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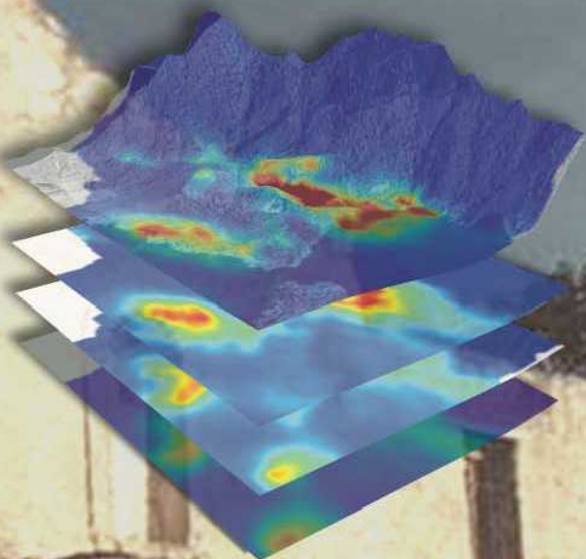

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MICROCLIMATIC AND GEOPHYSICAL SURVEYS ON CULTURAL HERITAGE (BASILICA OF SANTA CROCE - LECCE, ITALY). DATA INTEGRATION AND VISUALISATION (GIS).

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Abstract

The purpose of this work is to propose a model of integration between features of geophysical, physical, and chemical variables, obtained using multiple and different techniques, in the field of safeguard of works of art. Such type of integration has never been applied in this field, and the results of this application appear to be very powerful, in order to assess the reasons of previous or potential damages of the artistic monuments, due to physical and chemical conditions. Furthermore advanced tools for analysis, query, selection, and display have been used to seek patterns on a large number of data, that may not be visible without using them.

The results of the different surveys are displayed at the URL http://gis.unile.it/santacroce/radar, showing a method useful to explore relationships between different variables, during the local and the network analysis of the database.

Data available

The basilica of Santa Croce in LECCE is a baroque church internationally well known; the starting point for this research was the evidence that some altars: “Saint Oronzo” , “Saint Filippo Neri” and “Annunciazione”, are more damaged that the others (Figure 1 and Figure 2, points O, N, and A on the map in Figure 3). They present efflorescence of sodium chloride and a strong deterioration of limestone; our investigations have been performed to discover three possible causes that singularly or concurrently give these damages.

The possible causes of damages can be:

1. buried structures or subsurface anomalies;
2. not suitable microclimatic conditions;
3. deposition of pollutants.

Hence we have performed these measurements:

- Geophysical survey, using a ground-penetrating radar (GPR), to obtain information on buried structures or to locate and identify subsurface anomalies;
- Monitoring of the environmental microclimate, to discover dangerous cycles in critical periods, such as change of seasons;
- Analysis of the concentration of pollutants in atmosphere with the X-rays fluorescence in dispersion of energy (EDXRF).

Figure 1: $CaCO_3$ traces on the walls of “altare dell’Annunciazione”

Figure 2: $CaCO_3$ traces detail of the “altare di S. Filippo Neri”

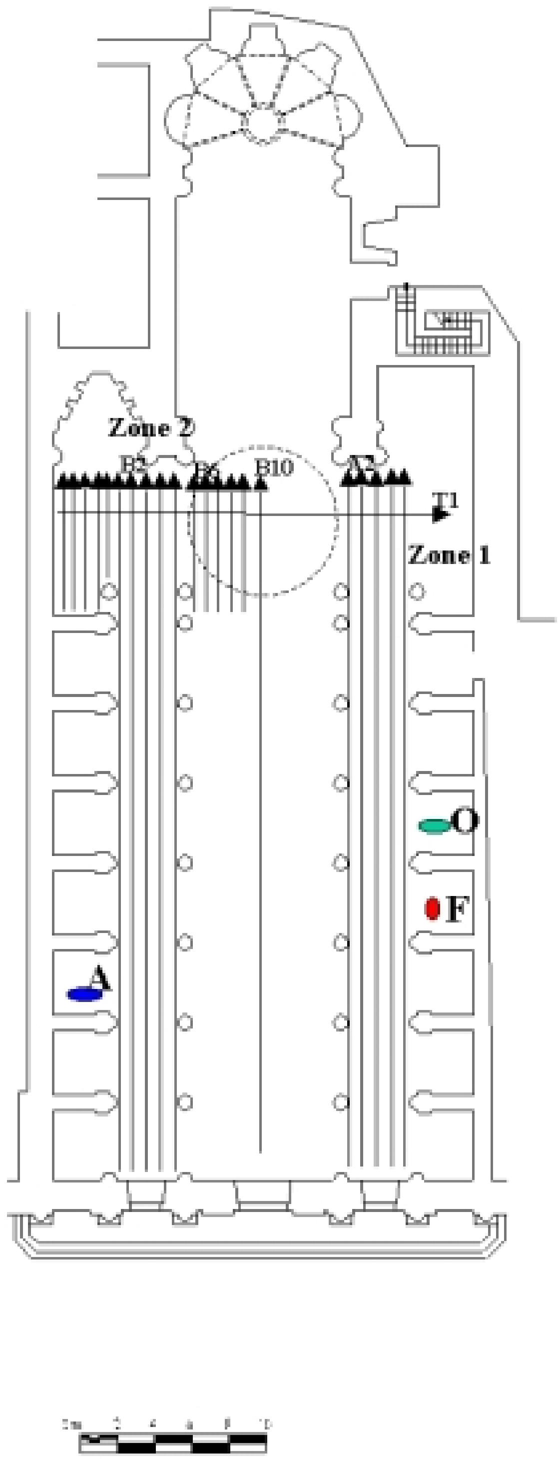

Figure 3: Basilica of St. Croce with the radar profiles location;

Data acquisition and analysis of GPR survey

The GPR survey, using a GSSI SIR-System2 equipped with 500 MHz antenna, was performed in summer 2002.

The following acquisition parameters were selected:

- data word length: 8 bit;
- samples per scan: 512;
- recording time window: 40 ns;
- gain function: manual;
- reference marks distance: 0.5 m.

Because of the variety of sizes of the expected archaeological targets, a 0.5 m line spacing was used for the reconnaissance survey, carried out in continuous mode on all the accessible parts of the church, due to the presence of columns, benches and other obstacles. Two different zones labelled zone 1 and zone 2 respectively (Figure 3) were surveyed.

The quality of the raw data did not require advanced processing techniques. However an appropriate processing has been performed for an easier interpretation using the REFLEXW software[1]. The methods used to process data have been:

1. horizontal scaling (100 scan/m); it allows an interpolation of the data in the X-direction on the basis of markers to be set manually or to be extracted automatically from the data;
2. amplitude normalisation, consisting of the declipping of saturated (and thus clipped) traces by means of a polynomial interpolation procedure [1];
3. background removal; the filter is a simple arithmetic process that sums all the amplitudes of reflections that were recorded at the same time along a profile and divides by the number of traces summed. The resulting composite digital wave, which is an average of all background noise, is then subtracted from the data set;
4. Kirchhoff 2D-velocity migration [2]; a time migration of a two-dimensional profile on the basis of a 2D-velocity distribution is performed. The goal of the migration is to trace back the reflection and diffraction energy to their "source". The Kirchhoff 2D-velocity migration is done in the x-t range, this means that a weighted summation for each point of the profile over a calculated hyperbola of preset bandwidth is performed. The bandwidth means the number of traces (parameter summation width) over which shall be summed.

