INTEGRATION OF ENVISAT-ASAR DATA IN A HAZARD-MONITORING-GIS ENVISAT PROJECT [ID 142]

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ABSTRACT

A substantial collection of multi-sensor SAR data sets (C-, L-Band) produced in the course of research on disaster monitoring in Iceland, carried out under the auspices of ESA, NASDA and CSA since 1992, is now at the disposal of the ongoing ESA project „Hazard Assessment and Prediction – Long-term Observation of Icelandic Volcanoes and Glaciers Using ENVISAT-ASAR and Other Radar Data" (ID 142).

This valuable material allows the long-term assessment and analysis of the surface changes observed in the highly active Neovolcanic Zone of Southern Iceland. Combined with other geoscientific information (air-based, space-based and ground data) this database plays an important role in devising early–warning methods.

To fully use all the space-related information at hand, a multi-source GIS has been developed. Processed ENVISAT-ASAR data are continuously fed into it.
This GIS, in addition to the results of 12 years of research, was specially developed to meet the conditions of the southern regions of Iceland and should enable near real time monitoring of surface changes and dynamic processes. Risk assessment and prediction models can be made available whenever needed.

INTRODUCTION

Due to climatic and physical conditions Iceland presents an ideal test site for monitoring subglacial volcanism with radar remote sensing. Approximately 11 % of the 103.000 km² volcanic island is glaciated, consisting mainly of the four large plateau glaciers Vatnajökull (8.100 km²), Langjökull (953 km²), Hofsjökull (925 km²) and Mýrdalsjökull (596 km²) [6]. The huge ice masses of these glaciers cover various volcanic systems with central volcanoes, crater chains and fissures. The rift zone of the Mid-Atlantic ridge is responsible for the high seismic and volcanic activity. Iceland´s Sudurland Fracture Zone (SE - NW) connects the eastern and western neovolcanic zones (SW – NE) in the southern part of the island. The active rifting continues from the center of Iceland as a single zone (S – N) to the north coast. The neovolcanic zone covers roughly 35.000 km², approximately 1/3 of the island (Fig. 1). Since the end of the last ice age, about 200 volcanoes have been active with a magma flow between 400 – 500 km³. Since the first human settlements 1.100 years ago, 40 km³ of magma have erupted from 30 volcanic systems [9] [4]. All Icelandic subglacial events are characterised by phreatic eruptions which melt huge volumes of ice resulting in glacier torrents (Icl. "jökulhlaup"). The subglacial eruption of Gjálp (Sept. 30 - Oct. 13, 1996) under Vatnajökull and the subsequent jökulhlaup (Nov. 5 – 7, 1996) are a good example of such an event today. During this 48 hour cataclysm, a volume of 3,4 km³ of meltwater was discharged at a maximum of 53.000 m³/s, destroying the local infrastructure (roads, bridges, dams, power and telephone lines, etc.) in Skeidarársandur [10].

TEST SITE MÝRDALSJÖKULL

Recent efforts have been directed towards the Mýrdalsjökull test site (596 km²). This plateau glacier covers the approximately 100 km² large caldera of the Katla central volcano (Fig. 1). In view of the eruption cycle of this subglacial volcano (dormant phase maxima 80 years, minima 13 years) and the marked increase in seismic activity since 2000, a fresh outbreak releasing huge glacial torrents is expected in the near future. At the peak of the last major event in 1918 the glacier's discharge reached a volume of 300.000 m³/s.

