Dynamic GIS and remote sensing for the diagnosis and geological monitoring of catchment areas

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Abstract. This work aims to propose an articulate project about specific exigencies of territorial civil engineering, particularly about a GIS on diagnosis and monitoring of the geological and environmental order of a geographic basin, integrated with remotely sensed data. This work shows an application of dynamic GIS useful for monitoring, control and anticipating of landslides and mining areas. The architecture of this GIS is realized with reticular technical maps and remote sensing data. In this project we analized a small area in the southern part of the "Calabrian Arc". Everyone knows how difficult is modeling of a landslide and monitoring of the subsurface because of the variety of numerous factors involved. For this purpose is suitable the creation of a dynamic GIS decision support where the input data are geo-referenced spatial information (geographical data and descriptive attributes) and output is the result of space-time processing and / or logical on these data. More specifically, on the ground monitoring stations, global satellite positioning systems and Landsat, Spot imagery (with different spatial and radiometric resolution) provide useful information to the central system (GIS) that processes the information and provides output to users both in the laboratory as in situ. Special relevance for the purpose of processing have the various models produced to create the logical connections between the individual thematic maps (if necessary realized) and to interpret and explain the data in the phenomenological or physical context of the system land. The processing models used are algorithms for union and intersection data and multidimensional statistical algorithms.

Keywords. Geological monitoring, Catchment areas, Monitoring of the subsurface, Control and anticipating of landslides and mining areas.

1. Introduction

Everyone knows how is complex both modeling a landslide and monitoring the subsurface, because of the variety of factors involved. To this purpose, it may then intervene to help the creation of a dynamic GIS decision support where the input data are geo-referenced spatial information (geographical data and descriptive attributes) and the output is the result of the computation space and time and/or logic performed on these data. More specifically, on the ground monitoring stations (monitoring terminals), satellite systems GPS and Spot and Landsat images (with different spatial and radiometric resolution) provide useful information to the central system (GIS) that processes information and provides the output to users both in the laboratory as in situ. Particular importance is given for the purpose of processing the various models designed to create the logical connections between the individual thematic maps (possibly realized) and to interpret and explain data in the phenomenological or physical context of territory-system.

The models used to process are so distinguished:
- algorithms of union and intersection data (available in all geographic information systems);
- algorithms of multidimensional statistics (useful for spatialise survey data on time and to integrate data on the ground with the data type of satellite remote sensing. Specifically, these models were tested for analytical photo-interpretation of Landsat and Spot imagery;

- diagnostic algorithms that introduce information as they are set on the theories that explain the structure of the territory or the propensity of critical events of the system.

2. Methods

This contribute represents a revision of a previous work (Barrile V., Pirrone G., 1999. *GIS per il monitoraggio geologico e ambientale*) implemented using new software, with appropriate amendments and tricks both technical and implementative.

2.1. Working tools, data input and management of information

Specifically, as mentioned, is considered a small area of the southern part of Calabria. For the realization of the work (carried out in various phases) were used the basic software Arcview 8.3, Arcinfo and Envi. The programs needed for modeling. implementation and management of GIS were written in the programming language "Macro Avenue" in AML (C language). The type of input data consists mainly of:
- Basic cartography;
- Analytical data or monitoring;
- Landsat imagery (seven bands) and Spot.

The base map is composed of several layers. certain acquired from existing maps or surveys on site, others by image processing. To each of them was associated the corresponding topography (Figure 1). The analytical data monitoring are constituted by a layer prepared for the acquisition data from sampling stations (in this stage, data were simulated) positioned on site (Figure 1). Note that to the layers "soil instability" and "subsoil instability", in addition to the attributes (code, length, perimeter, area, description) associated "automatically" (as well as the other layers), was also added the field "Volume" and two additional fields (Riskl and Risk2) that are not calculate automatically, useful later for the monitoring phase of the risk. Similar considerations for the attribute "Value" related to Layers "Gradients" and "Exposure" which will be discussed later. As for the layer "Measures" was prepared a "Table control units" containing three fields (Type, Code and Data) directly connected through a suitable function of "link" to the vector of the measures in the site (containing two fields related to the date of measurement and the numerical value of measurement), downloaded from the central system or directly via the network, or, indirectly, in a later stage.