Zone 1:

Zone 1 is located in the right side of the church.

The analysis made on diffraction hyperbolas in the radar sections allowed to estimate an average velocity of 0.07 m/ns for the entire zone. This average value was used for depth conversion.

The radar sections in Figure 4 show the signal behaviour in different parts of this zone, probably related to different soil conditions and to variable moisture content. In Figure 4 both the raw radar section (Figure 4a) and elaborate radar section (Figure 4b) relative to the profile labelled A2 in Figure 3 are shown. At time ranging from about 20 ns to about 24 ns (0.7 m - 0.84 m in depth) and at x distance from about 34 m to about 36 m a very strong anomaly (labelled A) is easily identifiable. It was noted on the radar sections relative to A2 in Figure 3 and to some profiles close to it. They are probably related, from the shape and dimension, to anthropic structures.

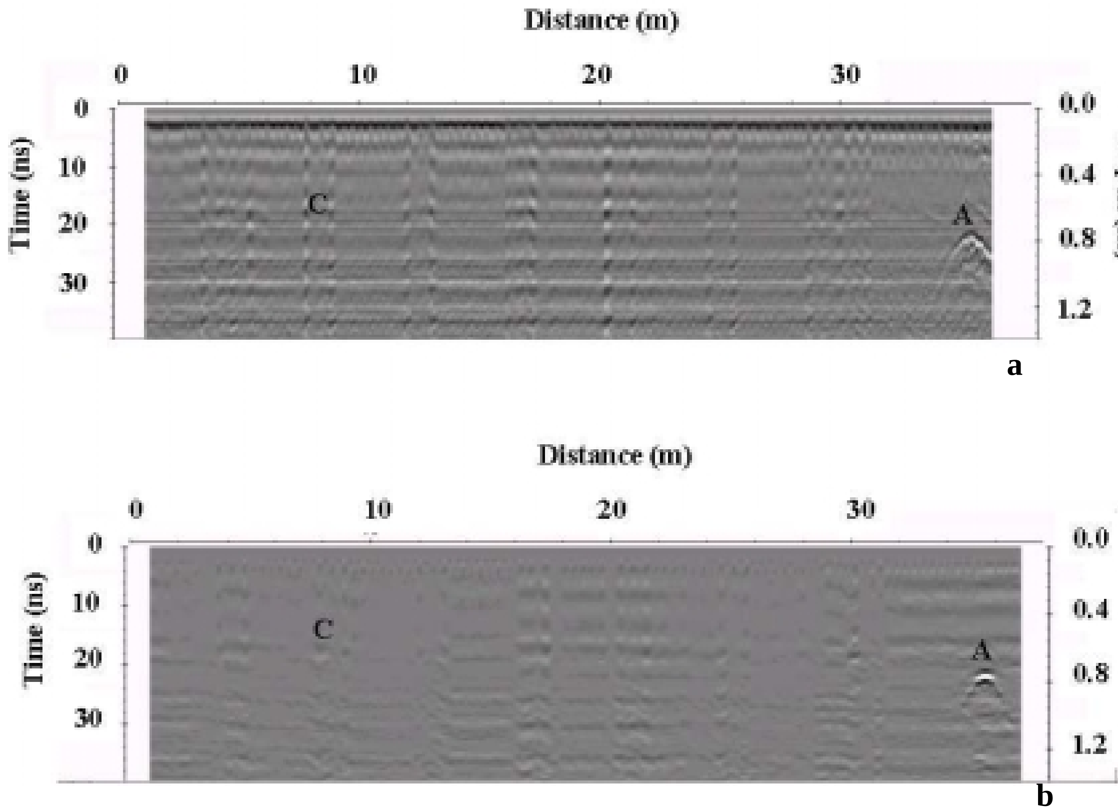

Figure 4: Zone 1: radar section relating to the A2 profile acquired with 500 MHz centre frequency antenna before a) and after the processing steps described in the “data acquisition and analysis” paragraph b);

Moreover, the diffraction hyperbolas visible on the data (labelled C) are probably related to the columns in surface.

As it can be seen from the radar section (Figure 4) any other event is noticed, probably because of either the more conductive soil (elevate moisture content) or the more homogeneous soil in this zone.

Time slices are generally useful to facilitate interpretation of complex radar data. By them its is possible to examine only reflection amplitude changes (or energy changes if the square value is used instead of the absolute value) within specific time intervals, and thus within consecutive soil layers of nearly constant thickness. Each time slice is, therefore, roughly comparable to a standard archaeological excavation level [3]. Really, because of possible velocity changes across the area and with depth, horizontal time slices must be considered only approximate depth slices. However, this is generally sufficient for most common applications. Areas of low reflection amplitude (or energy) indicate uniform matrix materials or quite homogeneous soils, while those of high amplitude denote areas of high subsurface contrast such as buried archaeological features, voids or important stratigraphic changes.

The time slice technique has been used to display the energy variations within the 10-15 ns, the 15–20 ns, the 20-25 ns, 25 – 30 ns and 30 – 35 ns two-way time windows, where the anomaly was observed in all radar sections acquired in the zone 1 with 500 MHz antennas. The selected two-way time intervals correspond to subsoil layers located, respectively, between 0.35-0.52 m, 0.52-0.70 m, 0.70 – 0.87 m, 0.87 – 1.05 m and 1.05 – 1.22 m in depth (assuming an average velocity value of 0.07 m/ns) (Figure 5).

One high amplitude anomaly (labelled A in Figure 5) is visible in the time slices 15–20 ns, the 20-25 ns, 25 – 30 ns and 30 – 35 ns. The shape and the size of the high amplitude anomaly suggest that it is related to the probable presence of a void (tomb ?).

