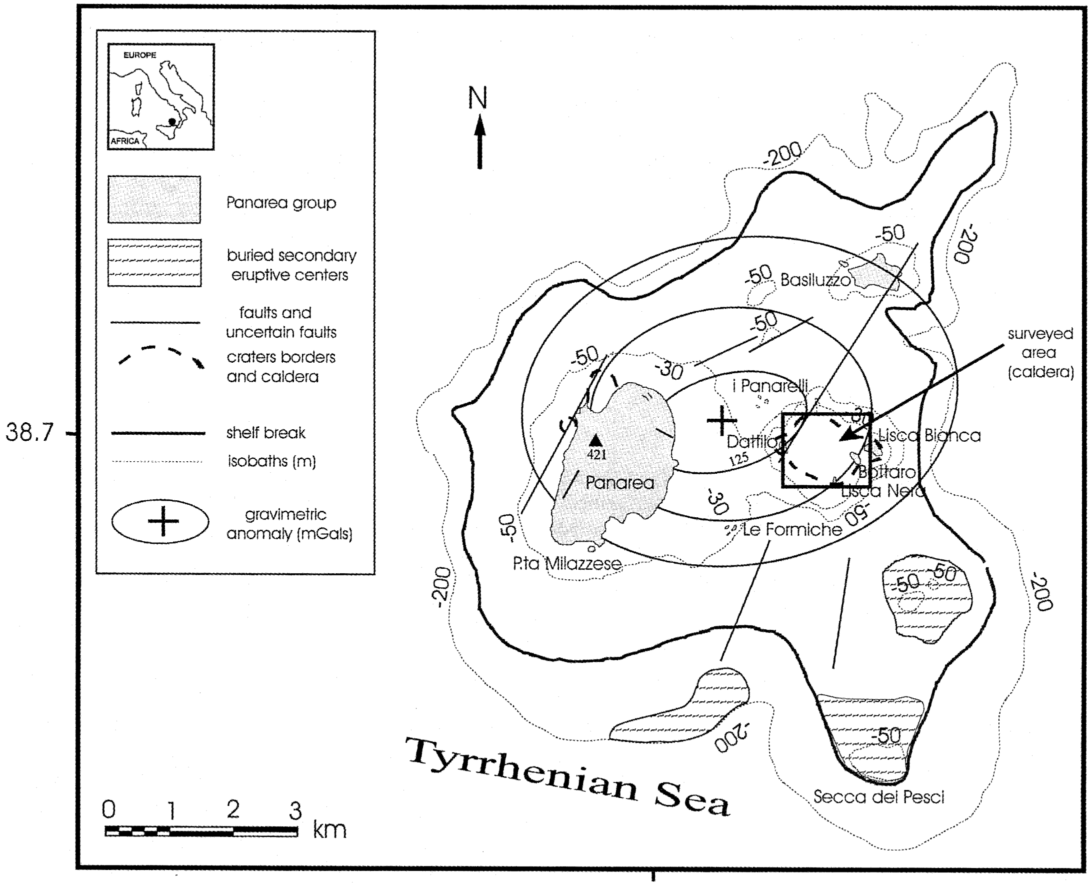

Fig. 1. The Panarea area (modified from Romano, 1973; Gabbianelli *et al.*, 1990, 1993).

Lisca Bianca, Bottaro, Lisca Nera, Dattilo and Panarelli (fig. 1), limits a shallow sea area that represents the remnant of a crater rim which collapsed ~ 134 000 years ago and border a subcircular crater depression characterised by an active fumarolic field (Lanzafame and Rossi, 1984).

2. GPS and depth data

Surveys were performed during June 1997 under favourable weather conditions. GPS data were collected by a DGPS system Leica MX9400 equipped with an RTCM-104 correction system. A radio bridge at UHF frequency working at 2400 baud rate was used to connect the reference and the rover GPS stations.

The reference antenna was set up on the II order geodetic station of the Italian triangulation network of the Italian Istituto Geografico Militare (IGM), located on top of Lisca Bianca island (Gauss-Boaga coordinates: East 2529824.18, North 4276759.36, Height 31.20).

The GPS antenna of the rover receiver and the echo sounder transducer were mounted at both ends of a three meter long pole and installed in vertical on the right tack of the boat (fig. 2). The antenna was set up at two meters above sea level and the echo sounder transducer at 1 m depth below the sea surface. Positions and depth data were collected at a sampling rate of 1 s by the DGPS and the echo sounder and stored in a Personal Computer which also had the task of managing the radio modem communication system between the reference GPS station and the rover one and to run a real time navigation software to sail along the required pre-planned routes. The rover GPS receiver, the echo sounder, the PC and the radio modem were all hosted on a six metres long boat, sailing at a constant speed of two knots during surveys. Boat speed was determined by the DGPS and the navigation software (table I).

More than 17 300 depth and position data were collected along 17.3 km of performed routes corresponding to 13 survey lines. Five of them were run along the NS direction and eight along the EW direction. A check for position and depth accuracies was performed at their intersections.

