GIS applications with Grass

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Abstract

The application of GIS has become fundamental in environmental studies since it allows the integration of heterogeneous data.
Several applications of the GRASS GIS where the use of different data types leads to the realization of environmental models are presented.
The GRASS GIS has been used to develop and test forest fire risk models combining several morphologic, vegetational and anthropic factors; it has been used to set up a new avalanche risk model which allows the evaluation of the ability of the different vegetation types to protect against avalanches. A procedure for the automatic determination of the forest coverage evolution has been developed using the GRASS image analysis capability. The production of GPS satellites' visibility maps has been automated using the shadow generation algorithm in GRASS. This algorithm is also used to evaluate solar radiation and its relation to vegetation types.

1. Introduction

The application of GIS has become fundamental in environmental sciences since it allows the integration of heterogeneous data coming from different sources. GRASS is one of the most interesting and powerful public domain software GIS (Ciolli 1999). GRASS is an open GIS, that is a software whose source code is free and can be modified. In 1995 we began to test GRASS as a tool to study landscape changes and risk assessment. Since that year we have developed different models, facing different problems and trying to stress hardly the tool to reach its limits.
GRASS is a very powerful tool to study and to evaluate landscape changes and natural risks, issues which are very important in a very rich in natural resources region like Trentino.

2. Avalanches risk management

The first test of GRASS was carried out on avalanche risk assessment. The southern part of the Alps is interested by frequent avalanche phenomena. It is very important to provide a suitable method to manage avalanche risk.
The avalanches represent a real problem as they can endanger inhabited zones or touristic areas and they can improve superficial erosion and solid transport affecting the hydrological characteristics of the alpine valleys.

The usual approach is based on the mapping of the avalanches occurred and reported by local foresters, found in historical documents or identified in aerial photographs on the "Carta di Localizzazione Probabile delle Valanghe" (C.L.P.V. i.e. Possible Avalanche Location Map).
Modern methods are based either on statistical approaches or on the evaluation of the morphology and vegetation characteristics. We have chosen to follow the latter approach because in this way it is possible to locate not only the events occurred but also the dangerous areas where no past events have been reported.
This could be useful in land management at different scales. Besides, it permits the evaluation of the influence of forest types on the avalanche risk. This kind of approach can be succesfully exploited using GRASS to store and elaborate different data.
Different kinds of data (vegetation, aerial photographs, 3D models) have been integrated in GRASS to evaluate land morphology and vegetation types.
Val di Pejo, located in the north-western Trentino, an Italian alpine region, has been selected as test area. This valley has been considered particularly suitable for this study because it shows frequent and sometimes huge avalanche phenomena and includes an inhabited zone directly menaced by an avalanche.
A digital terrain model has been created with the 3D algorithm of GRASS GIS. A map representing the different vegetation types has been obtained using the information of the Trento's Forest Management Bureau. The boundaries of the vegetation types in the maps used for forest management are generally approximated, so it has been necessary to verify the real extension of the different kinds of vegetation. An orthophoto has been obtained by differential rectification of digitalised aerial photographs using the DTM and some control points. The orthoimages have been used to test the real location of the boundaries and the extension of the parcels.
The avalanche risk areas have been recognised by applying morphologic criteria (slope between 28° and 55° and minimum surface of about 625 m^2, upstream slope change greater than 10°).

