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A New Broad-Band Seismic Network with Satellite Transmission in Catalonia (Spain)

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Introduction

The Geological Survey of Catalonia operates since 1985 a regional seismic network with the aim of monitoring the seismicity of Catalonia and surrounding areas (Eastern Pyrenees and Mediterranean Sea). The network grew progressively since 1985. It started with analoge, one component, short period stations and 8 years later it has 10 short period, one component stations using different communication and digital recording systems. In 1996 a new concept of seismic network was designed and planned in order to fulfill two main objectives: i) to provide rapid information to Civil Defense services and the general public and ii) to obtain systematically high quality data for the scientific community. It is planned to create robust, high performance field infrastructures and installing up to 20 stations equipped with three component broadband sensors with high dynamic range. The stations are based on VSAT platforms sending continuous almost real time seismic data via satellite to the Hub at the processing center of the Institut Cartogràfic de Catalunya (ICC). Data are continuously stored and processed with an automatic location system. Information is disseminated via Internet, after validation by seismologists. Event information and waveforms are available on our web page: www.icc.es. At present (May, 2001) 5 fields stations are operative.

The Network

The project of implementation of the seismological network is proposed in three phases as shown in Figure 1. Since 1999, the first three VSAT based seismic stations (numbered 1, 2 and 3 in Figure 1) with Güralp CMG-40T sensors (0.03Hz-50Hz) are operative, together with the reception and processing center. In a second phase, 2 new stations (numbered 4 and 5 in Figure 1) with STS-2 (0.01Hz - 50Hz) and Güralp CMG-3ESP (0.01Hz-50Hz) sensors have been installed. Three more stations are now under construction (6, 7 and 8 in Figure 1).

Figure 1. Implementation phase of the seismic network.

In a third phase about 12 more stations will be installed. Moreover it is planned to share data from stations belonging to other institutions as the Ebro Observatory, the Institut d'Estudis Catalans and the Instituto Geogràfico Nacional. A big effort is devoted to select adequate sites and to design and construction of the different elements of a remote station with the aim to have reliable, robust, low noise and durable stations. In Figure 2 a view of Organyà seismic station (CORG), in the Pyrenees, is shown with the seismometer vault, the instrumental house, the solar cells and the VSAT antenna. All stations are provided with high performance electrical and environmental protections.

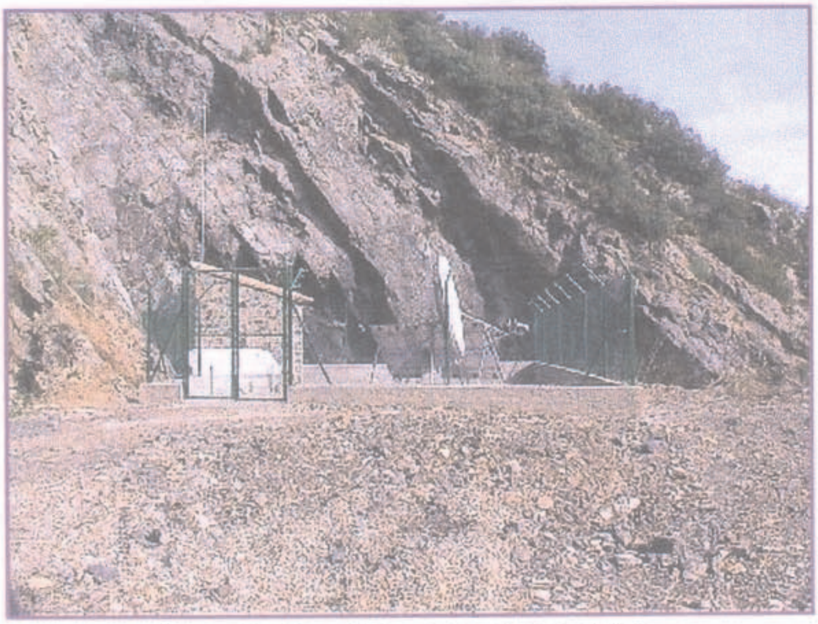
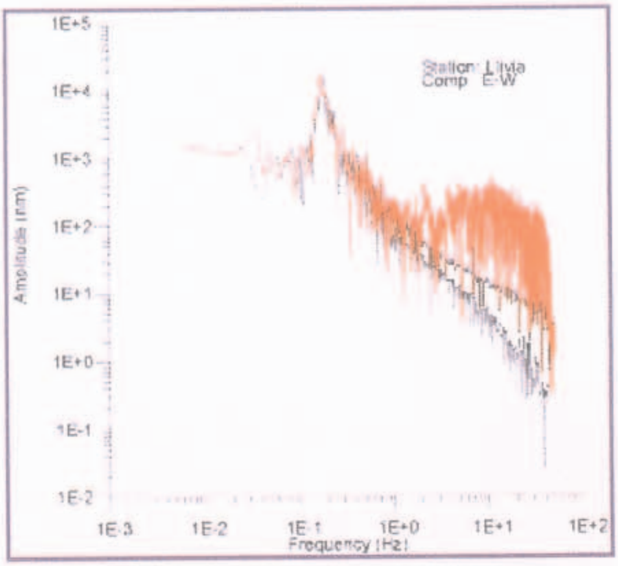