Mýrdalsjökull is divided in three glacial-morphologic units. The central unit is a 130 km² ice sheet consisting of the icecap Godabunga in the NW (1.480 m a.s.l.) and Háabunga in the south (1.450 m a.s.l.). The ice shield Slettjökull, with a size of 140 km², forms the northern unit and descends to 625 m a.s.l. The third unit consists of steep outlet glaciers to the east, north and south of the central plateau. These highly dynamic outlet glaciers descend from about 1300 to 100 m a.s.l.; examples are Entujökull in the NW, Kötlujökull in the SE and Sólheimajökull in the SW, where a small glacial torrent occurred on July 18, 1999 (Fig. 1).
Ice thickness and subglacial morphology of Mýrdalsjökull were measured with radio echo sounding

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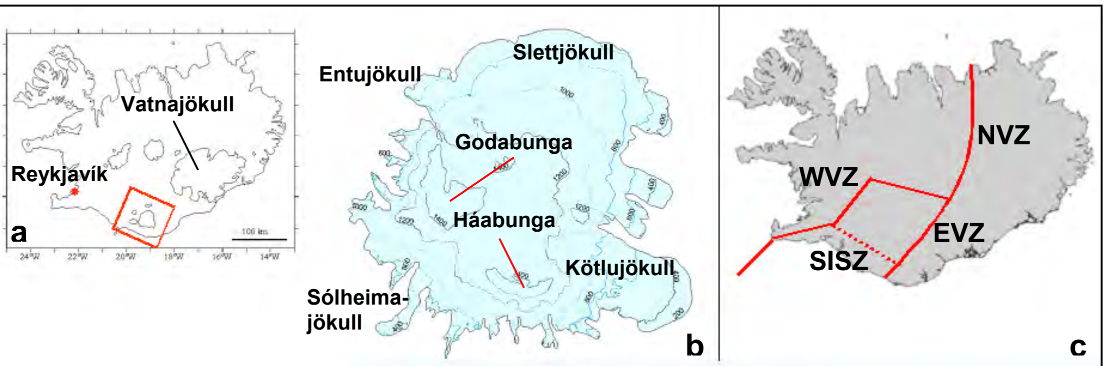

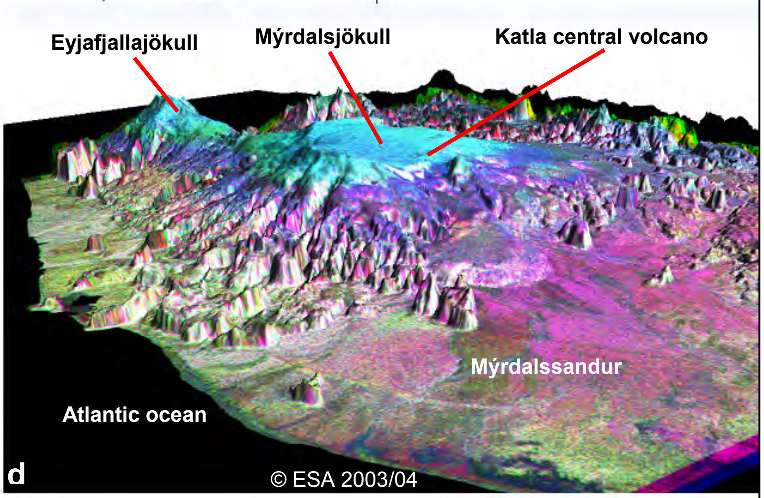

Fig. 1.

a) Location of Mýrdalsjökull testsite in Iceland

b) Enlargement of a

c) The Neovolcanic zone with the southern Iceland seismic zone (SISZ)

d) 3-D view of an RGB overlay of ENVISAT-ASAR images taken 31.10.03/05.12.03/09.01.04

in 2000 [1]. The 100 km² big caldera of the Katla central volcano contains app. 45 km³ of ice. The thickest ice-mass of the glacier, a 12 km² area 600 – 740 m thick, is located in the northern section of the Katla caldera. According to [1], the total volume of ice in Mýrdalsjökull is 140 km³.

The Mýrdalsjökull test site has experienced a sharp increase of seismic activity in the past years: In 2000 672 events, in 2001 405 events, in 2002 1803 events and in 2003 1577 events (>1.0 Richter scale). Considering the Katla eruption cycle and research findings sub-glacial volcanic activity and a catastrophic jökulhlaup at Mýrdalsjökull are to be expected in the near future.