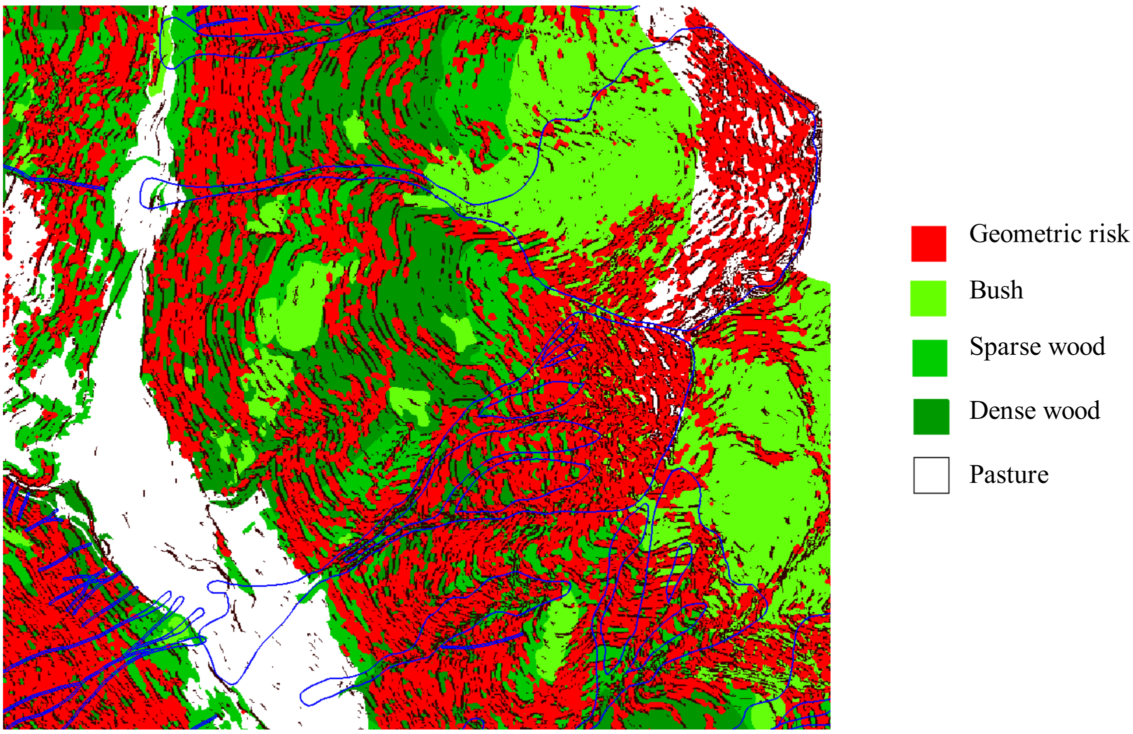

Figure 1 Avalanche risk map superposed with Carta di Localizzazione Probabile delle Valanghe, which highlights the borders of really happened event

An algorithm which uses these morphologic rules has been developed and applied to obtain a map of the "morphologic risk", i.e. areas showing an avalanche probability based only on their geometric features.

The vegetation has been classed in three different coverage types depending on its density, since the latter influences their ability to avoid the creation of a compact and homogeneous snow layer. A map of the vegetation's protection ability has been obtained. Both maps themselves can be useful to depict the risk situation but a dramatic improvement of the precise location of the risk areas is obtained by combining the two maps. The resulting map is used to assess the avalanche risk. This map has been verified comparing it to the C.L.P.V..
Three different regions have been recognised:
· real risk areas where our map locates high avalanche probability and the phenomenon has been reported;
· areas where the protection ability of the vegetation coverage balances the morphologic risk;
· areas where no avalanches have been reported but the vegetation cannot face the morphologic risk.
The real ability of the different vegetation classes to offer protection against avalanches has been evaluated by comparing the morphologic avalanche risk area with the extension of the events occurred.
The ratio between the real surface covered by avalanches on the C.L.P.V. and the potential surface obtained following the described criteria (clustering the vegetation in three different classes) highlights the importance of the vegetation coverage in protecting from avalanche risk. The creation and the use of the 3D model and its integration with digital images and environment data has allowed the elaboration of thematic maps which contain valuable information suitable for forest and land management.

	Dense evergreen wood	Sparse deciduous wood	Pasture or bush
$S_{avalanche}/S_{potential}$	0.096	0.148	0.453

Table 1 - Vegetation protection ability.

3. Evaluation of vegetation dynamic

In the higher part of many Italian alpine regions the population is rapidly decreasing and this fact directly influences landscape and forest management criteria. In particular, large pastures and agricultured areas are being covered by trees or bushes, which change how the landscape is perceived by people and may influence the CO_2 cycle. This is a well known trend but it is very difficult to evaluate the extension and the evolution of these phenomena as requested by some specific studies on sustainable development.
A new approach to this problem has been developed at the Laboratorio Ambiente e Territorio, which makes possible to determine changes of the forested areas over time. Series of aerial photographs taken in different years (1954, 1980, 1994) have been compared using automatic algorithms which exploit the GRASS GIS image analysis capability. This method has been tested chosing two different areas in south and north Trentino and has proved to be effective for the automatic determination of the widening of the forested areas. A precise knowledge of the forest coverage evolution is very precious to enhance forest and landscape management criteria. It can also be combined with demographic information to better explain landscape change.
This work is has been accomplished in three phases:
1. Orthorectification of the aerial images;
2. forest area recognition on each image;
3. comparison of the forest areas on the different images.