2.2. Structure of the SIT: From conceptual model to the logical model

The layers described above make up a "Spatial Archive" (Figure 1) which can be considered as a computerized map (static) on the situation geomorphologic-territorial of the study area, directly viewable and searchable with the classical management operations of a GIS static. It should be noted in this regard that the information contained in the layer "Geology" originate, as well as acquisition (digitization) mapping, also by interpretation of Landsat and Spot satellite images (Figure 3). Then this archive territorial established, the problem lies in deciding, on the one hand, if the "collapse" of data type is or is not at risk of landslides, and, secondly, the affected area can be treated as a possible "source mining". Is therefore necessary to identify a risk model that provides a degree of risk each time updatable in GIS, as well as an evaluation model can provide an "index of propensity mining". For simplicity in description the two issues are presented separately.

2.2.1. Landslide phenomenon

In this phase, in the absence of an adequate modeling (it is given importance in this work to the stages of structuring the system and implementing the algorithms and not to the actual modeling of landslide), we have assumed a risk model comprising:

- a component of "static risk" (Risk 2 in "Table instability") arising from the specific geomorphologic conditions and / or area of particular instability obtainable with an "appropriate modeling" from the archive area already set up;
- a component of "dynamic risk" (Risk I "Table instability") arising from external environmental data, obtainable with an appropriate modeling of data from measuring stations and updated in real time in GIS. (Figure 1).

A suitable modeling of these two sources of risk, a static one. the other dynamics provides a degree of overall risk for each instability. Specifically, the algorithm implemented is based on the management of tables and codes (Table 1). Any "collapse" in the area under study is therefore identified by a particular code (A, R, C, D), Each unit (Piezometer, Inclinometer, Pluviometer, GPS) is identified by a code (XYZK, where X identifies the particular instability where the control station is located, Y the type of unit, ZK the characteristic number of the control unit) alphanumeric string of 4 characters (Table 1). Taking into account the Table 1 and the flow chart of Figure 4, we report some of the comments in the program.
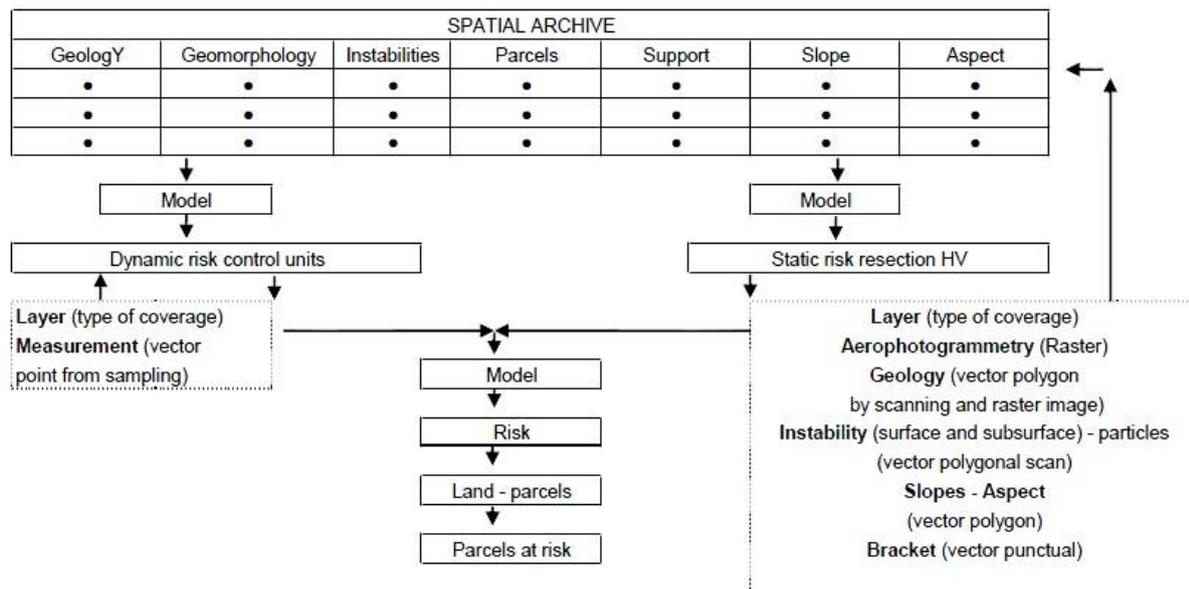

Figure 1.

