Centro di Ricerche Sismologiche

Monitoring in real time the North East Italy seismicity: the OGS-CRS experience with the Antelope software suite

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1. The seismometric network

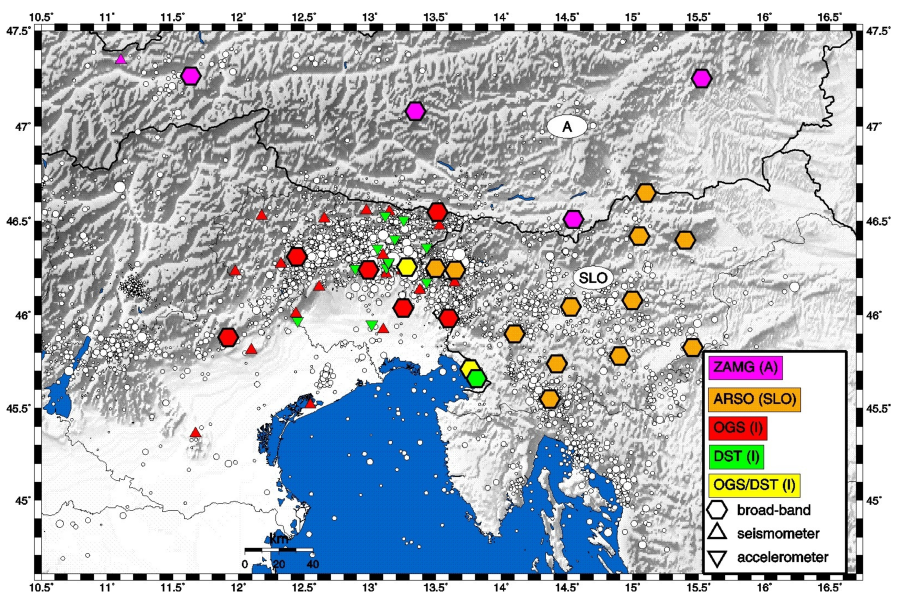

Fig. 1

The large amount of digital data recorded by permanent and temporary seismic networks makes data mining of great importance. The Centro di Ricerche Sismologiche (CRS, Seismological Research Center, http://www.crs.inogs.it/) of the Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS, Italian National Institute for Oceanography and Experimental Geophysics) manages a network of short-period, broad-band and accelerometric stations in North-eastern Italy (red and yellow symbols in Fig1, in Fig.2 the detail of the broad-band station on Mt. Zoufplan). It also acts as one of the data collection centers of the trans-national seismological network of the South-Eastern Alps, a virtual network developed since 2002 (initially in the framework of the EU Interreg IIIA project "Trans-national seismological networks in the South-Eastern Alps") in collaboration with the Earth Science Department of the Trieste University (DST) in Italy, the Civil Protection Department of the Friuli-Venezia Giulia Autonomous Region (DPCFVG) in Italy, the Environmental Agency of the Republic of Slovenia (ARSO), and the Austrian Central Institute for Meteorology and Geodynamics (ZAMG). The Antelope software suite has been chosen as the common basis for real-time data exchange, rapid location of earthquakes and alerting. Each institution has an instance of Antelope running at its data center and acquires data in real-time from its seismic stations and those of the other partners (Figure 1). Currently an extension of the project open to other parties has been submitted for evaluation to the European Union.

Antelope is a powerful software suite that easily allows sharing data in real time among neighboring institutions. However it must be tuned to each seismological data center needs in order to extract the special information required. At OGS-CRS we adapted existing programs and created new ones like: a customized interface to manually relocate earthquakes, a script for automatic moment tensor determination, scripts for web publishing of earthquake locations, waveforms, state of health parameters and shaking maps, plus scripts for email/SMS/fax alerting.