All these task have been carried out in automatic with a minimum operator work to obtain the forest area evolution. A time-wise comparison has been carried out on the binary maps representing the forest coverage at different years. This allows to discriminate the forest coverage change over time, both in a qualitative way and in a quantitative way.

The first part of the work consisted in the rectification of the aerial images taken in 1954, 1980, 1994 by mean of GRASS GIS orthorectification modules. In the following phase, the forest area recognition on each image was carried out in some different steps.

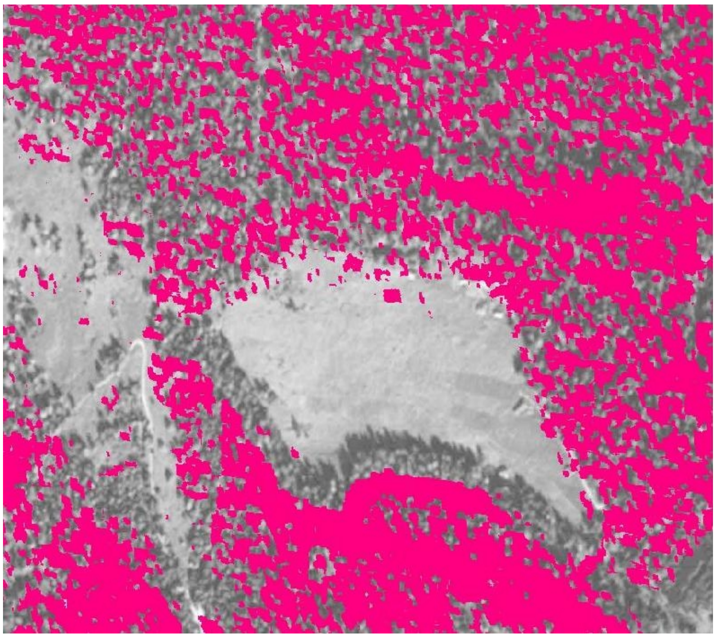

Figure 2 Comparison between forest coverage in 1954 and 1994 (1954 grey colored).

The first step of the image classification is the construction of the gray level distribution histogram. On each image two test areas which represent a forested area and a non forested area respectively have been chosen.

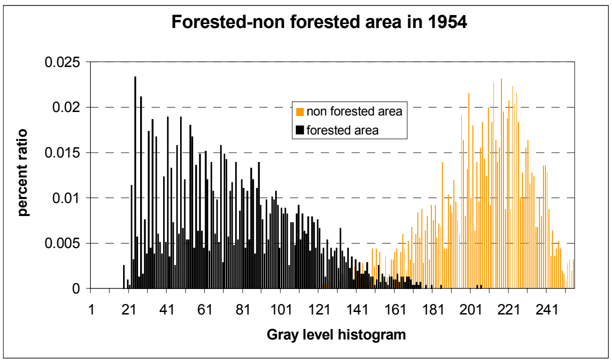

Figure 3 Image classification: construction of the gray level distribution histogram

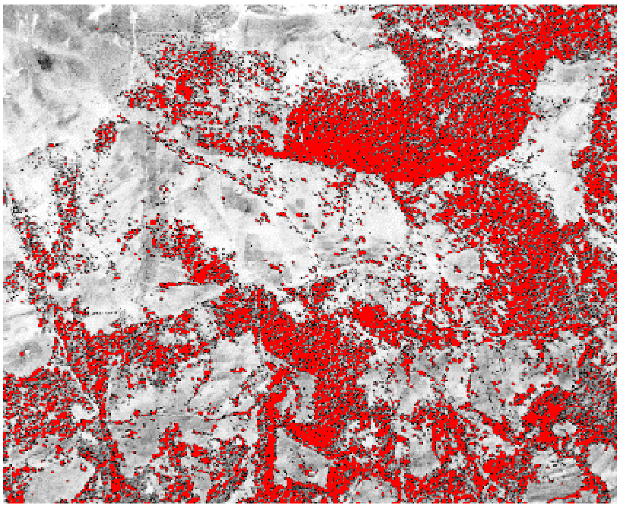

Figure 4 Problems of the classification technique. High gray level values due to noise in forest areas result in a leopard-skin pattern binary map and areas with dark shadows are classified as forested regardless to their real coverage.