After opening the Table control unit, the identification of the type of unit from the second character of the field code and the corresponding opening of the "Size Chart" (For each of the 4 types of control units are supplied with data collected from existing literature with a daily rate of detection) is carried a weighted average (weight gradually decreasing respectively Piezometres. Clinometers, Pluviometer, GPS) of the values obtained for the terminal so as to obtain numeric values in a range of values variable from 1 to 10. This will open the "Table of Risk", where we report two fields for each record that is the code of the unit previously selected and the value of the degree of dynamic risk measured with the average operator. The operation is repeated for all types of control units present in all the different areas of instability.

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Table 1.

TAB. INSTABILITIES
Code (A, B, C, D...)
Area
Volume
.
.
Risk 1 (i = 1, 10) – R1
Risck 2 (j = 1, 10) – R2

TAB. RISK	
Code	Value
AP01	2
AC01	4
AA01	2
AG01	1
AP02	7
BC01	3
.	.
.	.
.	.
.	.

TAB. CONTROL UNIT		
Type	Code	Date
Piezometer	AP01	200509
Clinometer	AC01	200509
Pluviometer	AA01	.
GPS	AG01	.
Piezometer	AP02	.
Clinometer	AC02	.
Pluviometer	AA02	.
GPS	AG02	.
Piezometer	BP01	.
Clinometer	BC01	.
Pluviometer	BA01	.
GPS	BG01	.
Piezometer	BP02	.
.	.	.
.	.	.
.	.	.
.	.	.

TAB. MEASURES	
Date	Value
200609	5
210509	10
220509	7
230509	7
240509	4
.	.
.	.
.	.

At the end of this operation, the "Risk Table" includes all units with their code and the corresponding degree of risk arising from the "modeling" of the external environmental causes at the time of the interrogation. This will open the "Table of instability" and identifies the particular instability (code in the first record of the same table), then opens the "Risk Table" previously completed and, with key code (first character of the first field code) add the values for the degree of risk of all systems present in that particular instability.

The value obtained is placed in the "Risk 1" of the "Table instability". In addition, in the same table had proceeded in advance to fill the field "Risk 2" relative to the risk assessed with a procedure static "rough" which, in the absence of adequate modeling, calculates the static risk (Risk2) for each instability performing the weighted sum of the volume of the numerical values (1 to 10 according to literature references) assigned to each subpart (Identity layer on the geology, geomorphology, slope and aspect provides for each subpart realized by "collapse original" one and the same code but different characteristic of "layer") of the particular instability in turn analyzed. At the end of the operations of iteration, in the table of instabilities will be present for each of instabilities taken into account, in real time equal to the time of sampling, two fields (both with numerical values from 1 to 10):

- Risk1 relative to the dynamic risk;
- Risk2 relative to the static risk.