DEVELOPMENT OF A GEOGRAPHIC INFORMATION SYSTEM (GIS)

With the combination of remotely sensed and ground data, important features of subglacial eruptions (e. g. seismic activity, subsidence and uplift) can be detected. For instance, in the ERS-2 project (AO.2 D 116) radar scenes obtained on October 1, 1996 clearly registered the ongoing changes under the ice. The outline and the extent of the eruption fissure could be captured about 24 hours before the Gjálp outbreak 1996 at Vatnajökull [7]. Therefore, the continuation of SAR remote sensing is important for the highly active volcanic zone at Mýrdalsjökull.

The integration of ENVISAT-ASAR data into our running project together with other geoscientific data should create a more effective system to monitor and predict subglacial eruptions.

Various layers supply data on the geology, the hydrology and the ice morphology of the test site Mýrdalsjökull. Lineaments and a precision DEM are provided. Furthermore, facts and figures of past seismic and volcanic events, such as locations of epicentres and eruption sites or details of meltwater discharges, are given.

The geo-information database for the ENVISAT project now consists of 15 distinct layers, which can be combined and correlated because of their unified reference system (Fig. 2).

Due to the large and varied remote sensing database collected over the past 20 years, it is possible to carry out long-term monitoring of the ice structures of Mýrdalsjökull. The SAR data archive comprises JERS-1/SAR, ERS1/2, RADARSAT and ENVISAT-ASAR data of the past 10 years. A rapid inclusion of the latest ENVISAT-ASAR images and their interpretations in the existing GIS is possible.

The GIS database and the fast merging of SAR scenes with other data is essential for hazard monitoring and risk prediction at Mýrdalsjökull.

