Glacio RADAR system and results

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Abstract— **Since 1997 the Istituto Nazionale di Geofisica e Vulcanologia (INGV) in Italy has been involved in the development of the airborne RES system named Glacio RADAR, which is continuously upgraded. Radio Echo Sounding (RES) techniques are widely used in glaciological measurements. They are based on the use of radar systems, to obtain information concerning ice thickness of ice sheets and ice shelves, internal layering of glaciers, detection of inhomogeneities, exploration of subglacial lakes and identification of physical nature of subglacial interface.**

The Glacio RADAR is mounted on an aircraft and flies at an altitude around 300m above the ice surface during the survey. The first prototype operates in bistatic mode with separate transmit and receive one wire folded dipole installed beneath the aircraft wings. It works at 60 MHz with an envelope pulse width variable between 0.3 μs and 1 μs. The receiving window is 64 μs which implies a maximum penetration depth (range) in the ice of about 5.3 km. The horizontal sampling rate is 10 traces/s at a mean aircraft speed of about 70 m/s. This would produce roughly 143 traces per kilometre (horizontal resolution of 1 trace every 7 m). The Navigation and geographical information is based on a on board GPS receiver giving longitude, latitude, altitude and time for the acquired radar trace. This radar was used in several Italian Antarctic Expeditions (1997, 1999, 2001 and 2003) and highlights of data results from these expeditions are presented here.

***Index Terms*— VHF Radar, RES-system.**

I. INTRODUCTION

Radio Echo Sounding (RES) system is an active remote-sensing instrument that uses the electromagnetic wave penetration into the ice to obtain information on the level of the bedrock, the ice thickness and its inhomogeneties, i.e. the internal layering of glaciers and subglacial lake exploration and identification of physical nature of subglacial interface in the framework of glaciological studies.

Since 1997, the Istituto Nazionale di Geofisica e Vulcanologia (INGV) in Italy has been involved in the development of the airborne RES system named Glacio RADAR, which is under continuous up gradation [1].

The Glacio RADAR was mounted on an aircraft DE HAVILLAND DHC-6 Twin Otter, that flies at an optimum altitude 1000 ft (around 300m) above the ice surface during the survey in Antarctic regions. During several Italian Antarctic Expeditions (1997, 1999, 2001 and 2003) a large amount of data was collected, with more than 60’000 km of flights in the eastern part of Antarctica and around the Italian base Mario Zucchelli station and Italian-French base station Dome C fig. 2.

II. GLACIO RADAR SYSTEM

The Glacio RADAR model used during the 1997 and 2003 Italian Antarctic Expeditions (Fig.1), operates at 60 MHz with an envelope pulse width variable between 0.3 μs and 1 μs. The carrier generator was developed using a Phase Lock Loop (PLL) frequency synthesizer, which could synthesize frequencies from 40 MHz to 75 MHz with 1 kHz step. In this way it was possible to fine tune the carrier frequency to reduce the reflected power from the folded dipole antenna due to mismatch.

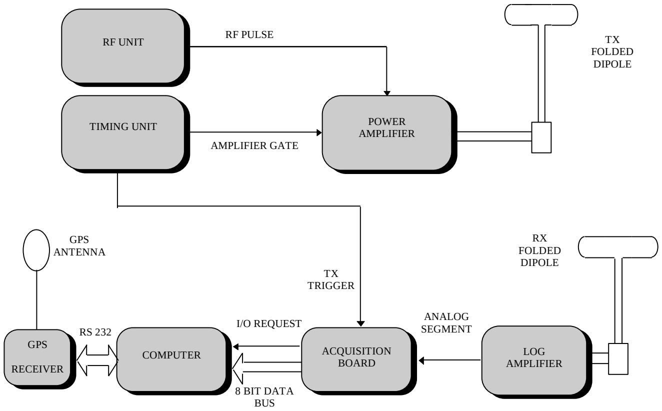

Figure 1 Glacio RADAR circuit diagram

One wire folded dipole constitutes the antenna system which exploits the wing reflectors to increase the gain. The 4 kW pulsed power amplifier allowed us to obtain an adequate amplitude echo signal at the input of the receiver.

The receiver listening time was 51.2 μs in 1997 and 64 μs from 1999 and consequently the maximum penetration depth in the ice has been about 4.3 km in 1997 and 5.3 km from 1999 to analyze deepest zone in Antarctica.