It is therefore possible, in the operation phase, perform a query on the "Table instabilities" relative to the fields R1 and R2 to detect, in real-time (data acquisition time, and reworking) details instabilities at risk, and, having made an intersection with the layer of the land parcels , to highlight the land parcels presumably at risk. It is observed that the layers "Slope" and "Exposure" were drawn up using the form "Grid" (generation of cell values from altimetry data available). Both in the case of the slope that exposure and 'was made a reclassification of values so as to obtain a grouping in a given number of classes of given amplitude.
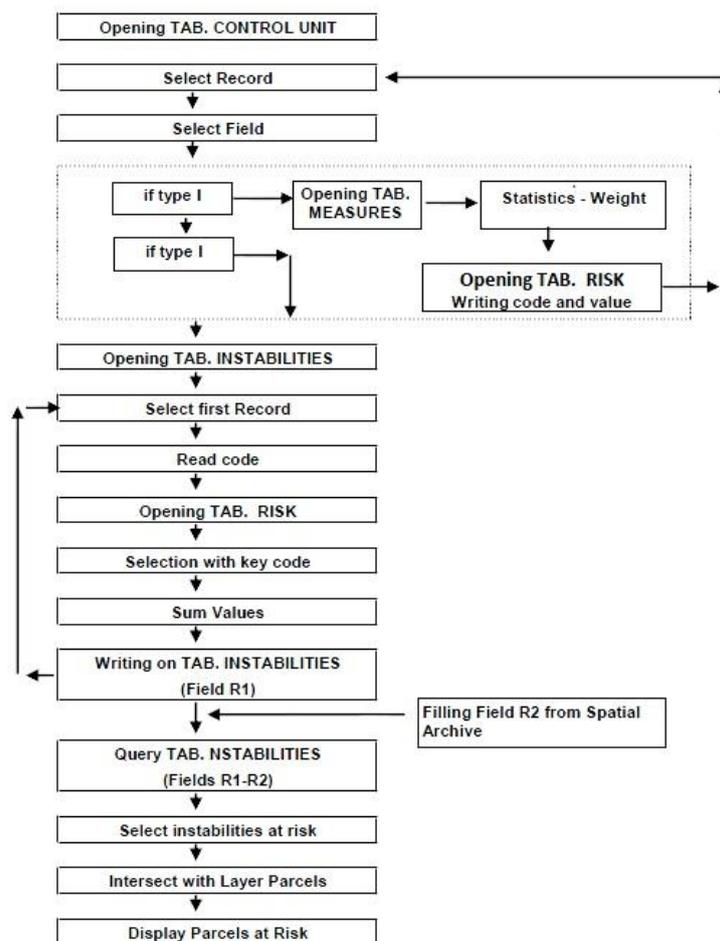
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Figure 2. Flow chart.

2.2.2. Mining phenomenon

As is known, a mining exploration project is generally divided into three phases:
- Geological classification;
- Stratigraphic research;
- Geochemical sampling.

A valid support may be provided by data from modern techniques of remote sensing integrated through advanced analytical models with data carried out from sampling campaigns on the ground. The end result is the production of a map of the mineral potential of an area. In the specific areas in analysis were classified by an index of mining propensity PM defined from the data sample collected (simulated) used to define thematic maps of "variables of knowledge of the area". In detail: PM=$\Sigma_i W_i X_i$ where the X_i are the variables knowledge of the area and W_i are the weights estimated. W_i therefore depend on the correlation between the individual X_i (thematic maps) and the event considered mining, the latter characterized by an appropriate statistical parameter defined in advance by the model used (currently still rudimentary). This is described in Figure 3.

We therefore considered the following variables X_i of knowledge of the area:
- Geological-lithological information (integration of Landsat and Spot imagery and subsequent comparison between different methods of classification and photo-interpretation);
- Geochemical information (sampling units simulated);
- Information resulting from spatial archive via "rudimentary model simulated" (stratigraphic sequence - thrust faults and faulting - uplifting and erosions - Tectonics).
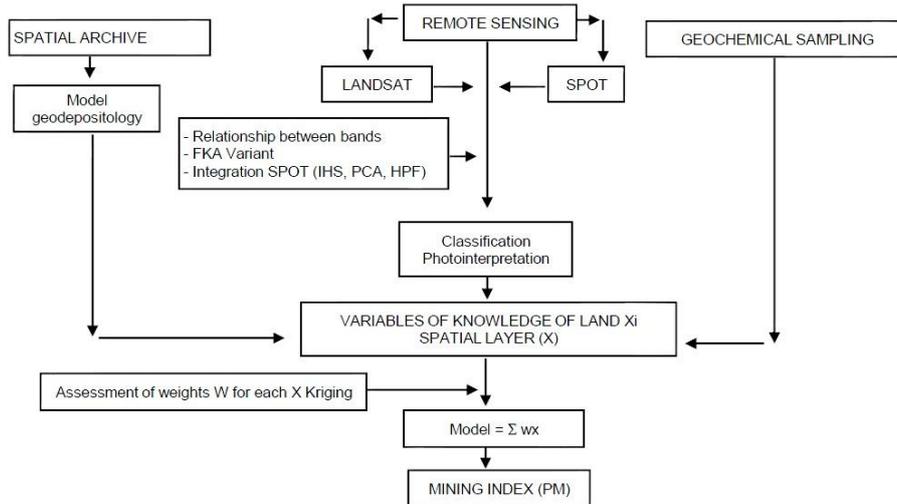
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Figure 3.