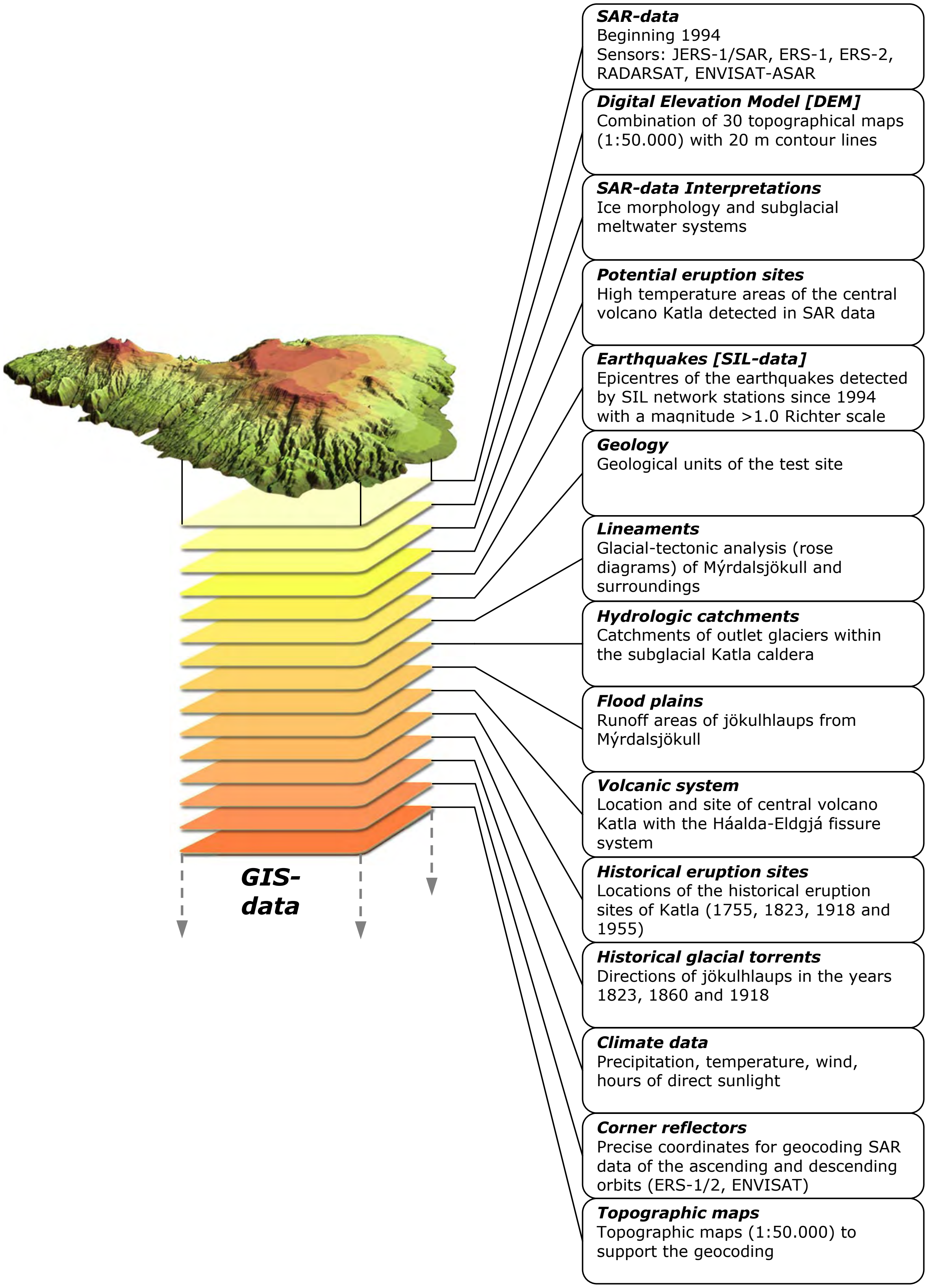

Fig. 2. Data layers of the Geographic Information System for hazard monitoring at the Mýrdalsjökull test site

SAR DATA PROCESSING

The primary purpose of the ENVISAT project is the implementation of an effective data processing chain utilizing the software ERDAS Imagine 8.7 and RSG (Remote sensing Software Graz) 4.60, as well as Arc View 3.3 for hazard monitoring. The integration of ENVISAT-ASAR and other SAR data (ERS-1/2) into the GIS is now possible in ca. 90 minutes (Fig. 3). Therefore, rapid risk assessment at the highly dynamic volcanic test site Mýrdalsjökull is now possible.

Due to the diverse configurations made available by the ASAR antenna, we were able to select the ENVISAT-ASAR mode IS 2 (incidence angle 21,5°) to provide continuity with the older ERS-1/2 data. We are also using ASAR products of mode IS 5 (incidence angle 37.5°) because of the high relief of the test site. For possible interferometric analysis in the future, the ENVISAT scenes are received as Single Look Complex data (ASA_IMS-1P) [11]. The first step in the data processing chain is the extraction of amplitude information from the SLC data with a simultaneous multi-look processing (Fig. 3).

A parametric rectification method is used to integrate the data into the GIS. This processing step is necessary due to SAR inherent recording characteristics and the influence of topography (layover, foreshortening and shadow). The terrain correction is achieved with an elevation model (contour lines 20 m) which was constructed under the ERS projects (AO.2 D 116, AO.3 A 238) and extended under the current ENVISAT project [6].

The 30 corner reflectors installed in 1995 and 1998, can be fully used in the current project because the ENVISAT and ERS satellites have the same orbit and incidence angle (IS 2 = 21.5°). Therefore, it is possible to reduce the processing time for terrain geocoding to 60 minutes. This is equally possible with the ENVISAT-ASAR scenes, mode IS 5 despite of the much steeper incidence angle (37,5°). The use of the corner reflectors enables a position accuracy of 1–2 pixel.