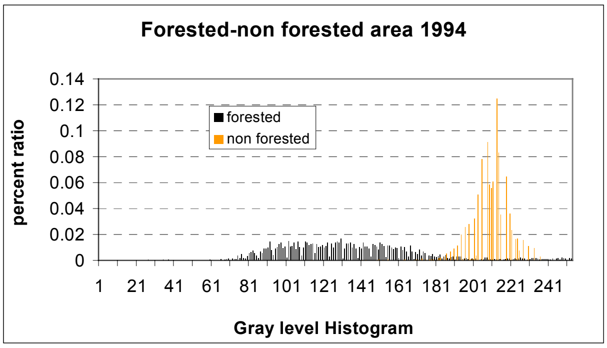

Fig. 5 Gray level histogram for test areas in 1994

A first classification scheme simply uses a threshold value to assign a pixel to a forest area rather than to a non-forest area according to its gray level value. Binary maps for forested-non forested area have been obtained in this way.

The threshold values have been chosen for each image by making minimum the error of attributing a pixel to the wrong class.

Some problems arise using this classification technique: high gray level values due to noise in forest areas result in a leopard-skin pattern binary map and areas with dark shadows are classified as forested regardless to their real coverage.

This can be easily verified by superimposing the obtained binary forest maps on the ortho-photos (figure 4).

A more sophisticated analysis has been carried out to avoid the problems above. The local gray level histogram has been compared with the histogram of the forest sample area. In each area the percentage of pixel which would be classified as forest with the previous scheme must be higher than the percentage in the sample forest area.

A 5x5 pixels mask has been applied to the binary map and the density of “forest” pixel has been evaluated. The central pixel has been classified as forest if the “forest” pixel density is equal or greater than the density in the sample forest area.

A further step of the elaboration involves a mask similar to the previous to obtain more homogeneous forest regions.

A final comparison has been carried out to verify the correspondence between the new classification and the "ground truth" of the ortho-photo (figure 2).
The third and last phase of the work, the time-wise comparison has been carried out on the binary maps representing the forest coverage at different years. This allows to discriminate the forest coverage change over time, both in a qualitative way and in a quantitative way.
Here we present the results of two different studies carried out respectively in Val di Pejo and Valsugana. The method has given very good results.

YEAR	Forest HECTARES	PERCENTAGE OF Forest
1954	1353.8371	42.77 %
1983	1527.4887	48.26 %
1994	1709.3085	54 %

Table 2 – Val di Pejo, Forest coverage per each year

YEAR	HECTARES	POPULATION	Employed. AGROFORESTRY
1954	1353.8371	2175	65.9 %
1983	1527.4887	1933	11.2 %
1994	1709.3085	1837	10.4 %

*Table 3 – Val di Pejo, C*orrespondence between the forest area coverage increase and the population decrease.

It is very interesting to mention that an exact correspondence between the forest area coverage increase and the population decrease has been observed.

Forest growth for areas	higher than 1000 m above the sea level	lower than 1000 m above the sea level
Total area in square km	11,57	15,62
From 1954 to 1983 [%]	19,9	7
From 1954 to 1983 [Square km]	2,3	1,1
From 1983 to 1994 [%]	6,8	2,3
From 1983 to 1994 [Square km]	0,79	0,36
From 1954 to 1994 [%]	26,7	9,3
From 1954 to 1994 [Square km]	3,09	1,46

Table 4 – Valsugana, before starting the analysis the binary map have been split in two different regions to separate the higher part (more than 1000 meter above the sea level) where the forest coverage is more continuous, and the lower part where the presence of little farms and houses makes the forest coverage more leopard-skin looking like (between 400 and 1000 meter above the sea level).