Particular attention was given to the phase of photo interpretation and classification of images. In extreme synthesis, we used the following methods:

- Interpretation of the relationship between bands (the image RGB to interpret was obtained by considering three special reports of the 7-band choices in relation to the covariance matrix of the logarithmic bands as well as the matrix of the eigenvalues and eigenvectors associated);

- Integration of Landsat and Spot. Specifically, were used various techniques:
    - IHS (converts the composition of the three bands RGB in the same physical elements, Hue, Saturation and Intensity of which is based perception by the human eye);
    - PCA (is similar to IHS technique but has no restrictions on the number of bands to which the analysis can be applied);
    - HPF (allows the simultaneous integration of the images Spot, with good spatial resolution, in those Landsat with high radiometric content);
    - Application of a geostatistical technique of non-linear type (variant Factorial Kriging Analysis (FKA).
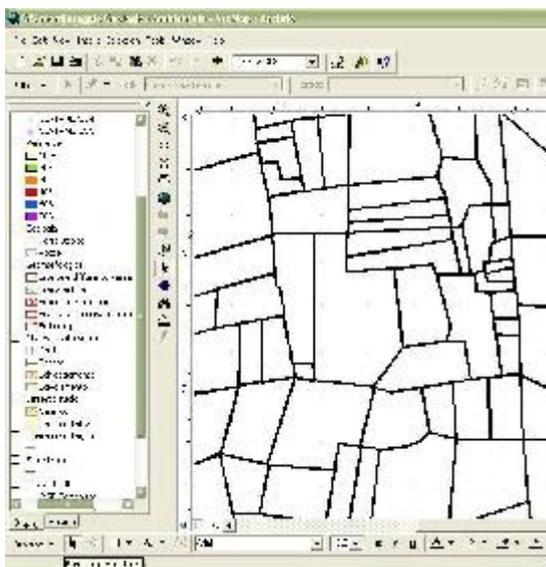
2.3. Application example of integration

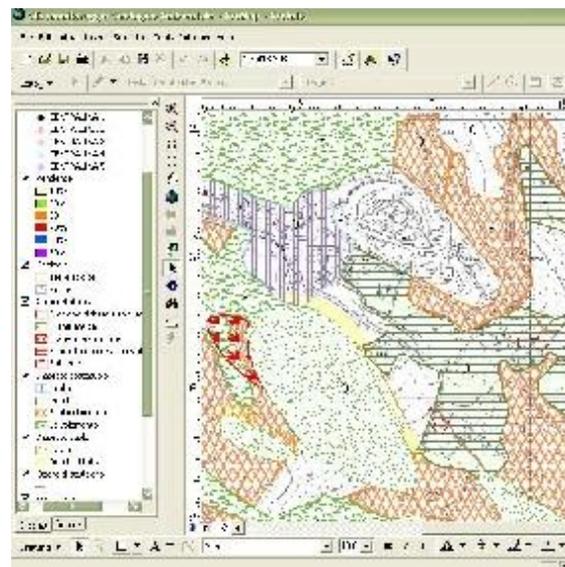**Figure 4.** Cadastral layer.

Figure 5. Overlapping of several layers.   .

Selected a particular instability, the following tables associated are automatically opened:
- Table Instabilities;
- Table Control units;
- Table Measures (with the device's convenient link).

When managing, after making the query on "Risk 1>5" and "Risk 2>7", are highlighted, among all the instabilities, the particular one for which are verified the characteristics required in relation to landslide risk (Figure 8).
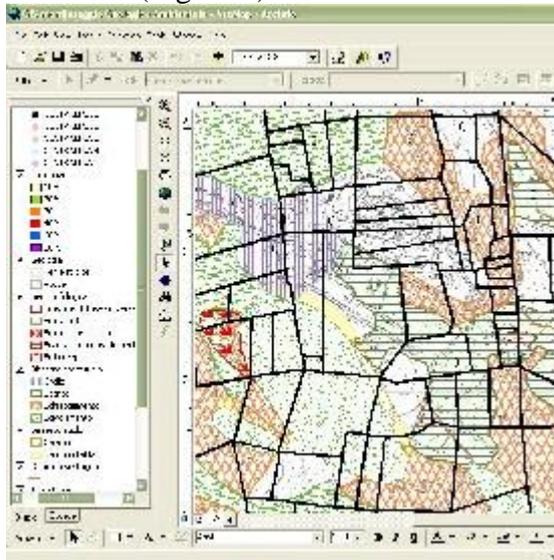