Figure 2. View of Organyà seismic station.

Records of high quality are obtained from the operating stations. An example of low magnitude (M_L=1.9) earthquake recorded at short distance (40 km) in Llívia station (CLLI) is shown in Figure 3, where broadband records obtained on a CMG-40T sensor are presented together with high-pass filtered records at 1 Hz. Fourier spectrum of E-W component is also shown together with the noise spectrum. A good signal/noise ratio is observed for frequencies higher than 1 Hz. Another example is shown in Figure 4 for a Japanese earthquake of M=6.5 recorded at Llívia station (Δ =90°) on a broadband CMG-40T sensor. A record of 1 hour of duration is shown and the Fourier spectrum of surface waves recorded on the E-W component is presented together with the noise spectrum. A good signal/noise ratio is observed between 10s and 100s.



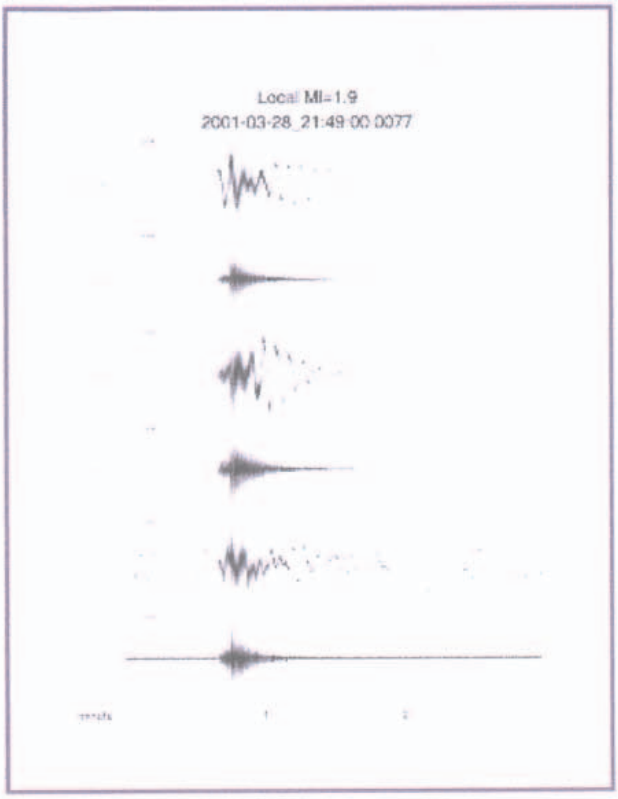


Figure 3. Left: Broadband records obtained on a CMG-40T sensor and high-pass filtered records at 1 Hz. Right: Fourier spectrum of E-W component (red) and noise spectrum (black).