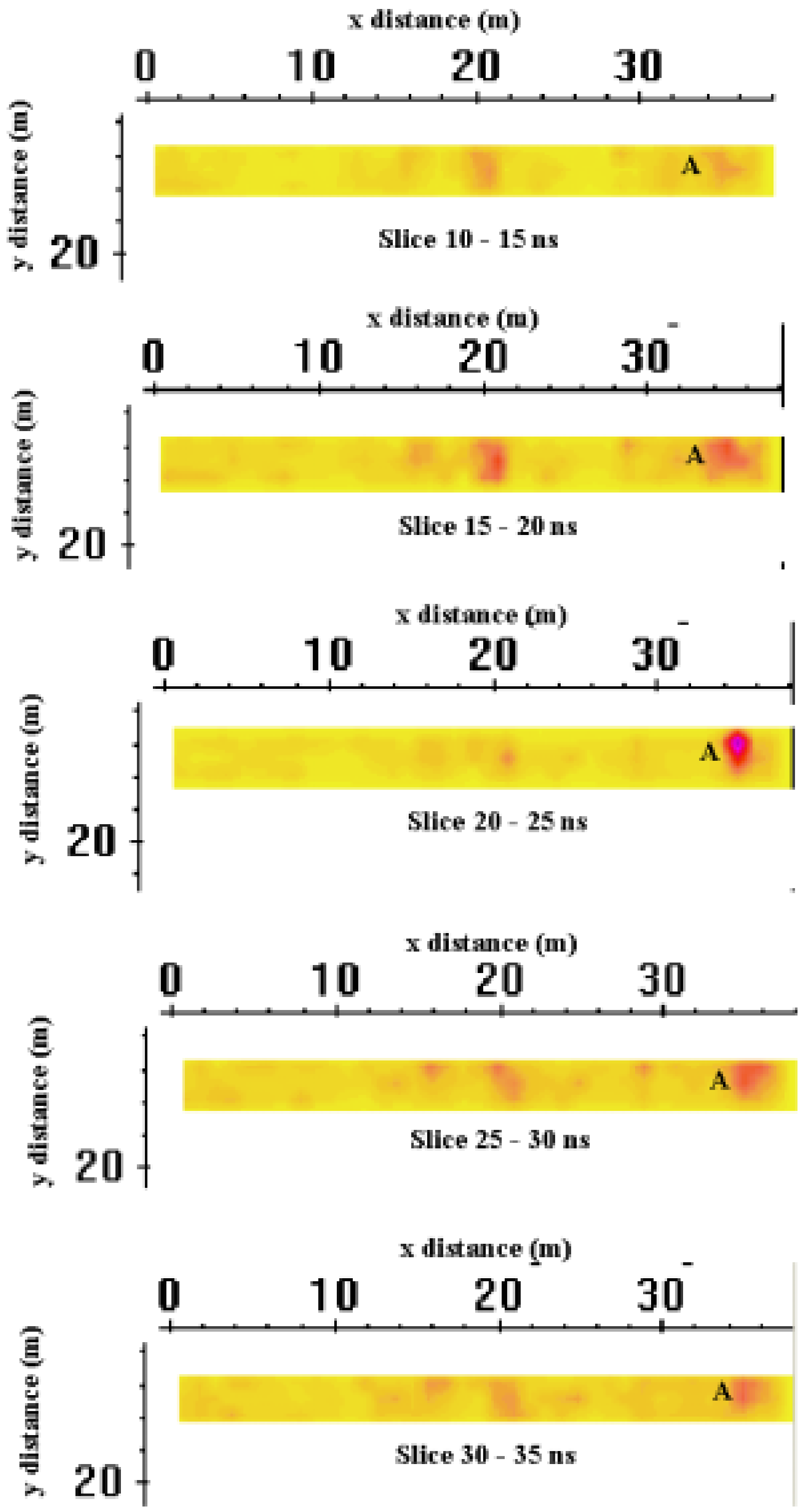

Figure 5: Zone 1: time slices;

Zone 2

Zone 2 is located in the left side of the church.

The analysis made on diffraction hyperbolas in the radar sections allowed to estimate an average velocity of 0.07 m/ns for the entire zone. This average value was used for depth conversion.

The radar sections in Figure 6 show the signal behaviour in different parts of this zone, probably related to different soil conditions and to variable moisture content.

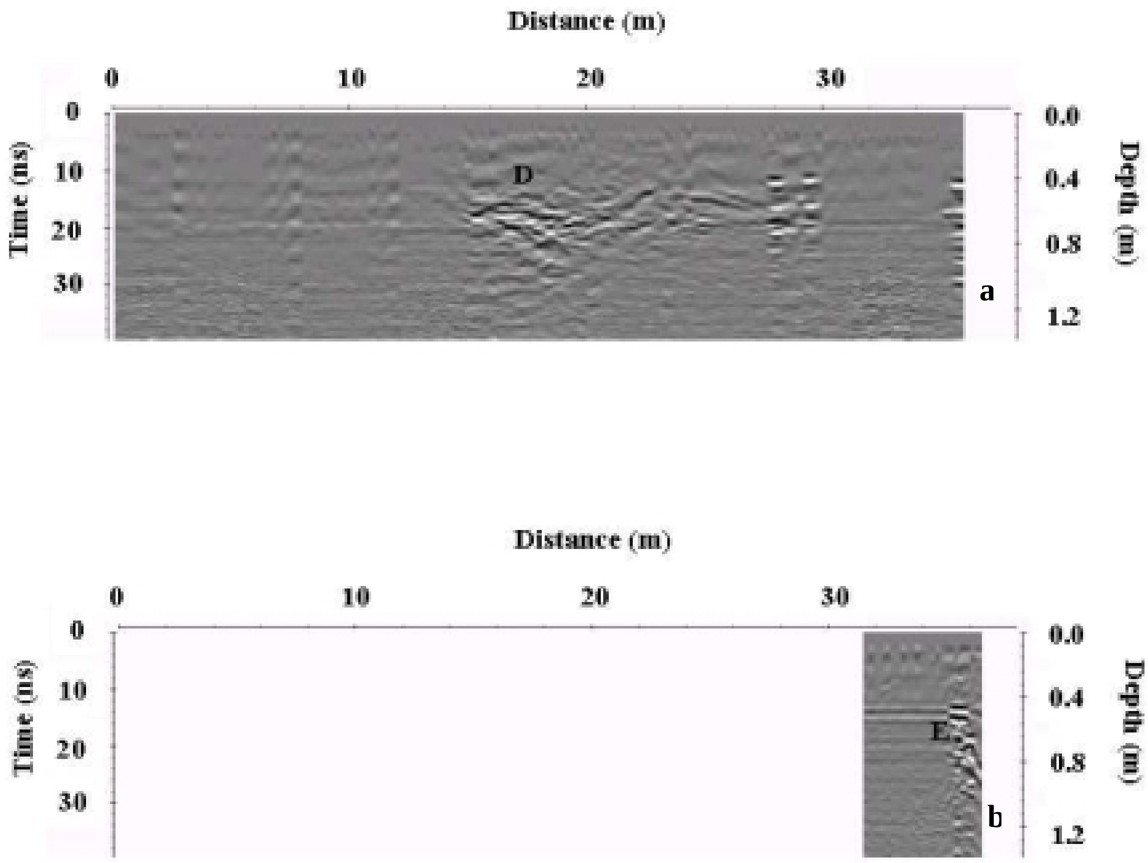

Figure 6: Zone 2: processed radar section relating to the B2 profile acquired with 500 MHz centre frequency antenna a) processed radar section relating to the B6 profile acquired with 500 MHz centre frequency antenna b);

In Figure 6 both the processed radar sections relative to the profiles labelled B2 and B6 in Figure 3 are shown. At time ranging from about 10 ns to about 30 ns (0.35 m - 1.05 m in depth) and at x distance from about 14 m to about 28 m for B2 profile (Figure 6a) a very strong anomaly (labelled D) is easily identifiable. It was noted on the radar sections relative to B2 and to some profiles close to it. It is probably related, from the shape and dimension, to anthropic structures.

At time ranging from about 10 ns to about 30 ns (0.35 m - 1.05 m in depth) and at x distance from about 34 m to about 37 m for B6 profile (Figure 6b) a very strong anomaly (labelled E) is easily identifiable.