Fig. 2

2. Analysis tools

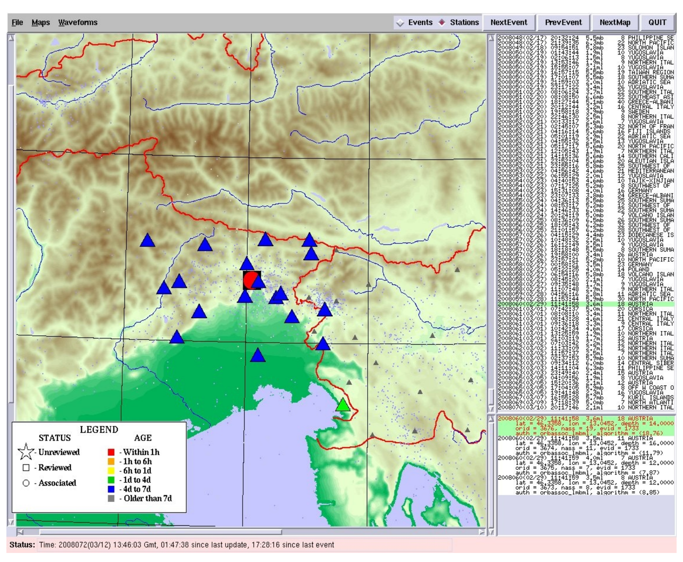

Fig. 3

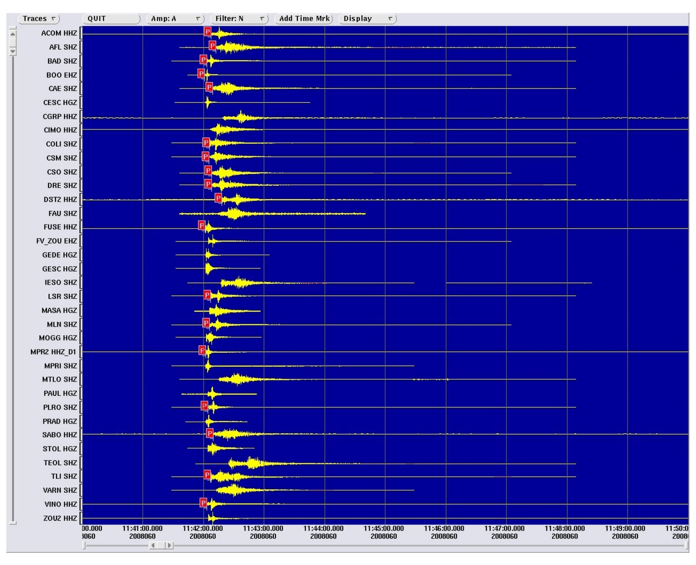

Fig. 4

Figure 3 shows the standard Antelope program *dbevents* that plots automatic and manual locations on a map showing also the contributing seismic stations: the corresponding web program is the modified version of the Antelope program *dbrecenteqs* (Figures 9 and 10 in the next panel). Figure 4 shows the standard Antelope program *dbpick* used for phase picking. Since 2004 at OGS-CRS for bulletin production we use the Anthony Lomax' SeisGram2k seismogram visualization and analysis software (Figure 5) that provides useful features like multi-component analysis tools, interactive zooming, scaling, rotation and transformation of the seismograms and animated, 3D particle motion visualization. In order to keep using the SeisGram2K software, we needed to feed SeisGram2k with picks and waveforms from Antelope: therefore we wrote in Java an ad-hoc interface - shown in Figure 6 - starting from software developed by A. Govoni. It automatically selects the time window from each event and cut the waveforms at the right length providing also all the information about picks in SAC format.