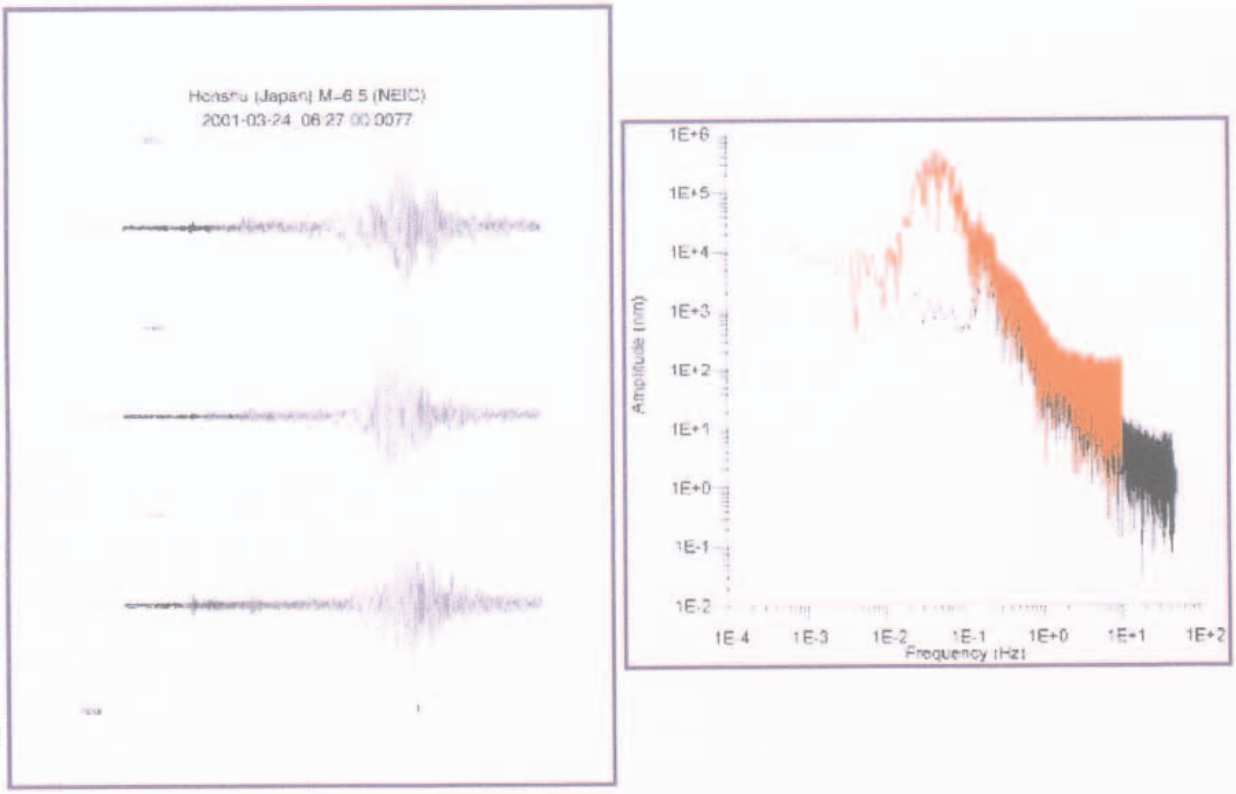


Figure 4. Left: Broadband records obtained on a CMG-40T sensor Right: Fourier spectrum of E-W

component (red) and noise spectrum (black).