The time slice technique was used to display the energy variations within the 10-15 ns, the 15–20 ns, the 20-25 ns, 25 – 30 ns, 30 – 35 ns and 35 – 40 ns two-way time windows, where the anomaly was observed in all radar sections acquired in the zone 1 with 500 MHz antennas. The selected two-way time intervals correspond to subsoil layers located, respectively, between 0.35-0.52 m, 0.52-0.70 m, 0.70 – 0.87 m, 0.87 – 1.05 m 1.05 – 1.22 m and 1.22 – 1.40 m in depth (assuming an average velocity value of 0.07 m/ns) (Figure 7).

The high amplitude anomalies (labelled D and E in Figure 7) are visible in the time slices 15–20 ns, 20-25 ns, 25 – 30 ns and 30 – 35 ns. The shape and the size of the high amplitude anomalies suggest that it is related to the probable presence of a void (tomb ?).

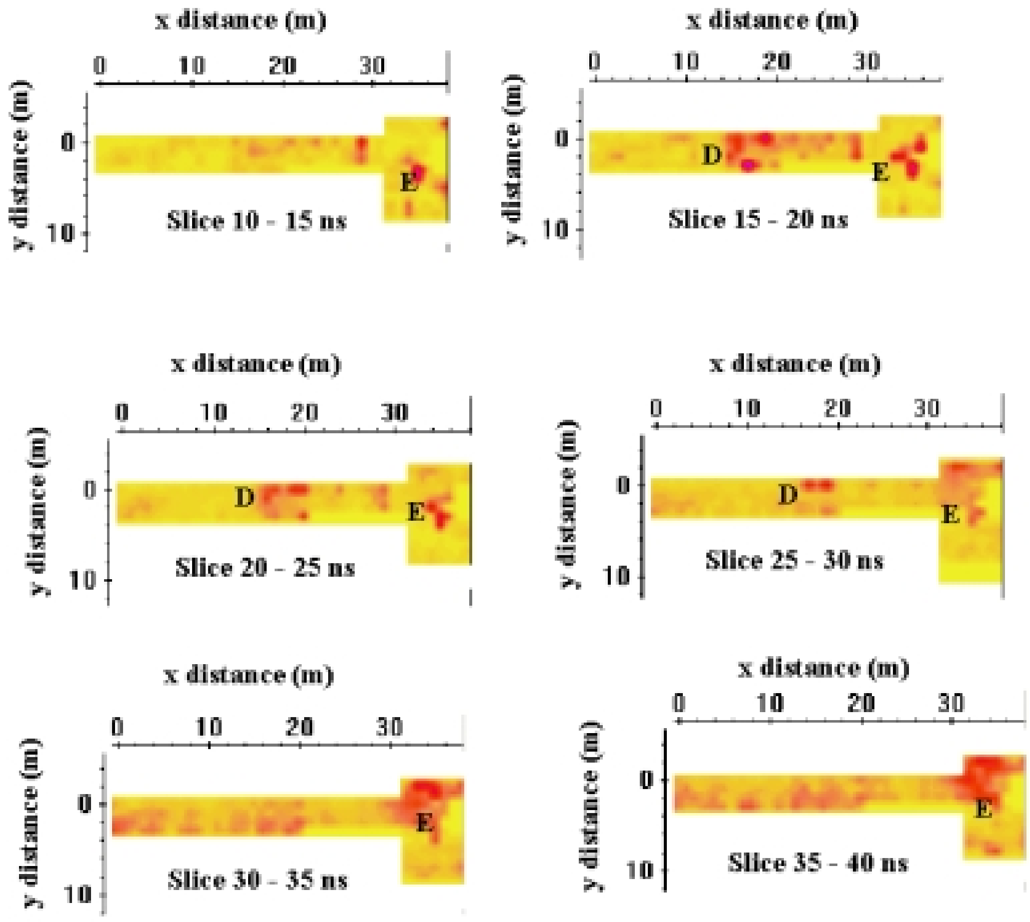

Figure 7: Zone 2: time slices.

Data acquisition and analysis of microclimatic survey

The basilica of Santa Croce is built with a very porous Miocene's limestone said "Pietra Leccese", a very easy to sculpture stone; the artists have modelled it in many ways, giving us the so called "Barocco leccese" (Lecce baroque). Unfortunately, its porosity makes it prone to degradation. Important damage phenomena happen because of interactions between the monument and the soil, and between the monument and the atmosphere. The former interaction is characterised by water infiltration, probably saltish; on the other hand, interaction with the atmosphere may be very complex, and consists both in moisture absorption from air, and in pollutants attack. An example of the latter is atmospheric SO_2, which is a product of petrol combustion; after sunset, stones irradiate, and cool more rapidly than the air nearby: this may give origin to a flux of humid warm air toward the stone surface, where water condenses; SO_2, if present in air, reacts with water, giving H_2SO_4 (sulphuric acid); the latter reacts with the stone (mainly constituted by $CaCO_3$), according to the reaction:

$$CaCO_3 + H_2SO_4 + H_2O \rightarrow CaSO_4 * 2H_2O + CO_2$$

The products are gypsum and carbon dioxide.

A faithful microclimatic characterisation [4] of a large indoor environment requests a thorough investigation of many climatic variables for many days, in several periods of the year (at least once per season, during one or, better, two years); in particular our survey covered the period from September 2001 to August 2002. The measurements of various microclimatic parameters, such as relative humidity (RH), specific humidity (SH), dew-point distance, air temperature (T), surface temperature, were performed as a function of time: sensors were put in strategic places and data was collected during many days, with suitable sample periods (about 15-30 minutes, in general). Other measurements were performed to build up static scalar maps of microclimatic variables, getting RH, T, SH etc distributions in the church at precise moments of the day.

For studying microclimatic variables as a function of time, we used the climatic analyser/data logger BABUC/A by LSI (*Laboratori di Strumentazione Industriale*), properly equipped with probes by the same factory. In particular we used an anemometer, PT100 contact probes for surface temperature observation, hygro-thermometric probes for air temperature and relative humidity measurements. The probes were distributed near stones with various damage levels.

Other T and RH data loggers (by Gemini, commercialised by RS Components) were used both inside the church (on a vertical line at different heights from the soil) in order to detect vertical temperature gradients and study vertical stability, and outside the church, to collect data about the external climatic situation.

The T and RH maps were built up by measurements taken by a psychrometer from TECNOEL: this portable apparatus allows recording dry (T) and wet (T_w) air temperatures, and consequently RH, with good accurateness.

The same instrument was also used to estimate T and RH gradients near the stone, in order to assess the presence of air, humidity, and pollutant fluxes near surfaces: two measures were taken (next to the stone surface and at some centimetres from it). The intensity and direction of hygrometric gradients let us determine when and where emissions or absorption of moisture took place (evaporation/condensation) and T gradients gave information on thermophoretic pollutant deposition/protection.

All collected data [5], interpolated using Kriging method, can be viewed by connecting to the URL http://gis.unile.it/santacroce/radar.