In order to enhance the information content on the ice structures –without crucially extending the processing time- the amplitude data are transformed into power images with the following simple equation:

$$P\,[db] = 10 * \log_{10}(A^2)$$

A = Amplitude

The result is a more homogeneous gray value distribution. Thereby, more details are visible on Mýrdalsjökull glacier as well as in the periglacial

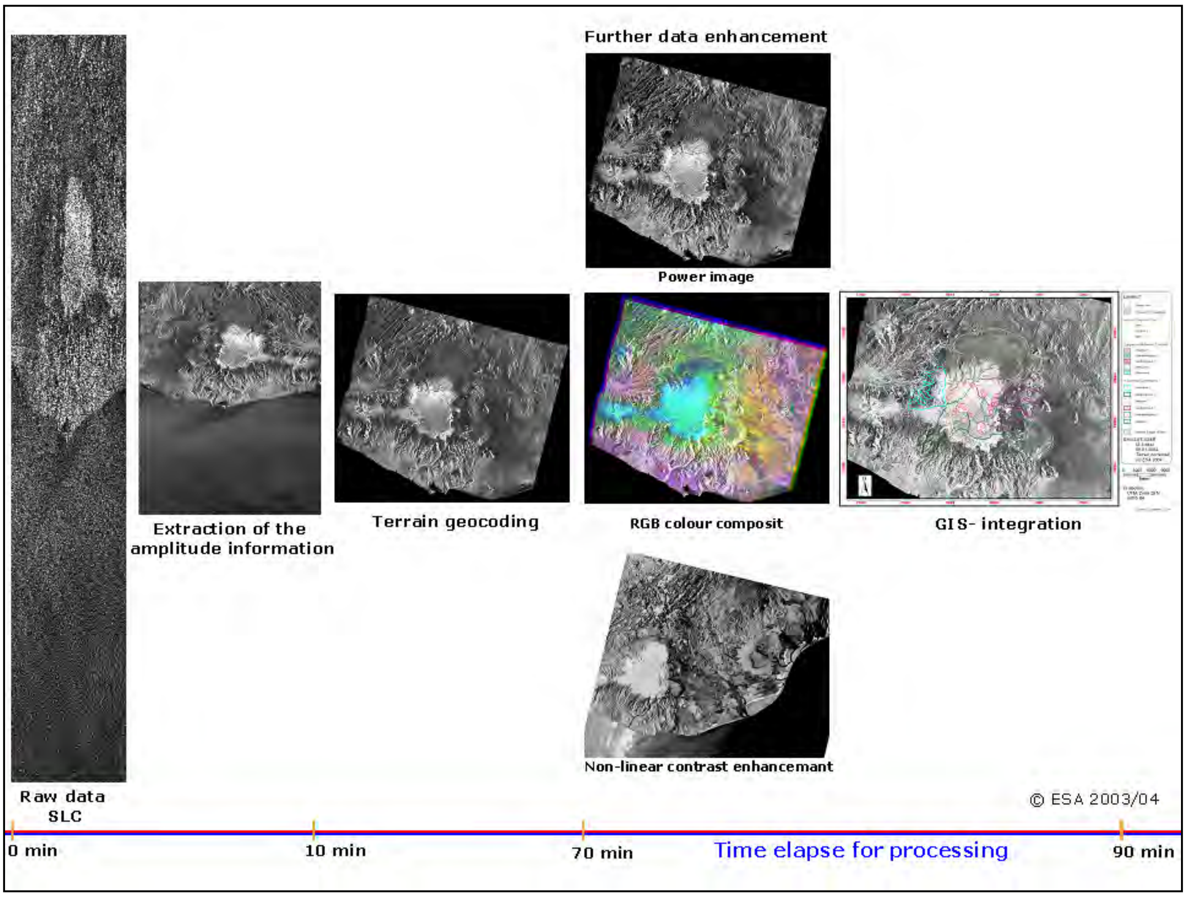

Fig. 3. The data processing chain

forefield. Furthermore, a non-linear stretch is made to optimise contrast (Fig. 4).

A next step in image enhancement is the overlay of selected SAR scenes to obtain a RGB colour composite. This is done by merging terrain geocoded scenes pixel by pixel to reduce positional distortions and other errors.

All processing steps mentioned are operated within 90 minutes. The SAR products are then fully integrated into the GIS for analysis of the actual risk potential for subglacial events.