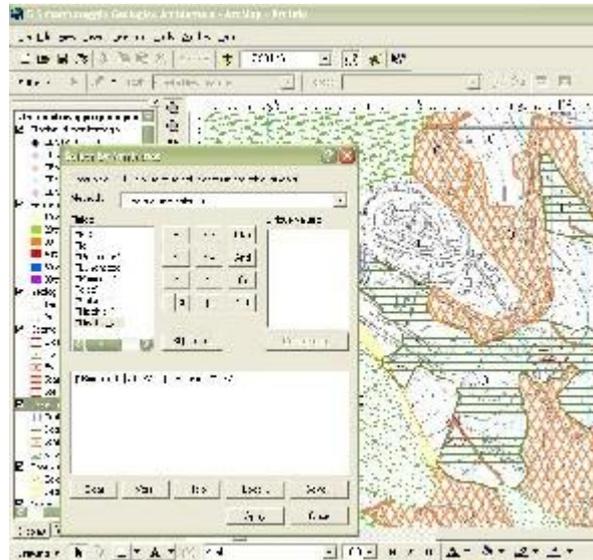**Figure 6.** Overlapping cadastral layer to various layers
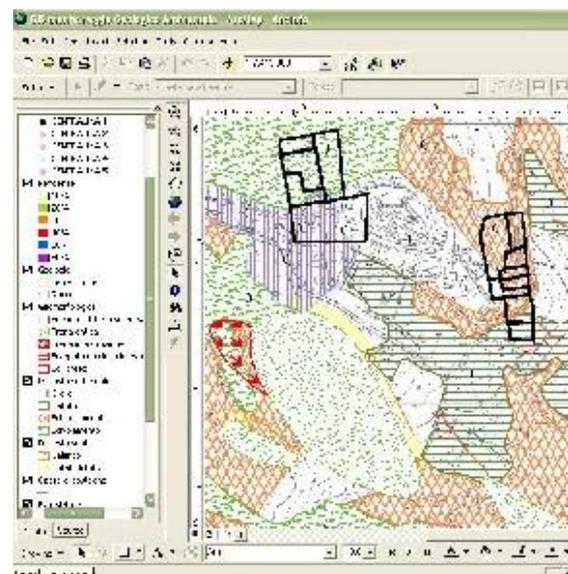

Figure 7. Query.

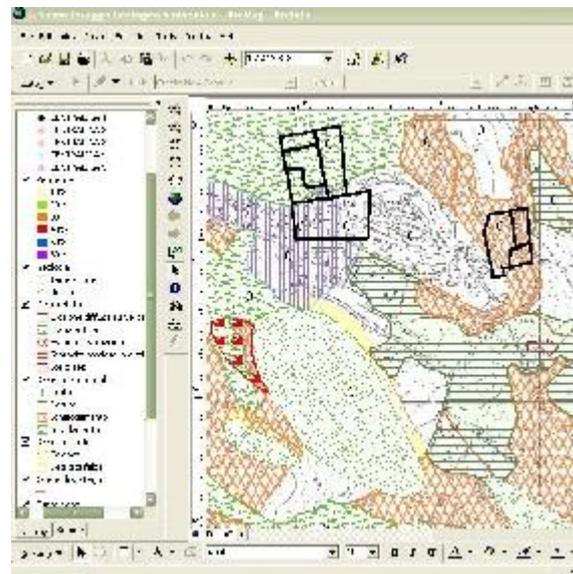**Figure 8.** Land parcels at risk of landslide.

Figure 9. Particles presumably at risk of landslides and potential mineral reserves of the subsoil.

3. Conclusions

The intersection of the "instability" identified with the layer relative to land parcels as well as that relating to the areas with mining index "positive" is used to show the parcels presumably at risk of landslides as well as with potential mineral reserves of the subsoil (Figure 9).

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The processing models used are algorithms for union and intersection data and multidimensional statistical algorithms, useful for accurate tracking data measurement and to integrate the data on the field with the data type of remote sensing satellites.

Inter alia, these models are tested for analytical photo-interpretation of Landsat and Spot imagery with diagnostic algorithms, introducing information based on theories that explain land use or the propensity to critical system events.

References

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