4. Evaluation of wildfire risk

Many different models for the evaluation of wildfire risk set up for different geographic areas have been developed all over the world through years. These models are different for the parameters involved and for their relative weighting. We have applied some of these models using GRASS GIS to compare their results for a test area in in South-western Trentino (Ledro Valley). Ledro Valley, covered by different forest types, is often interested by wildfires. Each forest type has different behaviour as of fires risk and fire spreading. Different fire risk maps have been developed using each model. These maps have been checked against the fires occurred during the last 30 years to select the best one for the test area (figure 6).
Some wildfire risk models have been tested and the results have been compared by mean of GRASS GIS. The risk models have been selected among those described in bibliography, especially coming from Spain and Portugal, countries in which a part of the mountain environment could be compared

with Trentino. Some other models like the one created by Purdue University, realized by mean of GRASS GIS.
The results of the application of the risk models have been compared with the real occurred events.
The models have been implemented by mean of r.mapcalc, an utility to carry out map calculation on GRASS raster files. Each model was displayed in a map and then compared with the others.
The model 1 in tab. 5 seems to be the best, because the real wildfires fall within high risk areas and are homogeneously distributed. In this map less than 5% of the areas interested by wildfires has been classified at zero risk. Apparently the other models seems to give better results but they simply consider most of the land as a high risk area: obviously this fact does not allow an effective classification of the territory in risk categories.
Using GRASS GIS it is possible to implement spreading models of a wildfire which calculate fire direction, speed and the spotting distance.

Risk	Model 1	Model 2	Model 3	Model 4	Valladolid	Purdue	Almeyda	CNIG
No risk	4.74	7.71	10.26	27.27	34.58	30.27	13.24	6.45
Medium-Low	41.14	64.69	67.88	6.54	32.25	38.58	29.68	36.34
Medium	48.82	25.60	19.91	35.60	28.78	31.15	40.70	50.67
Medium-High	5.30	1.99	1.94	30.09	4.39	0.00	16.26	6.54
High	0.00	0.00	0.00	0.49	0.00	0.00	0.12	0.00

Table 5 – Presence (%) of fire ignition points in each risk category for the different models. Different weights have been used for the various risk factors in models from 1 to 4.