System Description

VSAT network consists of a central data acquisition facility located in Barcelona, and remote stations around Catalonia (LIBRA VSAT Network, manufactured by Nanometrics, Canada). The Hub and remotes communicate via the Hispasat 1, a geostationary satellite using 100 kHz of bandwidth providing 112/64 kbps of data throughput. The system uses the same carrier for the inbound and the outbound, minimizing the required bandwidth (see Figure 5). At each station in the network (Hub and remotes) a slot within a time domains multiple access protocol (TDMA) is assigned, and it transmits only when authorized. At each remote site an HRD24 Nanometrics digitizer receives seismic signal from a broadband sensor installed in a vault, and samples it at 100 sps and streams the data to the remote VSAT terminal. The data are transmitted to the central Hub using UDP/IP protocol and a header (NMXP) containing a unique sequence number. When data are received at the Hub the sequence numbers are checked for continuity, and if data are missing, a retransmission request is automatically sent from the Hub to the remote. Data are stored in ring buffers at remotes (2.5 hours of backup) and are retransmitted to the Hub if requested. At the data acquisition center in Barcelona, received data are sent from the Hub over a LAN to one computer, in which they are stored into ringbuffers.

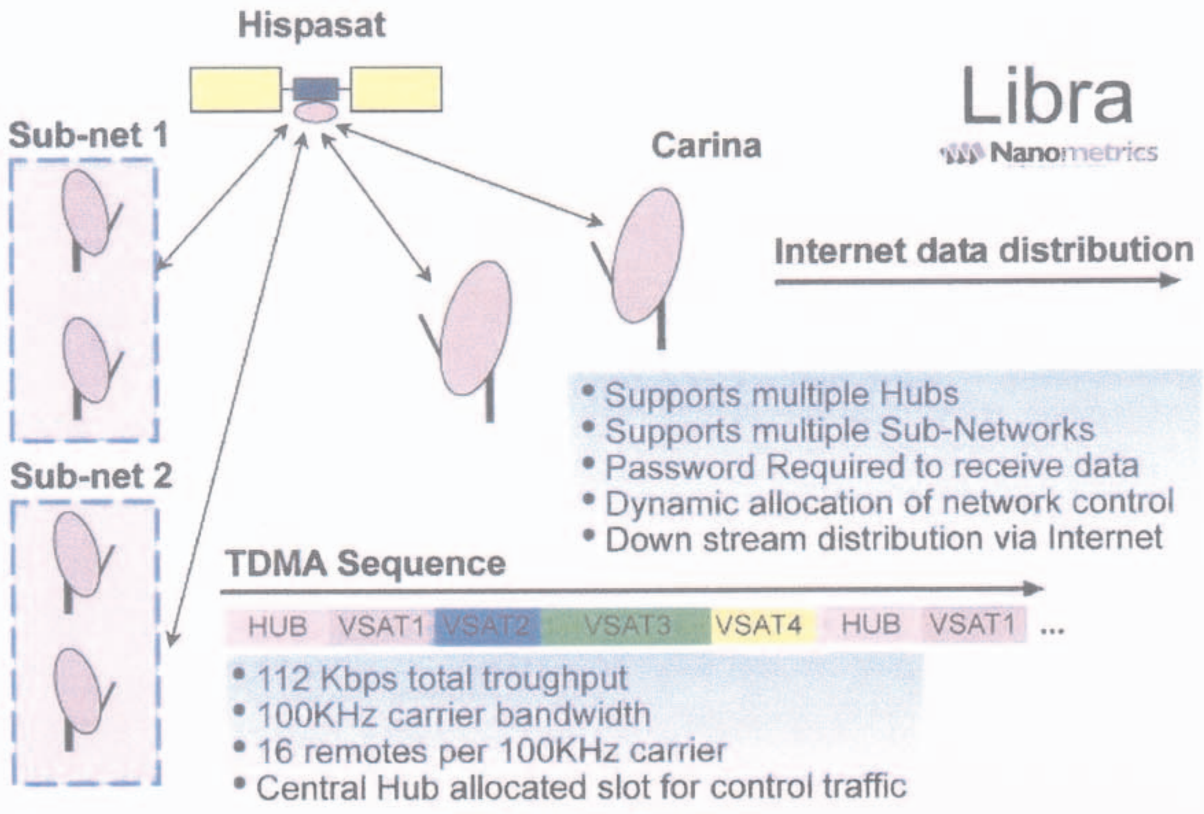


Figure 5. Libra VSAT network.