A sample of a map of air temperature is shown in Figure 8. Isolines are drawn with a 0.1 Celsius degrees resolution. One can see the effect of cold external air (near the entrance door, where temperature grows from about 3 to 10 degrees in a few meters). Temperature isolines clearly show this strong effect. The well localised warm point on the right side of the church is due to a lamp. The most uniform part of the church is of course the farthest from the entrance door, as shown by the low density of isolines.

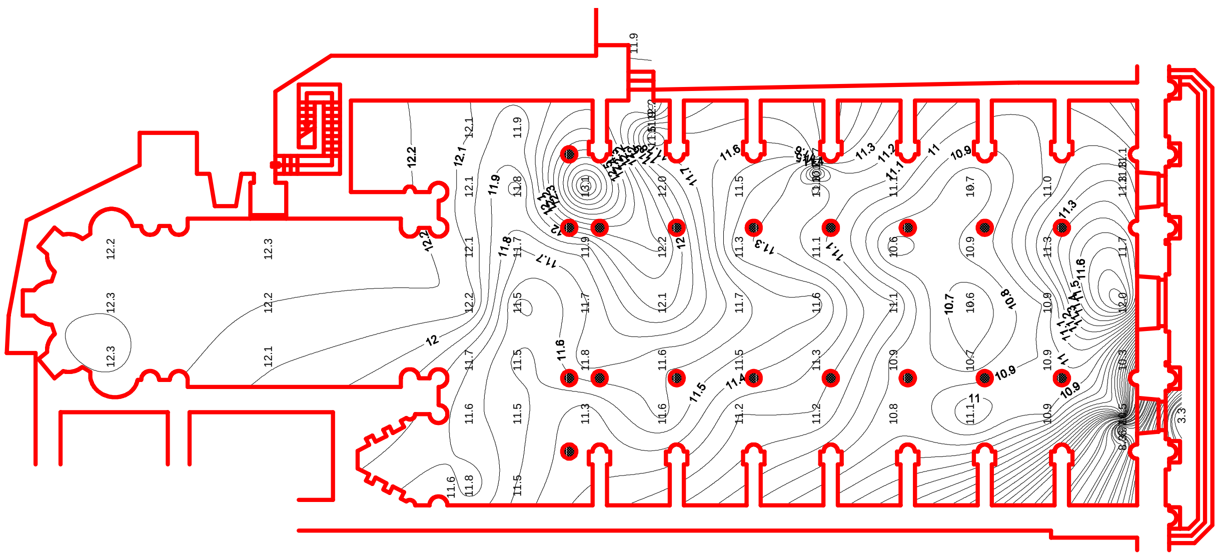

Figure 8: Temperature isolines (0.1 C resolution) on December 18, 2001, at 9.00 am.

Microclimatic conditions in the church look quite stable, due to the absence of any heating system, and to a moderate heating by sun radiation. The contribution of artificial lighting is also generally almost negligible. The main source of variation for thermo-hygrometric parameters is the opening of doors toward the outside, which causes a strong flux of air with different temperature and moisture content.

In almost all measurements, the wall temperature T_{sur} is greater than the wet bulb temperature T_w; the conclusion is that evaporation from the stone is always present. On the other hand, even if the RH level in the church is quite high, water condensation takes place quite seldom, as proved by comparing SH next to the stone and at a few centimetres apart; as a consequence, the evaporating water must come from the interior of the stone itself, not from air.

The efflorescence phenomena, too, suggest that an important flux of water from the stone exists: the water gets out by capillarity, then evaporating. In the process, the dissolved salt (mainly NaCl, as proved by chemical analysis) emerges. Efflorescence is not equally present everywhere, which makes us suppose diverse origins of the stones (different caves, or different layers of the same cave), or the presence of underground structures with a large water content.

However, the abundance of water in the soil is in accordance with what was supposed during the analysis of geophysical data: the absence of many events in the radar survey may be a consequence of the large underground moisture content.

Micropore condensation is probably present for Kelvin effect in pores with radius lower than 10^{-8} m, because of the high RH level near walls measured in some surveys: this phenomenon may also be a source of serious damage for the stone.

Microclimate conditions may also be responsible of stone aggression by air pollutants, because they contribute in pollutants diffusion by various mechanisms. Our surveys put in evidence that thermophoretic, inertial impact, Stefan flux depositions are quite infrequent in the colder period of the year, because the walls (as measured by the contact T probes) have slightly higher temperature T_{sur} than the air nearby, so the stone is protected from pollutant deposition; in Summer this situation changes because air is often warmer than the walls.

Data acquisition and analysis of EDXRF survey

EDXRF (Energy-Dispersive X-Ray Fluorescence) is a consolidated non-destructive technique for the determination of relatively heavy elements (with atomic number greater than 20), recently used for the determination of light elements such as sodium chloride and calcium sulphate [6]. The mixture of these two elements is one of the principal responsible of the degradation of works of art

Schematically, a typical EDXRF apparatus is made of:

- a low power X tube (with its HT power supply)
- a semiconductor X detector (with its cooling system, power supply, and an amplifier)
- a spectrum analyser (a multi-channel analyser with suitable control software).

The X-ray tube irradiates the sample, which emits fluorescence-generated X radiation. The latter invests the X-ray detector, connected to the multi-channel analyser.

Our apparatus is quite portable [6], all parts being contained in a small suitcase. The X-ray tube comes from Oxford Instruments; the detector is an Amptek Si-Pin photodiode, model XR-100T. The multi-channel analyser is an Amptek MCA800A.

The presence of sulphur and chlorine was assessed on the altars of both aisles, selecting various points for each altar. Care was taken to choose both points that looked more damaged, and better preserved ones. The collected spectra were then analysed to derive Cl and S concentrations.

The obtained results for sulphur contents are shown in Figure 9; the straight line superposed to left aisle altar points is the linear best fit line, while the curve superposed to the right aisle altar points is only a guide for the eye. Sulphur concentration diminishes as the distance from the entrance door becomes larger, and in general concentrations in the right aisles are lower than those in the left aisle.

Chlorine concentration is far higher on the altars of the right aisle of the church, the more damaged ones, than in those of the left aisle. The different concentrations of Cl in different altars can be a consequence of different stone origins, but could also be related to a larger quantity of water coming up from the soil, possibly related to the presence of underground structures.

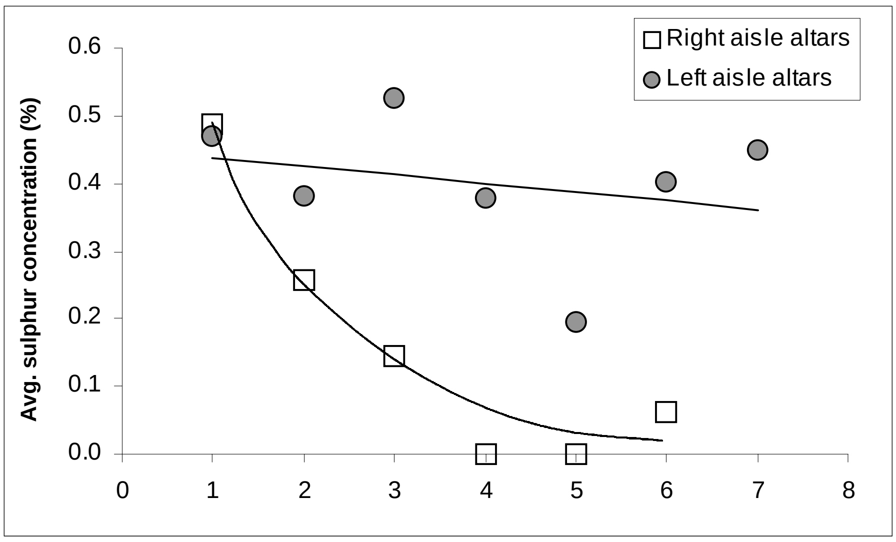

Figure 9: Average sulphur concentration measured on the altars of both aisles. X coordinate indicates the ordinal position from the entrance doors (e.g., the square at x = 2 represents the second altar, starting from the entrance doors, in the right aisle).