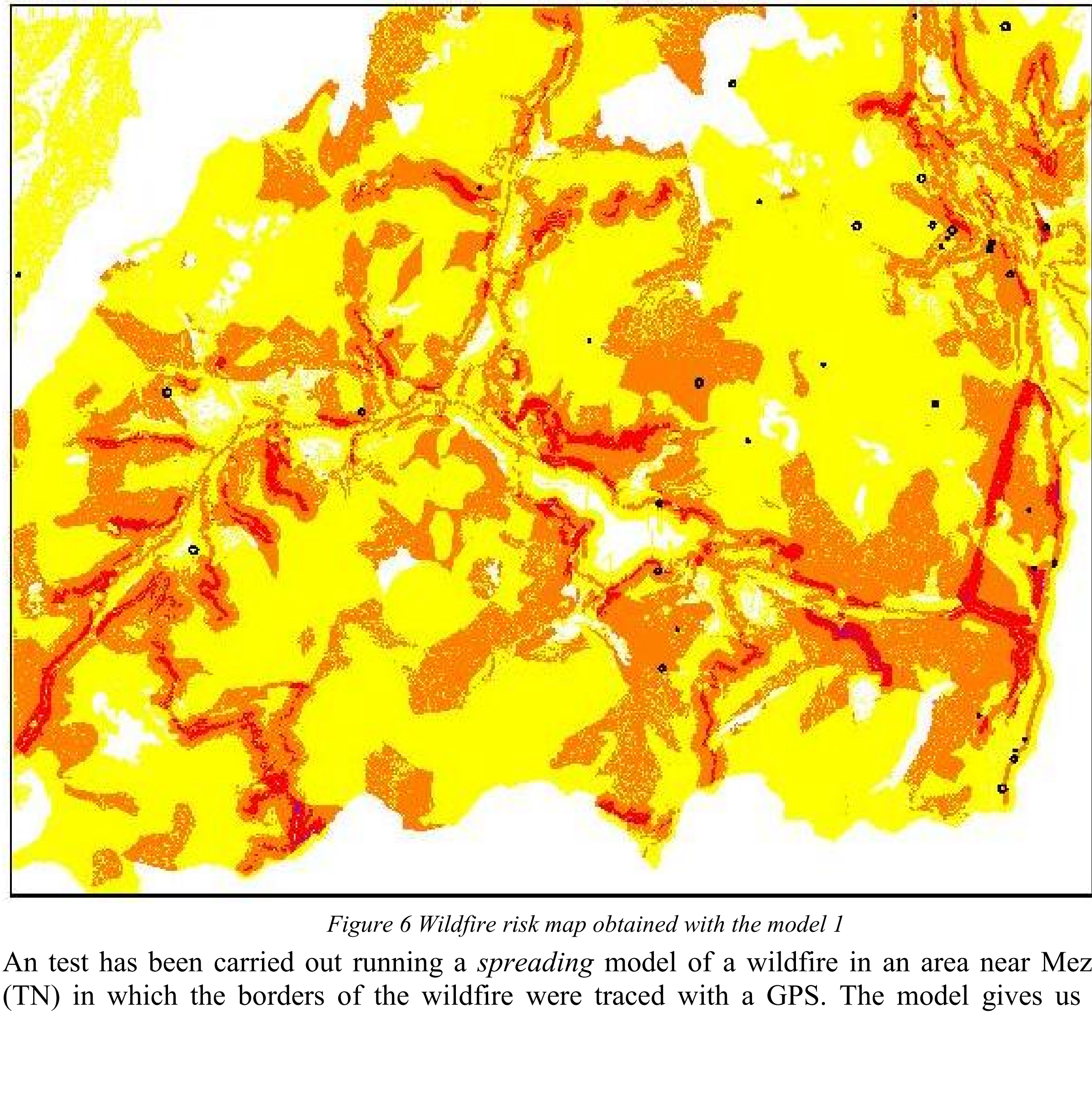

Figure 6 Wildfire risk map obtained with the model 1

An test has been carried out running a *spreading* model of a wildfire in an area near Mezzolago (TN) in which the borders of the wildfire were traced with a GPS. The model gives us a very responding shape of the wildfire but it is not so good in the definition of the time progression of the event (figure 7).

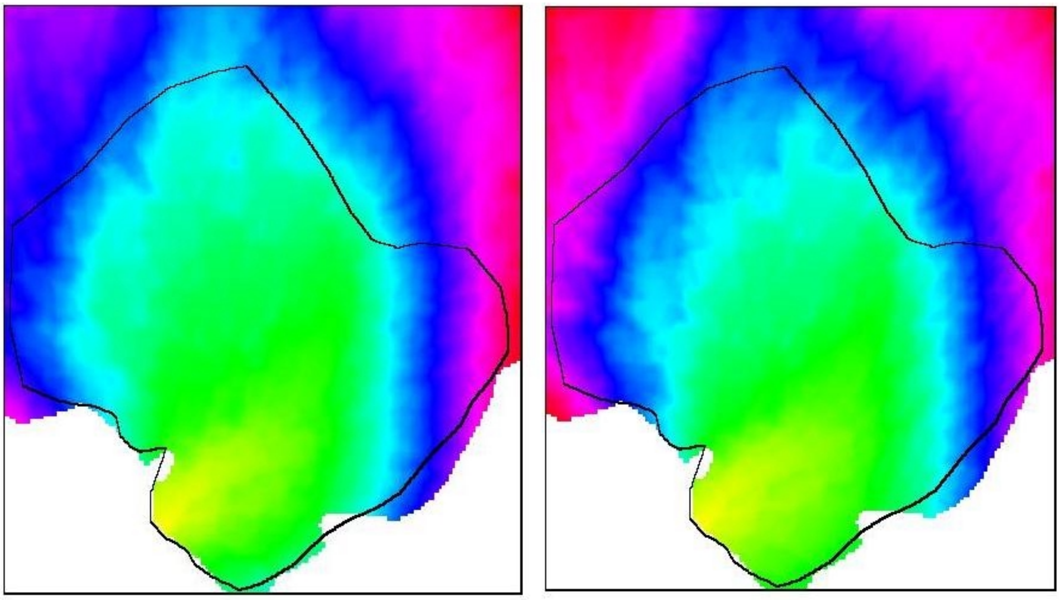

Figure 7 – spreading map of the wildfire near Mezzolago neglecting wind (left) and taking it into account (right). In black the wildfire area.