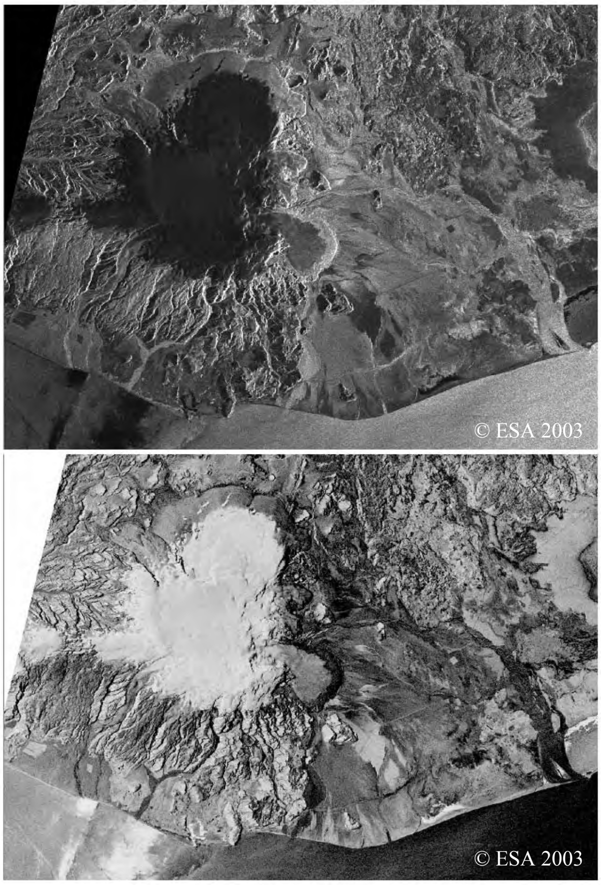

Fig. 4. ENVISAT-ASAR amplitude and enhanced power image, 27.07.2003

RESULTS

Our recent research demonstrates the possibility to generate fast and varied hazard scenarios by the integration of ENVISAT-ASAR images into the geographic information database comprising 15 layers.

The interpretation of the 5837 earthquakes (> 1.0 Richter scale) detected in the area of the central volcano Katla between Sept. 1994 and July 2004 indicates a significant increase in activity (especially since the year 2000).

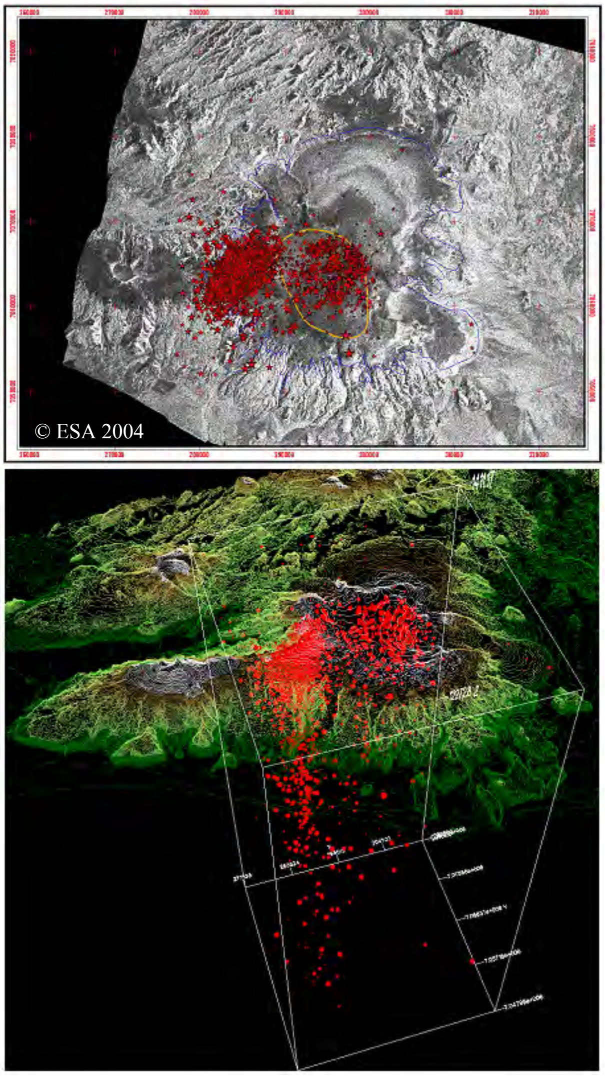

Fig. 5. Location of earthquakes shown in an ENVISAT-ASAR scene (23.04.2004) and a 3-D view of the area