Sulphur presence is important in every altar on the left aisle, while in the right aisle only the altars near the entrance door show significant quantities. This situation suggests a relationship between the sulphur presence and the polluted air coming from outside by the front-left entrance door, which is open all year long, or by both front-side doors, both open in Summer; this hypothesis is somewhat confirmed by the high concentration of sulphur found on the church front (values about 3%) .

Comparing Figure 9 with Figure 8, it is evident that the measure points, where larger S concentrations are observed, are also points where considerable temperature gradients are present due to the entrance door, causing a strong flux of polluted outside air towards the inside.

The relationship between the presence of pollutants (sulphur, in particular) in the church and the opening of exterior doors, suggests the installation of inner doors, with intermediate chambers equipped with filter mechanisms. This stratagem would isolate the church from the outside, thus contributing to its climatic stability and limiting the deposit of pollutants on the internal surfaces.

Data visualisation

We think that is important and useful to create a specialized database to access to the great variety of data available from so strongly multidisciplinary studies, especially for two reasons:

1. To reduce the time for sharing and integrating multiple information among scientists that co-operate in the same project or want to perform other surveys;

2. To produce a database ready to be integrated with other information and easily available to the public administrators, responsible for coordinating the management and the safeguard of works of art, consulting local jurisdictions and administering the art budget.

The coupled GIS software + Internet allows to work on the data, explore relationships between features, investigate important locations and topics and construct a query during the local and network analysis of the database.

This technique (http://gis.unile.it/santacroce/radar) is very powerful; it not only allows to easily co-ordinate a large group of researchers that co-operate in the same project but also allows public administrators, who already use GIS for various tasks, to maintain maps of historical buildings over many years. With such an interface the planning and the analysis of safeguard of historical buildings can be improved.

For these reasons the collected data was analyzed using a GIS package (ESRI-ArcView), with additional ESRI-tools such as: Cad Reader to work with CAD drawing themes, for example the map of the church in .dxf o .dwg format; Spatial Analyst tool, as the problem requires continuous surface (raster) modeling information, i.e. to create continuous surfaces from scattered point features; TIFF 6.0 image support to properly place the images (radar time slices) at the correct location in a view.

Other freeware scripts (available on http://arcscripts.esri.com) were useful for our aim; they are: KGDI, that allows the generation of contours or surfaces using the Kriging data interpolating method; EDTOOLS, to convert DXF file into polygons, to generate an analysis that requires combined information represented both as raster data and vector data (boundaries).

Mapserver [7] was used to display the obtained results on the WEB; it is an OpenSource development environment for building Internet applications (available on http://mapserver.gis.umn.edu). The logic of the process to obtain files for the network is shown in the flowchart in Figure 10.

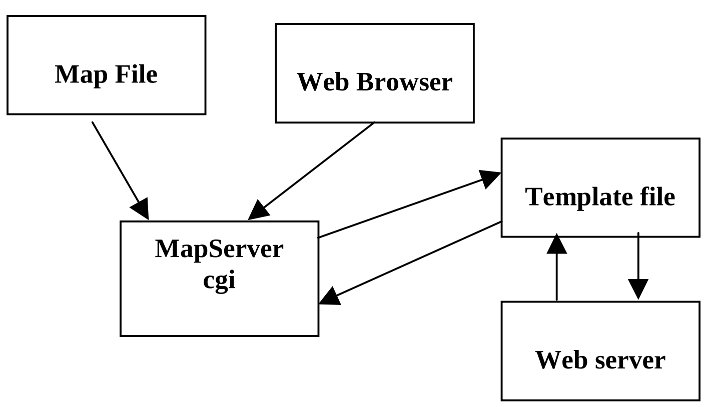

Figure 10: MapServer logic flowchart.

The parameters required to obtain a map can be inserted in a form as shown in Figure 11; a typical obtained map is shown in Figure 12,