This is probably due to the weight given to each forest type in the construction of the models which describe the behaviour of a wildfire in a forest. The GRASS models have been created for forests which are very different from the ones found in Trentino.

5. Automatic visibility maps of GPS satellites

A realistic forecast of the visibility of the satellites and their spatial geometric configuration is a key factor for the success of a Global Positioning System (GPS) survey. Planning procedure is possible with commercial software only for one point at a time and for assigned time interval. Moreover, the operator have to survey in sito the obstacles that can hide part of the sky. This is very onerous in mountainous region (natural obstacle) and in the urban area (artefact obstacle) for static survey, but becomes impossible for kinematic survey.

In this paper a first planning procedure with automatic GPS signal obstruction detection is described. The realized procedure has been supported by GIS GRASS interfaced with almanac data and Digital Elevation Model (DEM).
The approach has been suggested by GRASS a tool, originally for the sun's shadows determination, which realises visibility layers satellite by satellite.

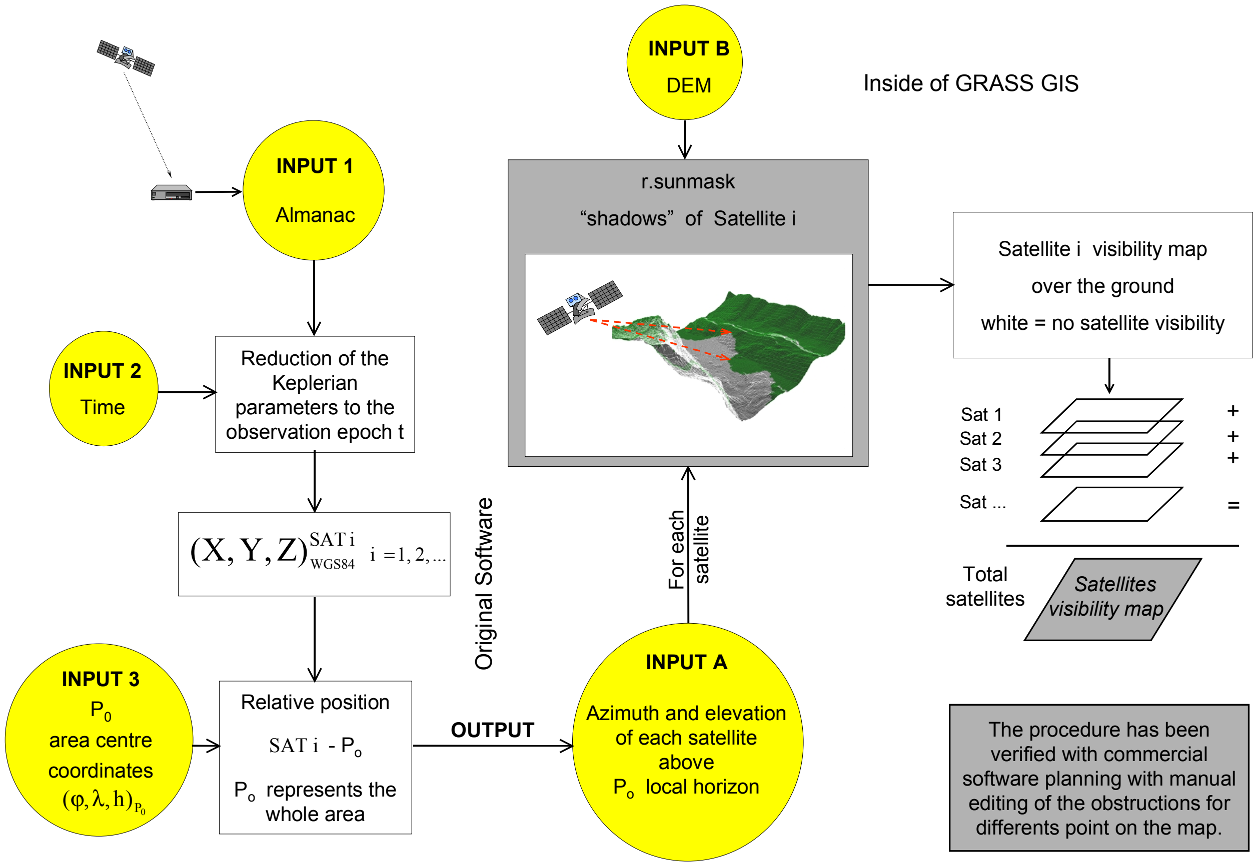

Figure 8 Scheme of the procedure to obtain satellites visibility map.