Acquisition system

The digitizer uses a fixed resolution sigma-delta A/D converter on each channel providing 120 dB of resolution after digital filtering and a sample rate of 256 kHz. Antialiasing filtering protection is applied to the signal using a DSP processor, which decimate the data to obtain the expected sample rate, in this case 100 sps. The digitizer can be modified to obtain the desired sensivity in nm/s/count, so we can combine different seismometers from the same network without significant differences in the output sensitivity. Seismic data are timed at each remote site using a temperature compensated crystal oscillator phase locked to a GPS time code receiver. Data are assembled into packets with CRC for error correction. Each packet includes a comprehensive header which holds parameters such as the sequence number, time in long seconds and the oldest packet available for retransmissions if required. To ensure efficient use of communications system the data are compressed prior to transmission. The compression scheme used yields approximately 1.2 bytes per sample and is fully recoverable with no errors. These data are recorded into local ringbuffers before be forwarded to the VSAT modem. So, system has a remote data backup of the last 2.5 hours of acquired data. One more feature of the digitizer is its capability for monitoring some parameters of the remote stations and generating multiple state of health messages. All this information are sent to the Hub. Thus, it is possible to monitor some parameters of the remote station, such as battery voltage, digitizer temperature, GPS status, bytes sent, log messages, etc. from the central site and have them stored into separate ringbuffers.

Communications system

Each remote station has a full satellite communications system, which basically consists of a Ku-band 1.8 m diameter antenna, a Ku-band VSAT modem, a GPS time code receiver, a Ku-band LNB and a Ku-band SSPB. The VSAT modem receives the seismic data packets from the digitizer and formats them as UDP/IP data prior to modulating the data for transmission over the satellite link. The transmission data rate of the VSAT modem can be set for either 64 or 112 Kbps. The Libra network distributes the bandwidth between a number of Lynx remote stations using a time domain multiple access protocol (TDMA). In a TDMA system a number of stations are configured to share the same frequency, each station transmitting during a precisely defined time window or slot. During one transmission slot, the selected remote site transmits at the full rate of 64 or 112 kbps. The durations of the slot is set to provide the required continuous data rate. The satellite communications system provides a half duplex communications link between each remote site and the central data acquisition facility. The TDMA configuration includes a number of inbound slots during each remote site transmitting seismic data to the central Hub and one outbound slot during which the central Hub communicates with all the remotes sites. The communications data rate for the Hub and the remotes is configurable by the user. In general, the traffic from the Hub to the remotes is very little, and it is used for data retransmission request, TDMA configuration command and remote control. Similar to the acquisition system, communications system has the capability to produce a fully state of health summary and to be remotely controlled. Thus, the user from the central site can monitor the state of each remote communications modem and perform a remote control of the communications parameters. Inbound seismic data from the remote field stations are received at the central site via a 3.8 m antenna. The indoor assembly consists of a Carina combiner/splitter module and a number of Carina transceivers. Each Carina transceiver tunes to a single space segment frequency (100 kHz) and receives all data from stations transmitting on that frequency. Typically, 16, 3-componnent remote field stations are configured to operate a single 100 kHz space segment channel. The Carina transceiver demodulates de seismic data and forwards it as TCP/IP packets to the central acquisition computer(s) via a 10Base-T LAN connection. We can consider the entire network as a WAN IP network, which is customized depending of the requirements. So, the network can include some subnetworks to obtain the desired topology. This facility allows different networks to share data in real time.

Data reception, storage and processing center

At the central site, an acquisition computer stores the seismic data into ringbuffers with a capacity of 16 days of data using NAQS Server software. NAQS Server software is a primary software element for data adquisition and seismic data handling. This software performs the following functions:

- Provides data error correction via the retransmission request of missing or corrupted packets from the remote stations.
- Stores all continuous time series data to disk based ringbuffers.
- Distributes continuous waveform, trigger and state-of-health data via TCP/IP private data streams.
- Records remote and central site state-of-health data to disk based ringbuffers.
- Monitors state-of-health data for out of range parameters.
- Provides for real time display of seismic waveform data.