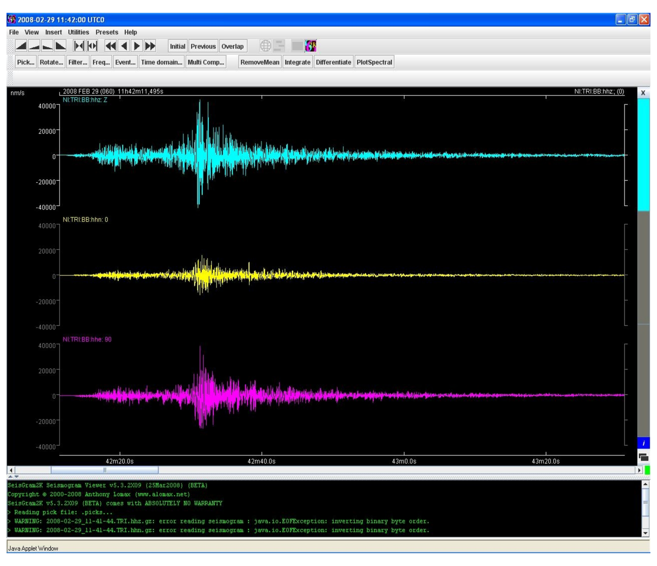

Fig. 5

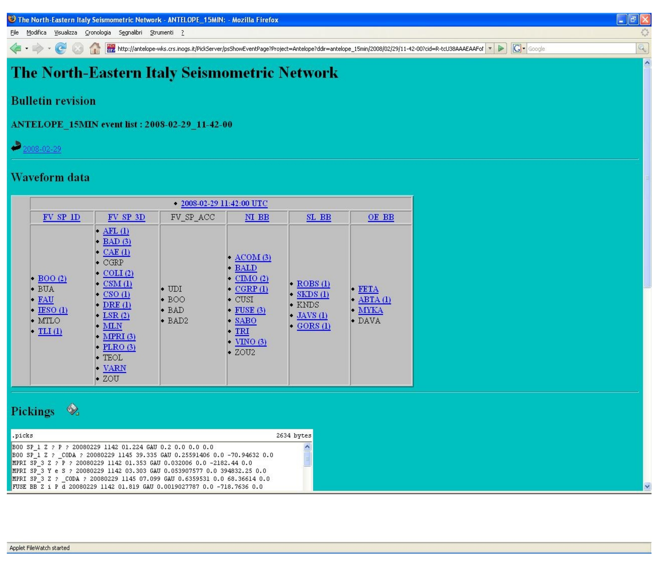

Fig. 6

3. Moment Tensor inversion

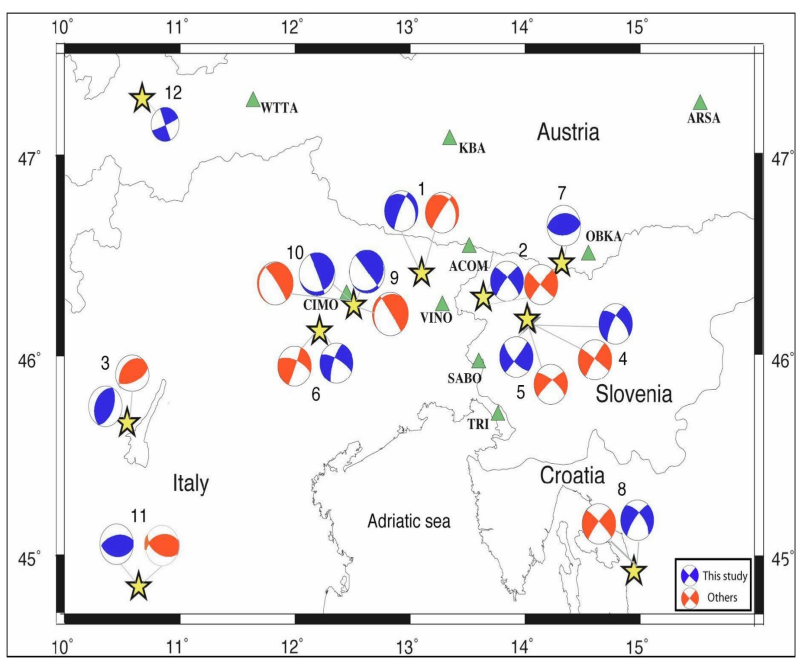

Fig. 7

N	Date	Time	M_w
1	2002/02/14	03:18	4.7
2	2004/07/12	13:04	5.1
3	2004/11/24	22:59	4.8
4	2005/01/14	07:58	3.8
5	2005/01/14	08:05	3.6
6	2006/12/28	14:10	3.6
7	2007/01/01	14:59	3.8
8	2007/02/05	08:30	4.3
9	2007/02/26	05:50	3.8
10	2007/02/26	14:16	3.6
11	2007/05/09	06:03	3.9
12	2007/05/19	16:19	3.7