The epicentres of the earthquakes occur in two distinct swarms: a western and an eastern cluster. The western cluster is located outside the caldera, between Mýrdalsjökull and Eyjafjallajökull (Fig. 5). The annual distribution of earthquakes in this cluster peaks in fall and winter. The eastern cluster is located within the

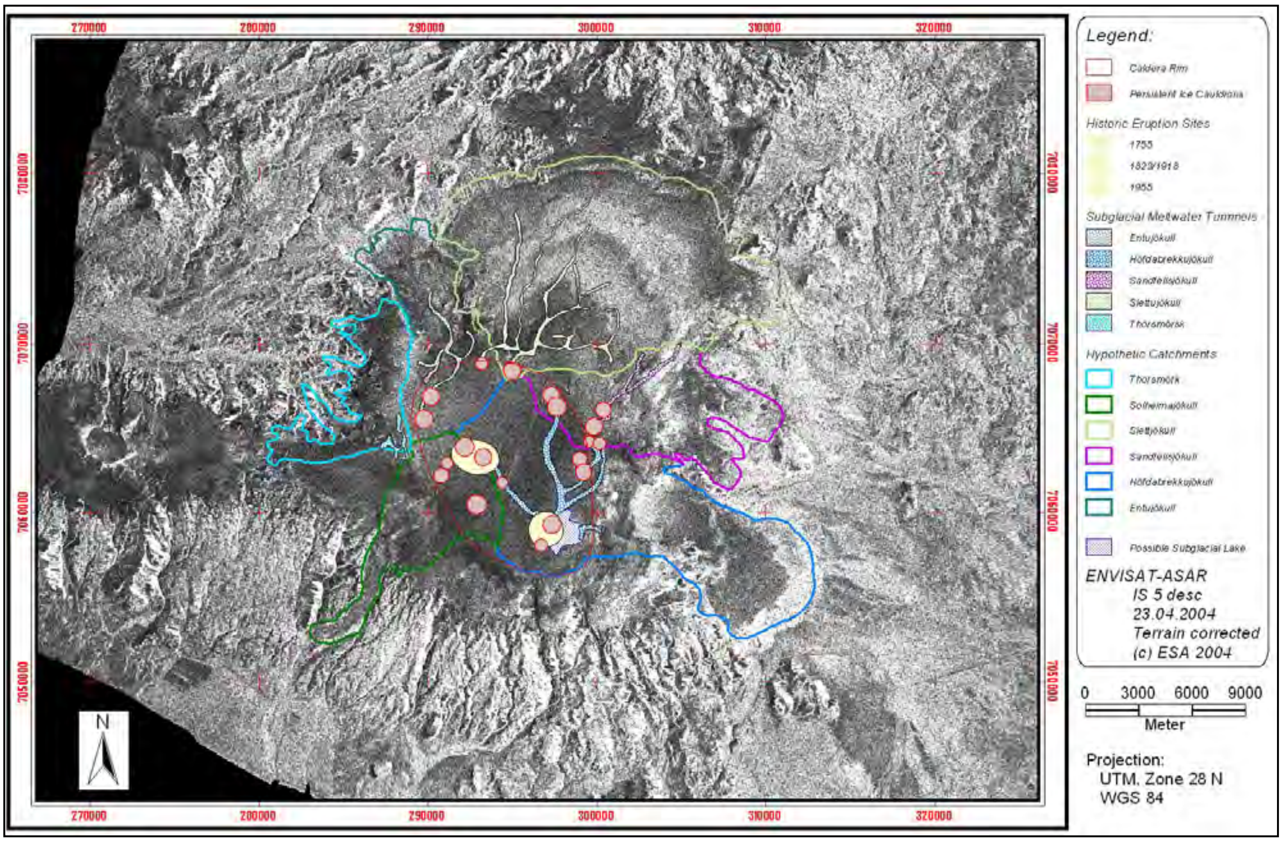

Fig. 6. ENVISAT-ASAR scene (23.04.2004) fully integrated in the GIS

Katla caldera. Earthquakes in this swarm occur mainly during the summer months when the pressure of the ice sheet is reduced due to ablation or triggered by other meltwater processes [2].

Every linear subglacial structure is connected to a single depression which represents a geothermal active location. Altogether, 20 geothermal active spots are found in the area of the Katla volcano: 16 within the caldera, and four just outside the north-eastern rim (Fig. 6).

A comparison of the 20 geothermal locations with the known eruption sites of 1755, 1823, 1918 and 1955 indicates a stable position of these “hot spots”.

It is possible to predict the periglacial regions threatened by a devastating jökulhlaup by exact coordination between the geothermal locations, meltwater tunnels and their corresponding catchments.

A precise prediction and risk analysis of a subglacial eruption or glacial torrent is now possible by integrating ENVISAT-ASAR data and their interpretations into the Geographic Information System.

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REFERENCES

1. Björnsson H., Pálsson F. & Gudmundsson M. T., Surface and bedrock topography of the Mýrdalsjökull ice cap, Iceland: The Katla caldera, eruption sites and routes of jökulhlaups, *Jökull* 49, 29-46, Reykjavík, 2000.