The receiver consists of a low-noise logarithmic envelop detector with a dynamic range of 80 dB. The acquisition system uses high speed IC’s and flash converter. The received echo signal is digitized (8 bit) at the sampling frequency of 20 MHz with an error in the received echo time of about 50ns. The receiver sensibility is -100 dBm which is good enough to detect the signal that suffers a loss of about 160 dB mainly due

Research was carried out in the framework of the Project on Glaciology of the PNRA-MIUR and financially supported by the PNRA Consortium through collaboration with ENEA Roma.

to, surface scattering at the various interfaces, inhomogeneities in the ice volume, geometrical attenuation and absorption in the media etc.

The transmitted pulse repetition rate (PRR) is 100 traces/second and to increase the signal to noise ratio, the average trace is calculated on every ten received traces. The horizontal resolution is 7 m/trace at a mean flight speed of 100 - 120 kt (185 - 220 kmh^{-1}) . The vertical error is ± 4.2 m [1] which is compatible with 50 ns sampling time, while the range is covered by 1280 digitized samples per trace.

The acquisition software, for the acquisition board, has been developed in C language and allow an easy management of records and files. The software provides the acquisition of GPS data via the RS232 serial port so that each data file has its own header and tail which specify location (longitude, latitude, height) and time of survey.

The location of the radar traces was obtained by a global position system (GPS) Trimble 4000 SSE system (L1 and L2 frequency), with a geodetic antenna mounted on the fuselage, and synchronized to the radar acquisition. The precision in x, y coordinates used to geo-reference the radar data was ± 20 m (without pseudo-range differential correction).

All radar profiles (examples in fig. 4, 5) were processed with a software package designed for the radio-echo sounder. Ice thickness was calculated using a constant electromagnetic wave propagation velocity of 168 m µs-1 [2].

The surface elevation was based on the European Remote sensing Satellite (ERS–1) radar altimeter data [3]. Bedrock elevation was calculated by subtracting the ice thickness from the surface elevation by ERS – 1.

This radar has been employed in several Italian Antarctic Expeditions (1997, 1999, 2001 and 2003) with continuous improvements in the electronics, signal acquisition and elaboration. Two new enhanced Glacio RADARs have been designed and realized by INGV and will be used in the next campaigns exploiting new techniques in the real-time signal processing [4]. To increase the resolution and the general performances of the system, 180 degrees phase reversal code sub-impulse duration has been reduced. The working frequencies of the new phase coded radars are 150 MHz and 300 MHz allowing significant improvement in the antenna system. In fact, 4 folded dipoles for each antenna constitute two phased arrays with a gain of 18 dBi that includes the effect of wing reflectors.

III. GLACIO RADAR RESULTS

The measurements, obtained using the Glacio RADAR system during five Italian Antarctic Expeditions (1995 - 2003), have been used in different frameworks. From these measurements it has been possible, for example, to determine and to analyse the bottom morphology and the ice thickness of the David Glacier Drygalski ice tongue in East Antarctic region [5][6]. In the same period, the combination of satellite-tracking velocity datasets with airborne radar surveys of ice thickness allowed to calculate the discharge of Priestley, Reeves, David, Mawson and Mackay outlet glaciers. Successively, using the changes in ice fluxes of these floating glaciers, it is possible to determine basal melting and freezing rates, and surface mass balance of the outlet glaciers [7]. The surface mass balance changes are driven by climate changes and is determined by the difference between net snow accumulation and ice discharge across the outlet glacier.

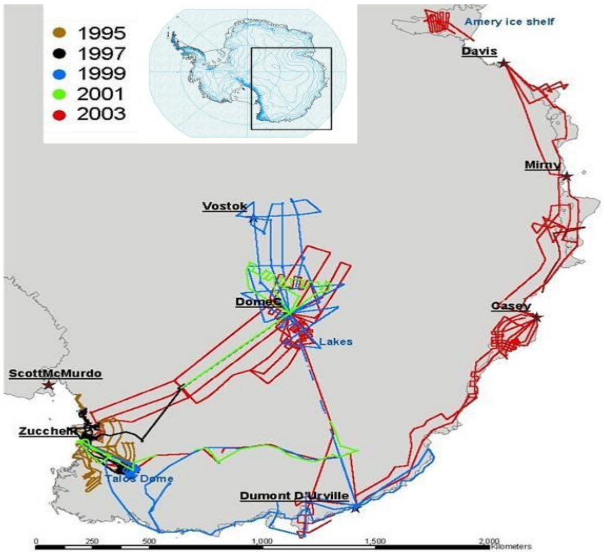

Figure 2. Italian Antarctic campaigns.