Table 1

We also implemented the Time-Domain Moment Tensor INVerse Code (TDMT_INVC, Dreger 2003) to compute - near real time - the seismic moment tensor of local and regional seismicity using data recorded by the CRS broad band network. At the date the procedure is activated for ML ≥ 3.9 earthquake, using scripts we developed deriving data from the Antelope database and converting them in SAC format. We performed several tests, using synthetic and real data, to check the sensitivity of solutions to the station geometry and to the velocity models available for the study region. Our tests revealed hat though the minimum number of stations depends on the epicenter position and on the source radiation pattern, a complete station coverage is not required when three component stations are used and even one station solution can be effective (Saraò 2007). In Fig. 7 we plot the seismic moment tensor (blue beach balls) computed for 12 earthquakes (yellow stars) occurred in the Friuli Venezia Giulia area and surroundings between 2002 and 2007 with Ml ≥ 3.6 (Table 1). The results are compared, when possible, with focal mechanisms (red beach balls) computed by different approaches (SED automatic moment tensor, MEDNET RCMT, first polarity fault plane solutions). The agreement is excellent. Figure 8 shows the details of the solution obtained for an earthquake of magnitude Mw 3.9 occurred near Reggio Emilia on 2007/05/09 (earthquake number 11 in Figure 7 and Table 1) using 4 stations.