Backups of all the seismic and state-of-health data stored into ringbuffers are made often, to ensure the data integrity and for a final storage. Seismic data and triggers are automatically processed by a Data Analysis Computer, which performs the automatic event detection, and determinates the hypocenter and the magnitude of the earthquake. A complete documentation of each event location is automatically generated.

Performance of the Network

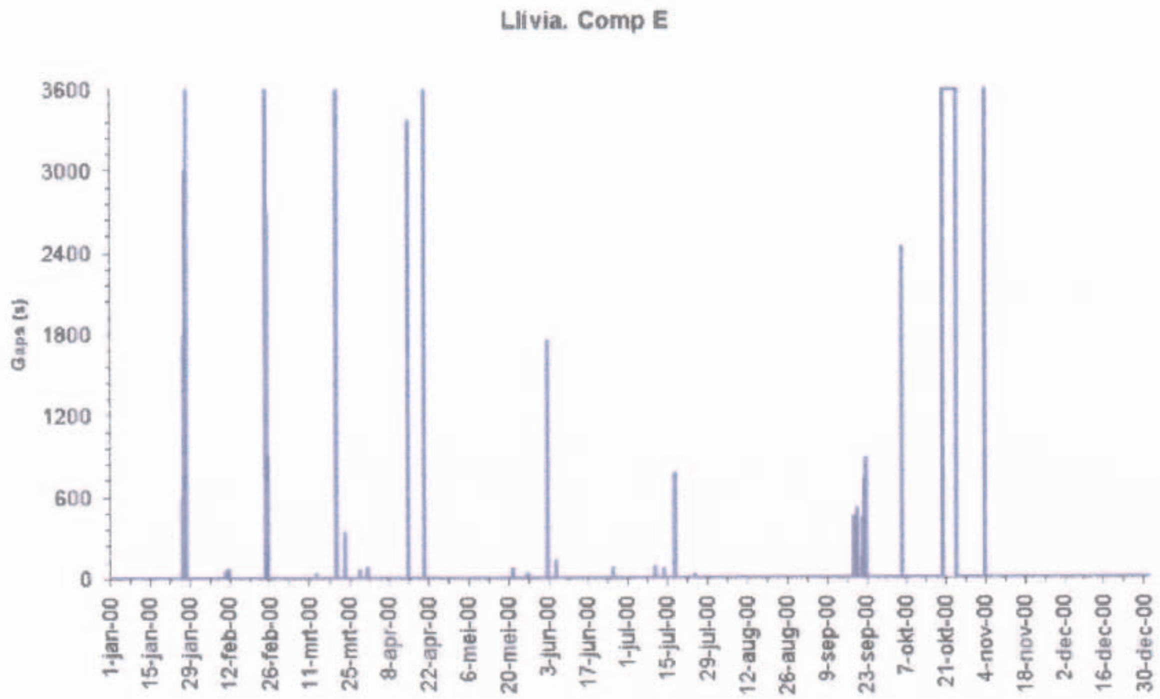
The network is producing records of high quality, due to the quality of the sensors, the acquisition system and the effort devoted to the selection of sites and the construction of infrastructures in order to obtain robustness, reliability and durability of the components. It has been intended to have a good electrical, thermal and seismic isolation of the main sensitive elements of the station. In this paragraph the performance of the network is analyzed from the point of view of the data transmission, which is the most peculiar aspect of the network. In fact there are several events that may cause loss of data: rainfade, GPS losing lock, LAN problems, remote power fail, wind misaligning fields stations and Hub antennae, solar eclipse. Only the first four events were observed during one year of observation, mainly frequent GPS losing lock. We present some plots with the duration of gaps per hour and percentages of retransmissions for one year of operation of the network, extracted from the State of Health files that are continuously produced by Libra Network enabling us to have an estimation of the performance of data transmission. Figure 6 shows the gaps of transmission (duration) for 2 stations of the network (Llívia and Avellanes) for the year 2000. The results from the analysis of these plots may be summarized as follows:

- when there are coincidence of gaps in different stations (gaps on January and

February shown in Figure 6), the origin of the data loss is the stopping of the central site for maintenance,

- the gaps with more than one day of duration (November on Avellanes station and October on Llívia station) are due to a technical intervention for reparation,
- other gaps are mainly due to weather causes, as hard rainfalls.

For the Llívia station, the gaps for 2000 sum a total of 7.3 days (635128 seconds). From this total 6.8 days are due to technical intervention. The remaining 0.5 days are randomly distributed along the year and represent a monthly percentage of 0.1 to 0.3%. From a total sum of gaps of 18.3 days in Les Avellanes station, 17.5 days represent technical interventions. From the remaining 0.8 days, 0.5 days are concentrated in the period from June 6 to June 21 and represent a 3% of this period. The others 0.3 days, like in Llívia station, gaps are randomly distributed along the year.



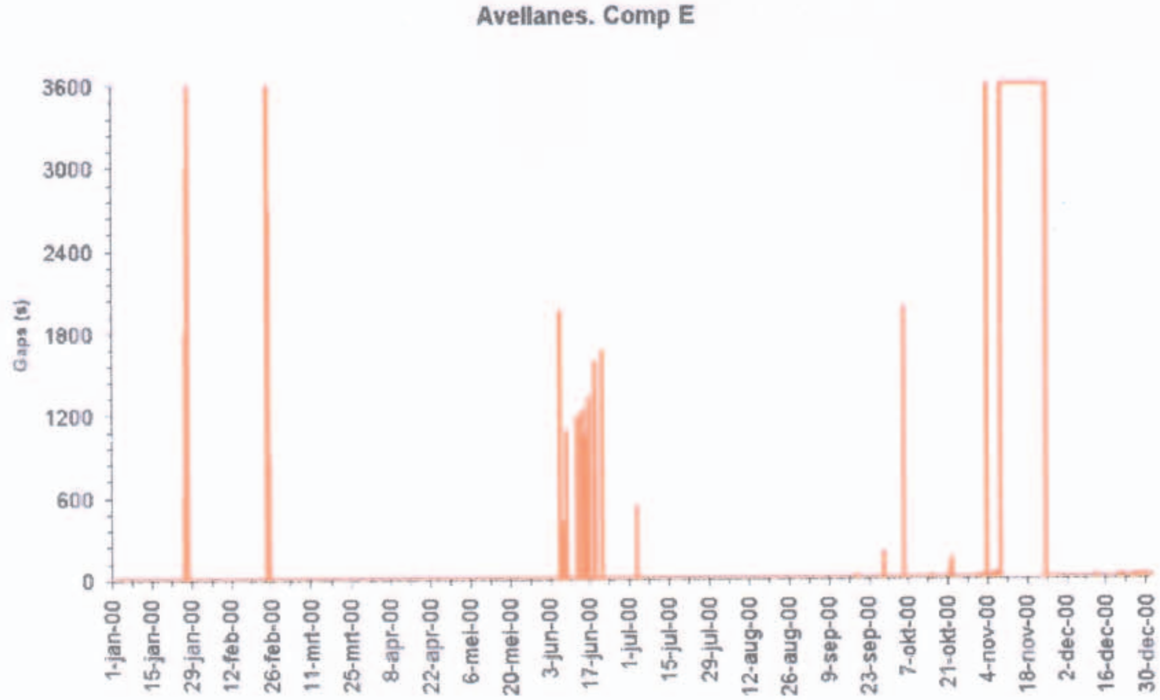


Figure 6. Gaps of transmission in seconds per hour, observed on two stations, for the year 2000.