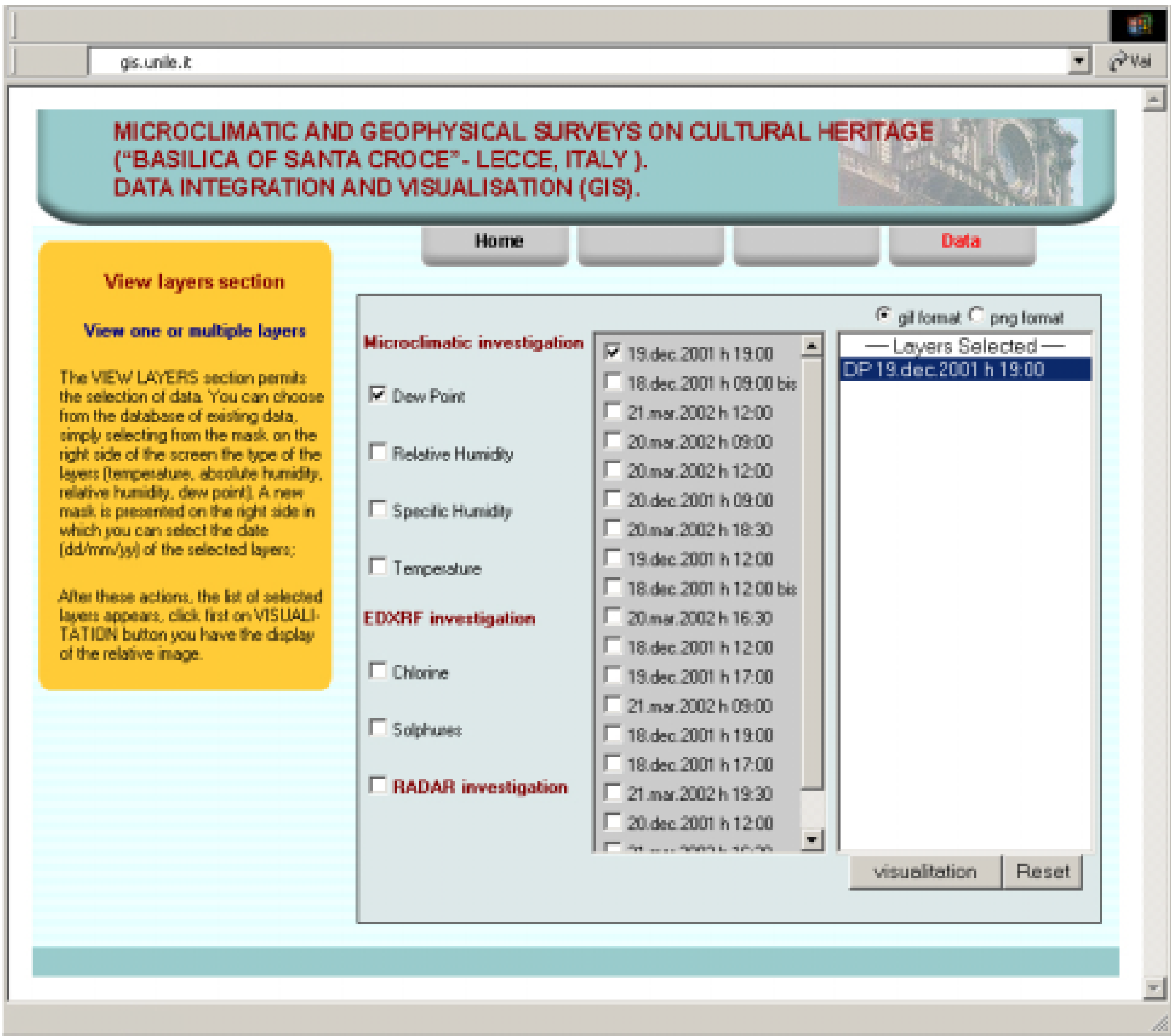

Figure 11: A form for inserting data to be processed by the CGI script.

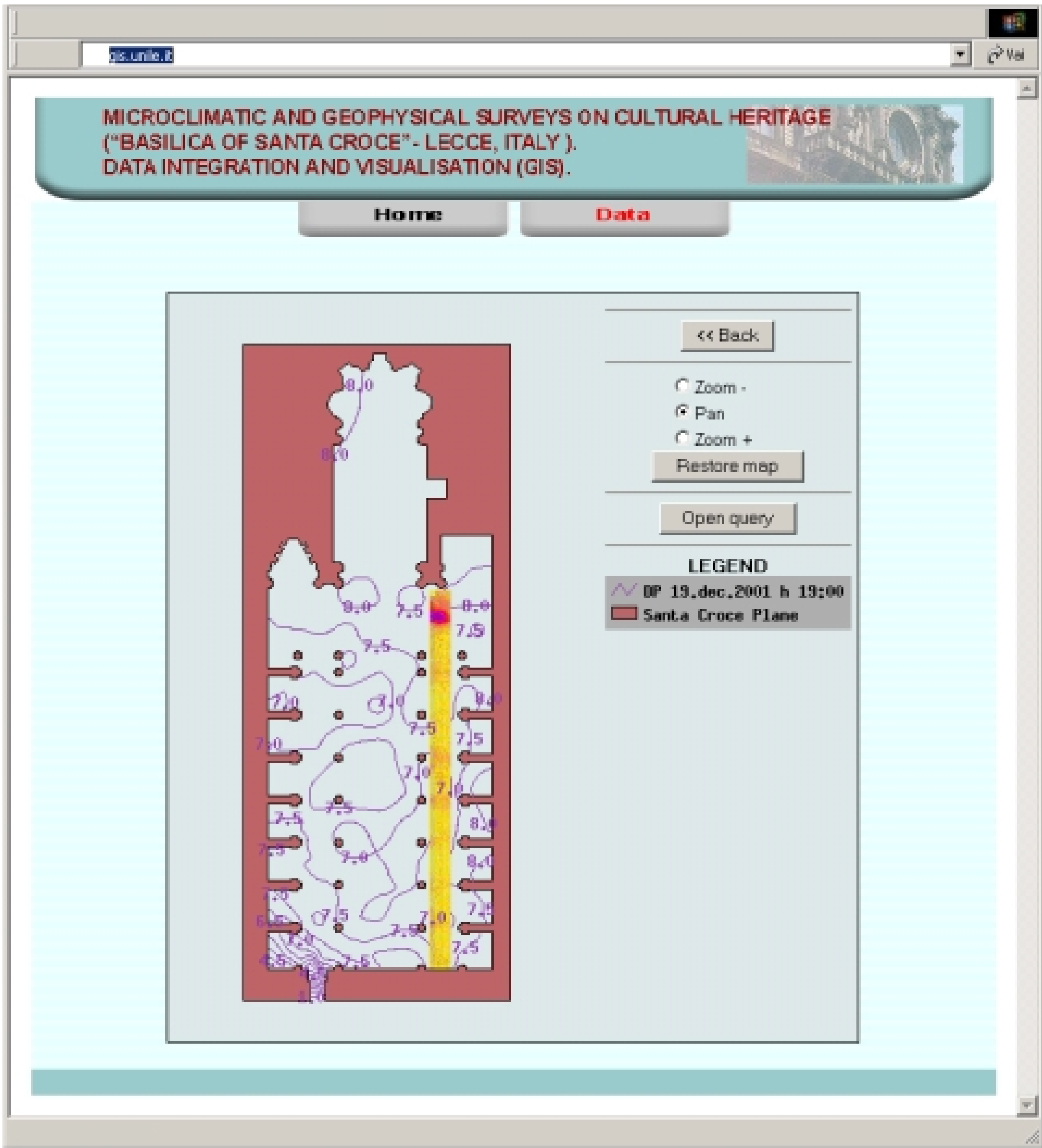

Figure 12: A typical map, produced by MapServer, after processing by the CGI script.