This RES system also conducted many measurements in the Antarctic region in support of different projects such as, the EPICA (European Project for Ice Coring in Antarctica), TALDICE (Talos Dome Ice Core Project). The precise bedrock topography has been reconstructed at Dome C in Antarctica [3]. The knowledge of the topography of this region was fundamental in choosing the optimal location for deep ice-core drilling at Dome C [8]. In the same framework, the bedrock topography map shown in fig. 3 has been produced for the TALDICE drilling project. From the map the deep ice-core drilling point location (cross and triangle) in the Talos Dome region was selected in the flattest and low ice flux zone [9]. The 3D map has been realized using the bedrock RADAR survey combined with the ice surface elevation from ERS-1 satellite radar altimeter.

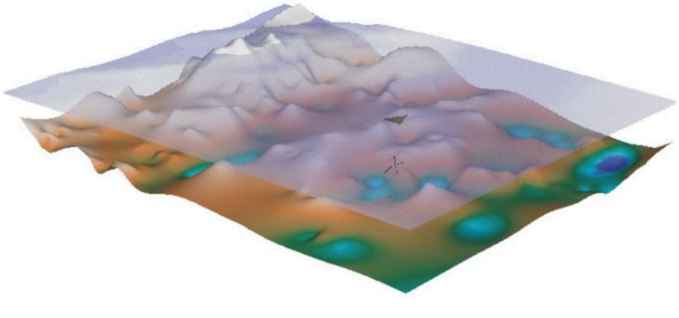

Figure 3: Talos Dome region 3D map.

During the 1999 and 2001 Italian Antarctic Expeditions, extensive airborne radar surveys were carried out over the region Vostok-Dome C and the Aurora trench (about 6000 km of radar tracks were acquired). The aim was to define the morphological characteristics of the Aurora Trench and to improve the subglacial lakes exploration (fig. 4 shows the Vostok lake radar signal) [10]. The radar data allowed to determine the ice thickness and the bedrock topography (the red line in fig. 4) over the entire area; in addition, the analysis of the shape and the amplitude of the bottom reflections, revealed 30 radar profiles as sub glacial “lake” mirrors already catalogued and 19 new subglacial lakes in the Dome C Vostok region [11],[12].

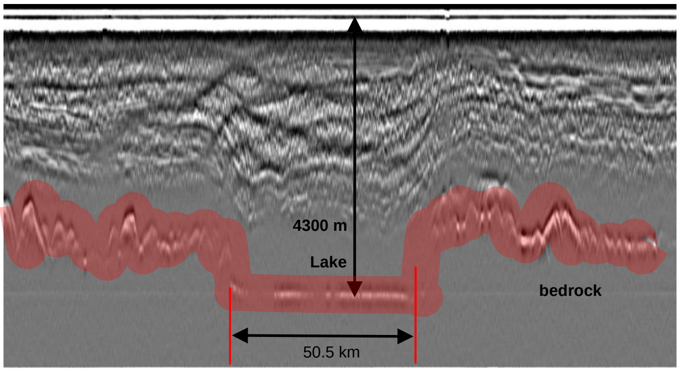

Figure 4. Vostok lake RADAR signal

The Aurora trench deepest point (on fig 5), located at 118.328° E; 76.054°S, shows bedrock elevation of 1549 m below the sea level and an ice thickness of 4755 m [11]. This location must be counted among the thickest ice coverage ever discovered in Antarctica .

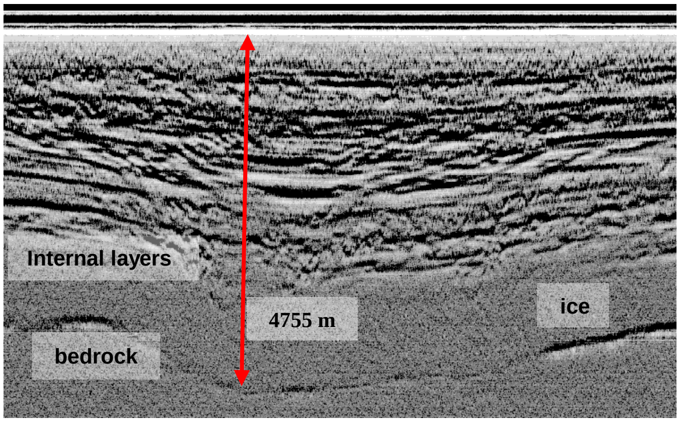

Figure 5 Aurora trench deepest point

2003 campaign is the widest Italian Radar measurements (more then 30’000 km in 35 flights) to estimate the bedrock topography and the mass balance on eastern Antarctic ice-cap. All the new data collected are under elaboration and will be published in next years.

A new data analysis will start to distinguish the different bottom interfaces ice-water or ice-rock to map the hydro-geological network of the bedrock in Antarctica.

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