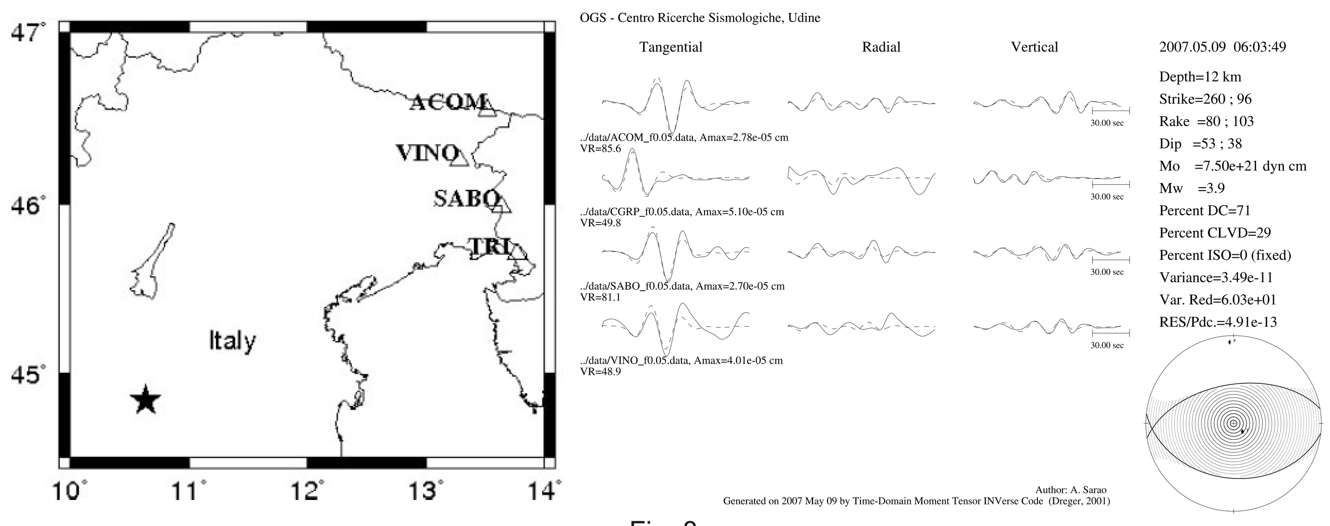

Fig. 8

4. Alerting

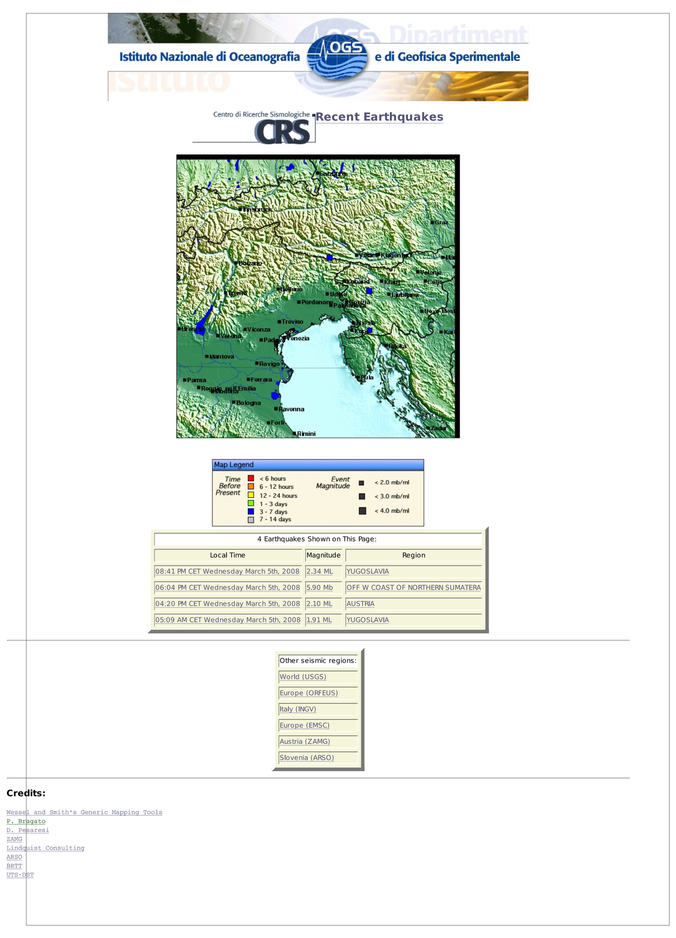

Fig. 9

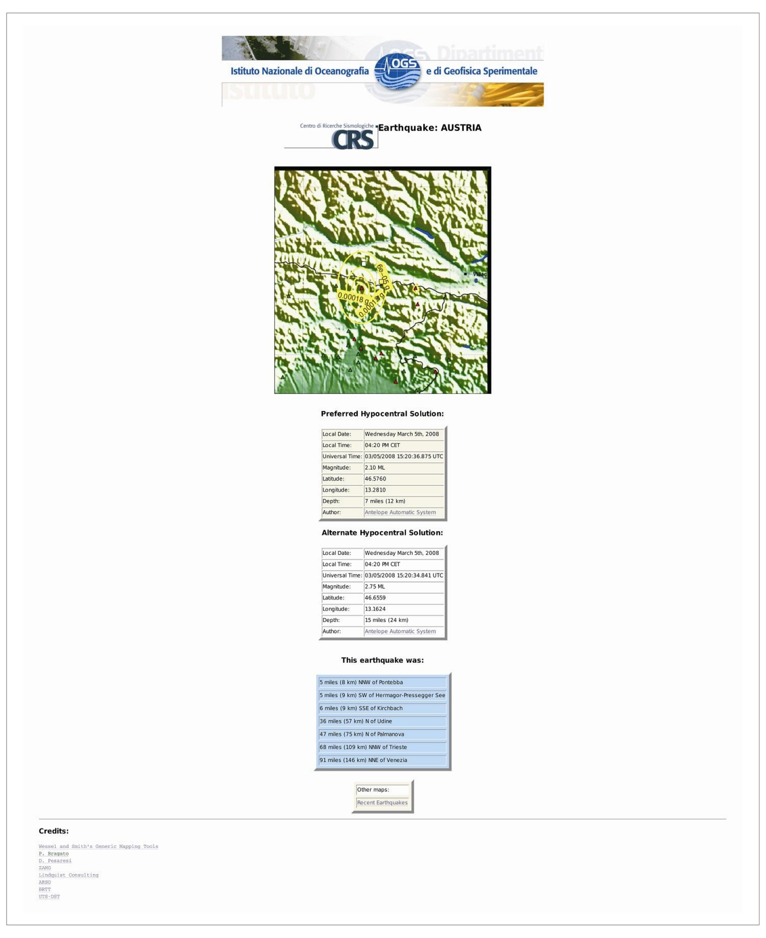

Fig. 10

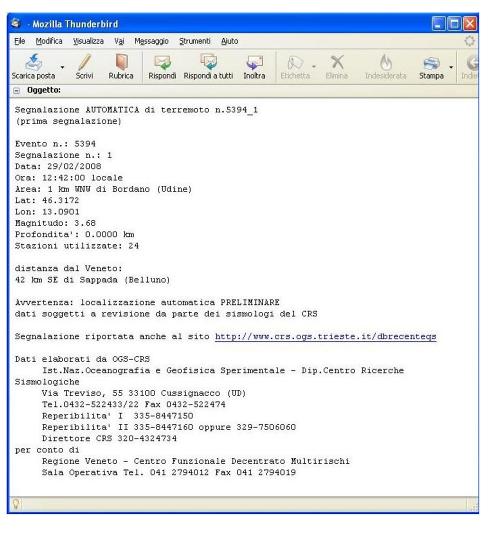

Fig. 11

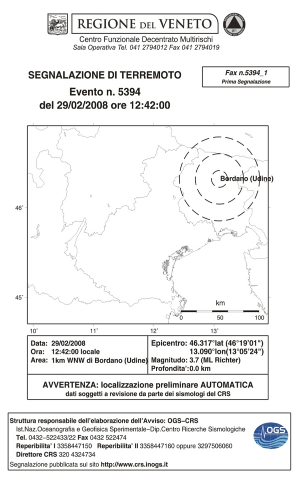

Fig. 12

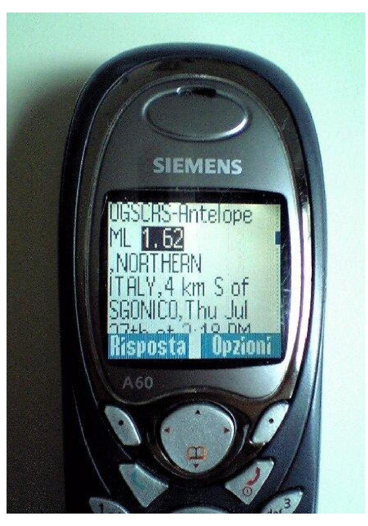

Fig. 13

The automatic and manual locations of the earthquakes occurring in northeastern Italy and surroundings are published on the web as soon as available (typically 2-3 minutes after the event for the first automatic location). The main page (Figure 9) reports the list of events sorted by time as well as their map representation. For each earthquake there is a specific web page (Figure 10) showing the different locations with indication of the preferred one, time, magnitude, nearest cities. The map shows also the assessment of the ground acceleration in yellow lines of equal intensity. Peak Ground Acceleration (PGA) values are derived from the standard Antelope *dbgme* program using the Bragato and Slejko (2005) empirical ground motion attenuation relation for the North-East of Italy.

Earthquake parametric data (latitude, longitude, origin time, depth, local magnitude, region and nearest cities) are also automatically sent via email (Figure 11), fax (Figure 12) and SMS (Figure 13) to OGS-CRS operators, Civil Protections and interested authorities. In order to achieve this, modification of the existing original and contributed Antelope software was necessary.