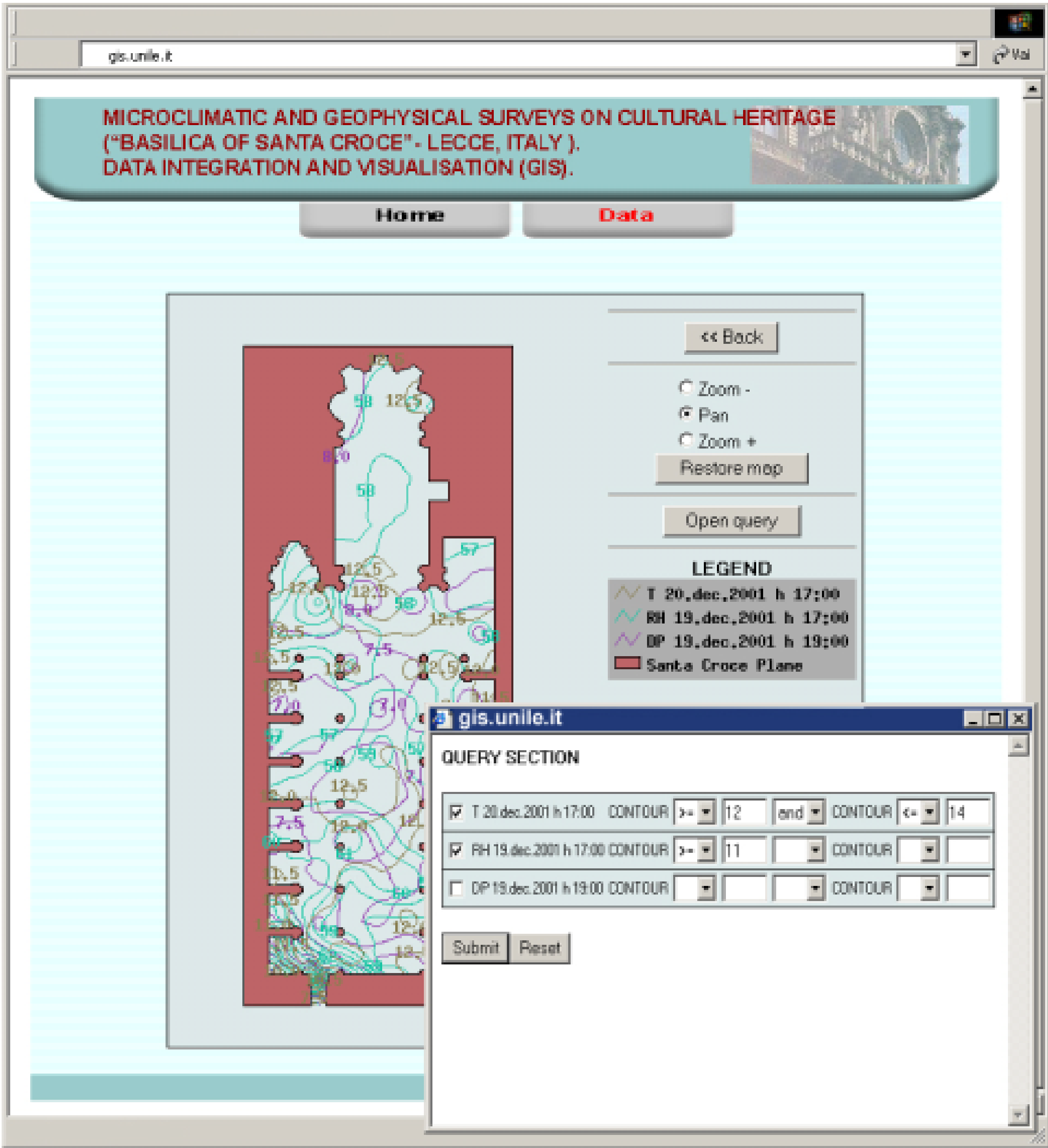

Figure 13: A form for constructing queries.

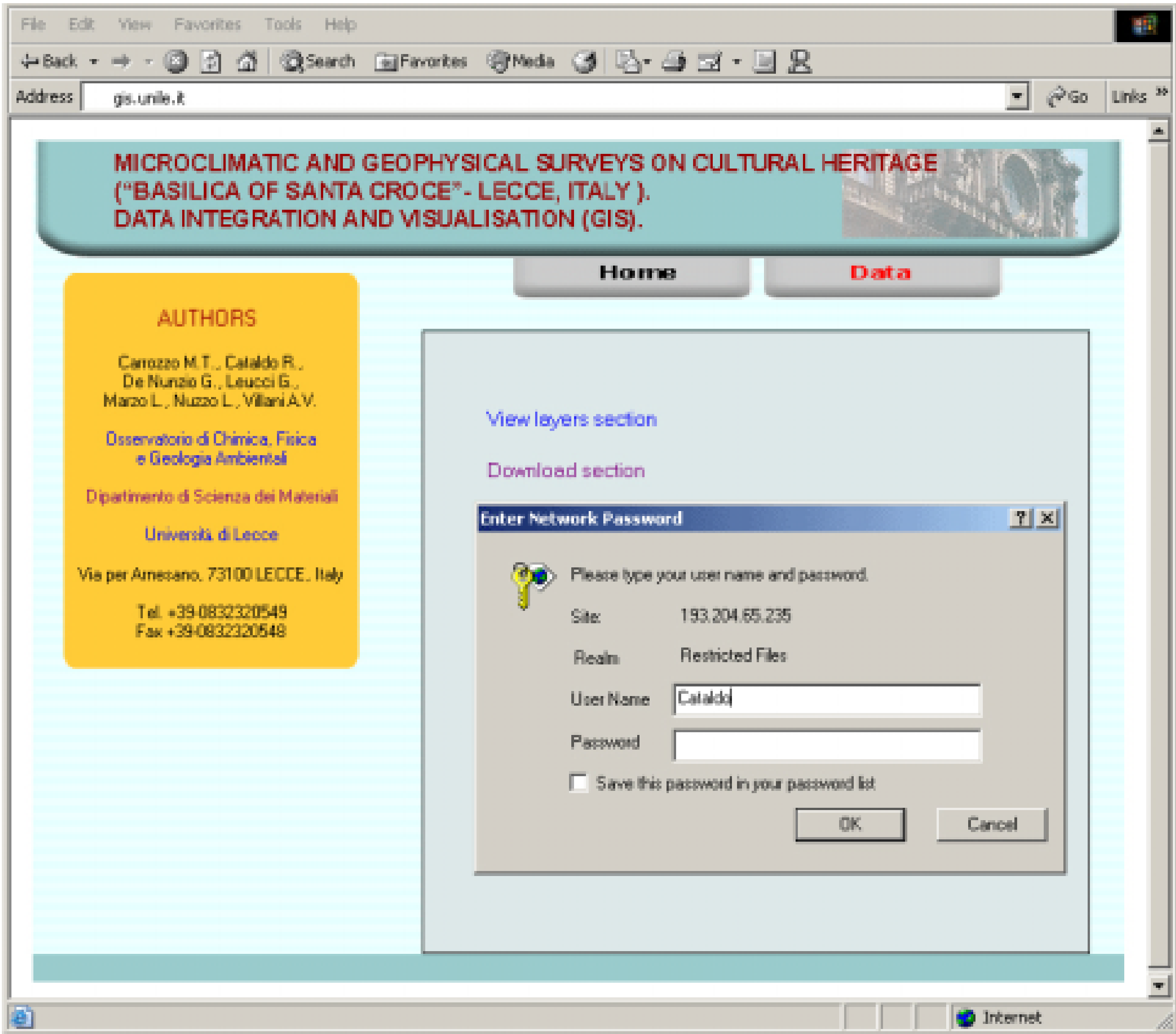

Figure 14: Data download form.

The programs were developed as Common Gateway Interface (CGI) executables to be run on a Unix or Windows platform (such as Apache or Windows NT/2000 Web Server). All the applications were written in PERL [8] that dynamically interacts with MapServer, allowing easy navigation across the tables.

Analyses based on the Boolean logical operators can be made, as shown in Figure 13; data selection and query can be performed by inserting parameters that will be processed by a Perl script.

It is possible, under a secure connection (using https protocol) with password authentication (Figure 14), to download in compressed format ASCII tables, shapefiles (.shp, .shx, .dbf, .sbx, .sbn), and radar sections (.dzt). The shapefiles can be managed using a GIS tool or, for example, Surfer; the radar sections can be read with Reflexw or Radan for Windows or Matlab (Dztread.m e Headerdzt.m are available for this purpose).

Conclusions

We believe that the proposed model is very flexible and the integration of the data is very useful to achieve conservation goals; these work shows not only an increase in the knowledge of the problem, but also the possibility:

- To reduce the time for sharing and integrating multiple information among scientists that co-operate in the same project or want to perform other surveys;
- To produce a database ready to be integrated with other information that can be employed to make recommendation to the public administrators, responsible for coordinating the management of work of art.

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