2. Einarsson P. & Brandsdóttir B., Earthquakes in the Mýrdalsjökull area, Iceland, 1978-1985: Seasonal correlation and connection with volcanoes, *Jökull* 49, 59-74, Reykjavík, 2000.

3. Jakobsdóttir S. S., Gudmundsson G. B. & Stefánsson, R., Seismicity in Iceland 1991-2000 monitored by the SIL seismic system, *Jökull* 51, 87-94, Reykjavík, 2002.

4. Krafft M., *Führer zu den Vulkanen Europas Band 1: Allgemeines – Island*, Stuttgart, 1984.

5. Larsen G., Holocene eruptions within the Katla volcanic system, south Iceland: Characteristics and environmental impact, *Jökull* 49, 1-28, Reykjavík, 2000.

6. Münzer U., Bahr T., Weber-Diefenbach K., *Katastrophen-Monitoring am Beispiel Islands. Schlußbericht Förderkennzeichen 50 EE 9706*, München, 2000.

7. Münzer U. & Weber-Diefenbach K., Remote Sensing of Subglacial Eruptions in Iceland and Development of Related Warning Systems, *Proceedings „International Conference on Early Warning Systems for the Reduction of Natural Disasters" (EWC '98)*, 515-520, Berlin, 2003.

8. Rott H., Sturm K. & Miller H., Active and passive microwave signatures of Antarctica firn by means of field measurements and satellite data, *Ann. Glaciol.*, 17, 337-343, 1993.

9. Saemundsson K., Outline of the Geology of Iceland, *Jökull* 29, 7-28, Reykjavík, 1979.

10. Snorrason Á., Jónsson P., Pálsson S., Árnason S., Sigurdsson O., Víkingsson S., Sigurdsson Á., Zóphoniasson S., Hlaupið á Skeiðarársandi Haustið 1996. Útbreiðsla, Rennsli og Aurburður, *Vatnajökull. Gos og Hlaup 1996*, 79-137, Reykjavík, 1997.

11. Björnsson H., Rott H., Gudmundsson S., Fischer A., Siegel A. & Gudmundsson M.T., Glacier-volcano interactions deduced by SAR interferometry, *Journal of Glaciology*, Vol. 47, No. 156, 58-70, 2001.