Planar positions were computed in real time by the Winbat navigation software (Badin,

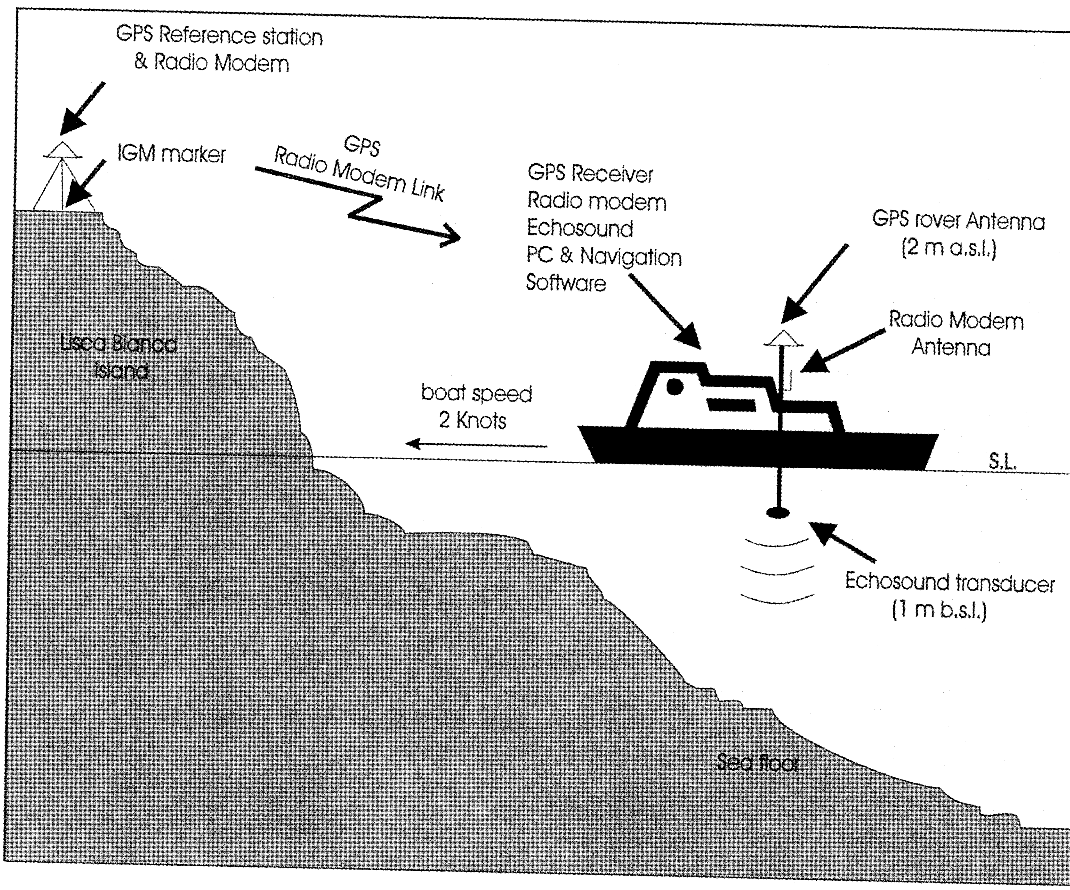

Fig. 2. Scheme of the survey tools. In the on board instrumentation, the PC has the task of storing positions obtained by DGPS and depths measured by the echo sounder, both collected at 1 s sampling rate. The PC is also used to manage the radio modem software that links the reference and the rover GPS receivers and to run the real time navigation software.

1997) with an accuracy of ± 30 cm (standard accuracy of the system). The software manages both position and depth data simultaneously: coordinates and depths were converted into a data file written in ASCII format, suitable to be managed by numerical and graphic software. Coordinate transformation from WGS84 (GPS reference system) to Gauss Boaga Systems (IGM) was performed automatically in real time by the navigation software during the data acquisition, applying the three parameters Molodensky formulation (translation from ellipsoid centre).

Depth measurements were performed by an Odom SDH-13A echo sounder system, equipped with a digitiser Odom Digitrace, an electronic transducer working at 210 kHz and with 9° of aperture cone, an optimal depth operating range up to 100 m and an accuracy of 1 cm. In order to obtain accurate depth measurements, the transducer was calibrated for sound speed in the water at the beginning of the survey. Calibrations were performed both, at the beginning and at the end of the survey. Tidal corrections were applied to depth data by measuring tide amplitudes by a Brancker TG-205 automatic tide gauge. Data were collected every 5 min at Panarea harbour during surveys. Corrections were neglected due to the small values of the observed tide amplitudes (≤ 10 cm). For this reason we assumed as 0 m the height of the sea level.

Table I reports the general features of the surveys.

Table I. General features of the surveys.