The analysis of the retransmissions carried out by the system during 2000 for Llívia station is shown on Figure 7. It can be seen that the daily percentage of retransmissions never exceeded 15% of data. Retransmissions have been efficient and so loss of data is very scarce. The few percentage of retransmissions indicate that almost real time transmission is efficiently achieved.

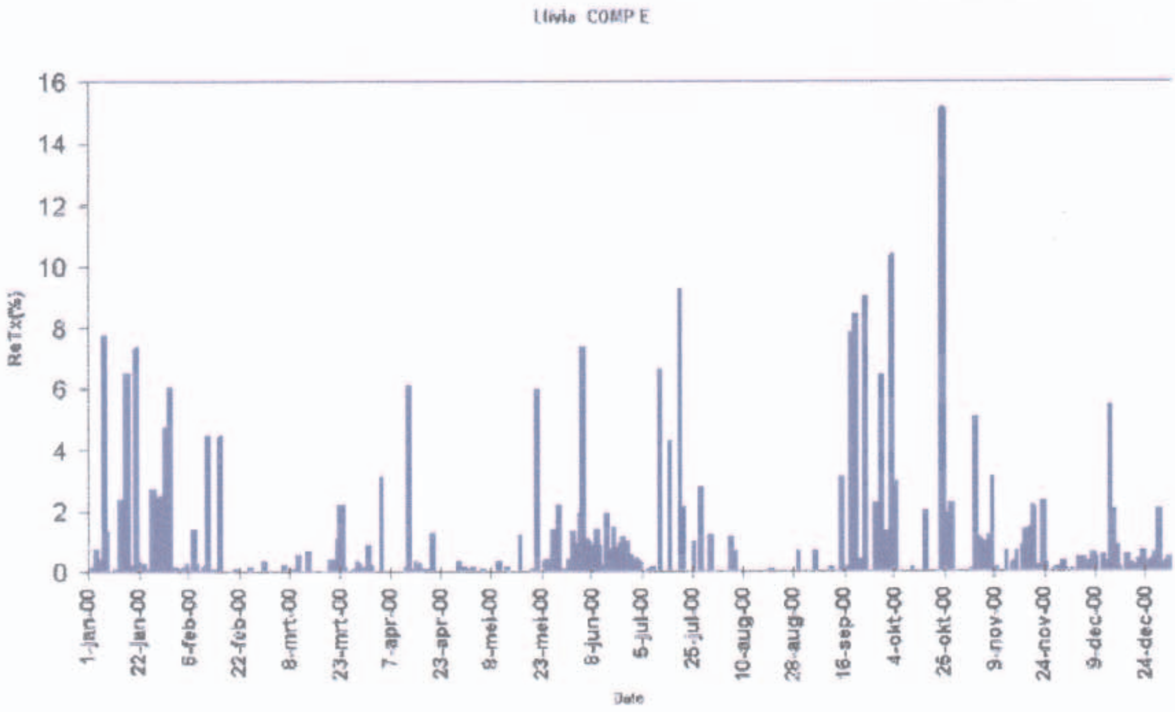


Figure 7. Retransmission of data per day, in percentage observed on Llívia station for the year 2000.

Conclusions

The seismic broad-Band VSAT network of the ICC, operating since 1999, has today (May 2001) 5 fully functioning stations, and is in the process of installing 15 more stations. The network is based on the Libra Network System manufactured by Nanometrics Inc., with VSAT platforms, transmitting data in quasi real time mode. The high effort devoted to construct robust infrastructures, on adequate sites, with special emphasis on electrical and environmental protections yields to a better efficiency of the network. After more than one year of operation, the reliability of the system has been improved, observing very few loss of data due to transmission. The continuous transmission on quasi-real time is very useful and the data obtained are of high quality. Continuous satellite transmission is safe and affordable using efficient TDMA techniques. In our case, the cost of the described satellite transmission is much lower than the use of systems based on dedicated telephone lines.