5. State of health monitoring

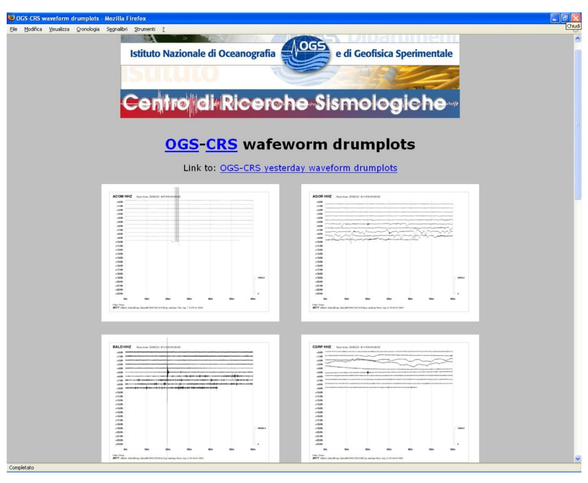

Fig. 14

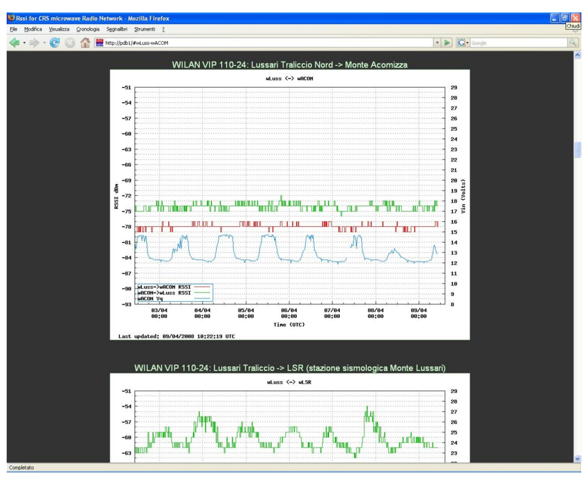

Fig. 15

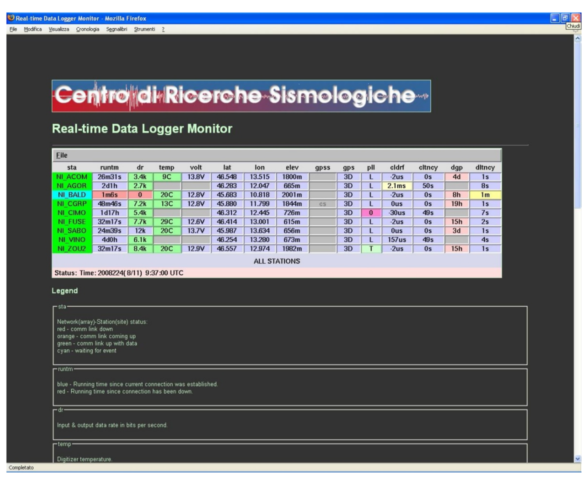

Fig. 16

Visual tools help to monitor the state of health of the system. Much of them are made available through the web for remote control.

Figure 14 shows drumplots of the waveform data published on the web: it helps in monitoring the real time seismicity and the correct functionality of the seismic stations. The drumplot web page is automatically refreshed every 5 minutes, while the daily drumplots of the single seismic stations are stored as JPG files in the Antelope database for further analysis.

Fig.15 shows the HTML page displaying, for each radio-linked station, a 10-day graph with RSSI (Received Signal Strength Indication) and battery voltage plots. The graph helps to detect anomalies in radio transmission and battery state of health and charge.

The web page shown in Figure 16 is updated every 5 minutes: it shows state of health parameters like run time, data rate, temperature, voltage, GPS status, clock drift, clock latency, data gaps and data latency for the broad band seismic data loggers: it makes uses of the standard Antelope program *dlmon*.

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