Marine Digital Terrain Model of Panarea caldera	
DGPS system	Leica MX9400
DGPS radio bridge system	Satelline (UHF frequency) at 2400 bps
DGPS reference station location	Lisca Bianca (IGM)
DGPS accuracy (standard)	± 30 cm planar
Echo-sounder	Odom SDH-13A
Echo-sounder aperture cone	9° (at 210 kHz)
Echo-sounder operating range	0.5-100 m
Echo-sounder accuracy (standard)	0.5% ± 1 cm
DGPS and echo-sounder sample rates	1 s, synchronised
Tide gauge	Brancker TG-205 (at Panarea)
Tide amplitude	< 10 cm
Total route length	17.3 km (13 pre-planned single routes)
Boat speed	2 knots (~ 3.6 km/h)
Sampling density	1 per m
Points collected	17 300
Cross-check points	3 (positions and depths)
Sea state	calm
Wind force	0-1
Atmospheric pressure	1018 millibars
Atmospheric temperature	+ 25 °C

3. The marine DTM and conclusions

DGPS techniques coupled with an echo sounder system and real time navigation softwares offer a powerful tool to perform a marine DTM with high accuracy and in a short operating time. This technique was applied to Panarea caldera area (Aeolian Islands) combining depth and position data, simultaneously collected along preplanned routes.

Figure 3 displays the plot of the marine DTM of the seafloor computed by the triangulation interpolation method normally used for bathymetric surveys. The small spots at the centre of the depression (~ 27 m depth) are related to a dyke that displays a 4-6 m vertical dislocation and is affected by an intense fumarolic activity as reported by Bellia *et al.* (1987).

Because GPS is a very accurate navigation system, it can be used as a positioning tool to repeat periodically the same bathymetric profiles, which are computed with a standard accuracy of about ± 30 cm in the planar component. If we consider the tidal effect and the accuracy of the echo sound employed, we obtained an accuracy ± 10 cm for depth determination.

This methodology represents a powerful tool to investigate marine areas along coastlines subjected to active volcanic and tectonic activity. Combining terrestrial and marine

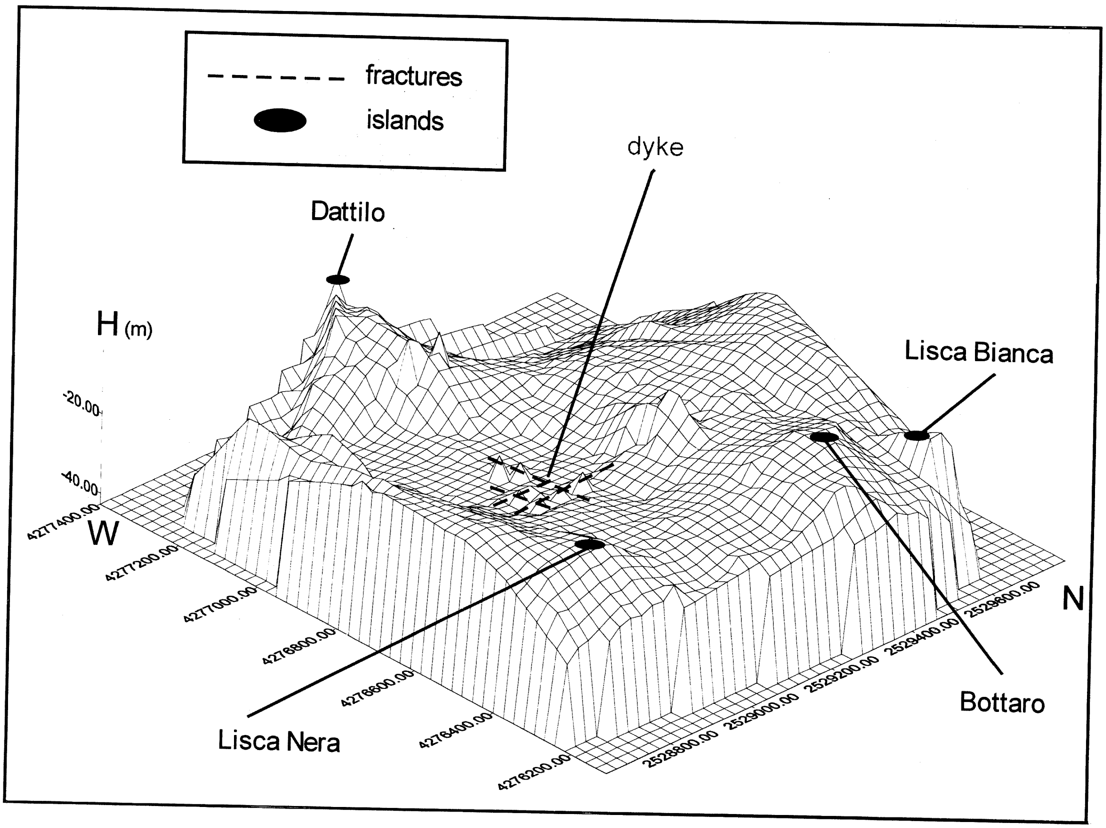

Fig. 3. Digital Terrain Model of the caldera. The morphological relief at the centre of the depression corresponds to a fractured dyke with a vertical dislocation ranging from 4 to 6 m.

DTMs of coastal areas, a 3D topographical data set both of land and seafloor can be obtained for geomorphological applications, tsunami effect prediction along coastlines and volcano-tectonic monitoring for hazard mitigation.

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