The procedure scheme is shown in figure 8, composed in three main steps.
The first step is to compute satellites' positions above the local horizon from almanac data (input 1) for the chosen time (input 2). An external software has been realised to compute satellites WGS84 coordinates through reduction of the (pseudo) keplerian orbits parameters, from an almanac data in ASCII format. Satellites' relative position from latitude and longitude of the considered area centre P_o (input 3) are computed.
Azimuth and elevation of each satellites above the local horizon in P_o (barycentre of the area; step 1 - output) and DEM (centered on P_o) are the inputs of the GRASS algorithm r.sunmask (step 2 – input A and B), that automatically takes into account effects of satellite signal obstructions on different pixel. A binary raster shadows map of the considered satellite is obtained, where each pixel contains the value 1 (black) if the satellite is visible, 0 (white) elsewhere.
The last step is obtained with algebra map inside GRASS (r.mapcalc). It produces satellites visibility map, through direct sum of each satellite layer (number of layer with "black" pixel): in the resulting map the value of each pixel is the number of visible satellites for the site.
With this procedure it is possible to obtain satellite visibility for a local area and not only for a single point. The area extension and the reliability of the procedure, depends obviously on requested accuracy and on algorithm and data approximations.

In tab. 6 the approximations and their sources are presented, computed in term of elevation uncertainty. Their effects in term of shadow uncertainty are computed for an obstacle height of 2000 m with cut off elevation signal of 20°.
Accuracy can not be higher than 1' due to the almanac ephemeredes sources uncertainty.

Shadow's variation due to almanac data and DEM uncertainty increases from 5 m to about 30 m, considering 10 m of uncertainty in eight. DEM eight uncertainty is generally lower with small spacing grid, on the other hand computational load increases considerably; a good compromise between computing velocity and shadows accuracy may be obtained with a 40 m grid spacing DEM.
The first approximation in this procedure is to consider satellite's signal "ray" as parallel, as it is usually done for far sources like the sun. This is justified from a satellites distance of about 20.000 km, that corresponds to differences of 1' at 6 km (like almanac data). Consequently azimuth and elevation of each satellite are computed only one time above local horizon of the area centre P_o, i.e. relative positions (earth surface-satellite) are considered the same for each pixel of the raster covering the area.
The influence of the use of different reference frame in eight, for satellites datum (WGS84) and DEM datum, may be considered lower than DEM effects no more than 10 m for shadow edges.

Approximation kind	**Source**	**Uncertainty** in term of elevation [degree] / shadow
Data	Almanac ephemeredes	1' / 5 m
	DEM	30 m
Procedure	Unique local horizon of the area centre P_o	1' within a 6 km radius / 5 m
	Height Different Reference Frames WGS84 (sat) and national (DEM)	< 10 m

Table 6 Approximations

As a result this procedure produces satellites' visibility maps with uncertainty level lower than 1 pixel using a DEM spacing of 40 m.

A real example is shown in figure 9. The realistic planning procedure, points out an unexpected low satellites visibility area, where only three satellites are visible on the Adige valley axis, generally considered a good zone for a survey.
Therefore planning with realistic obstacles is very useful particularly in critical zones like highly urbanised area and mountain area, to plan static survey but especially for kinematic and stop&go surveys, like road network survey and environmental monitoring.
Summarizing, the procedure described here to obtain GPS planning with automatic computation of obstacles is based on GRASS r.sunmask algorithm and the algebra map tool r.mapcalc. This first and simply approach, although not an optimal procedure, is very important to test limits and potential of the idea.
Future developments will produce satellites' visibility and their geometric contribution on survey precision taking into account spatial satellites configuration (DOP parameter), computed on local area or along a generic trajectory.

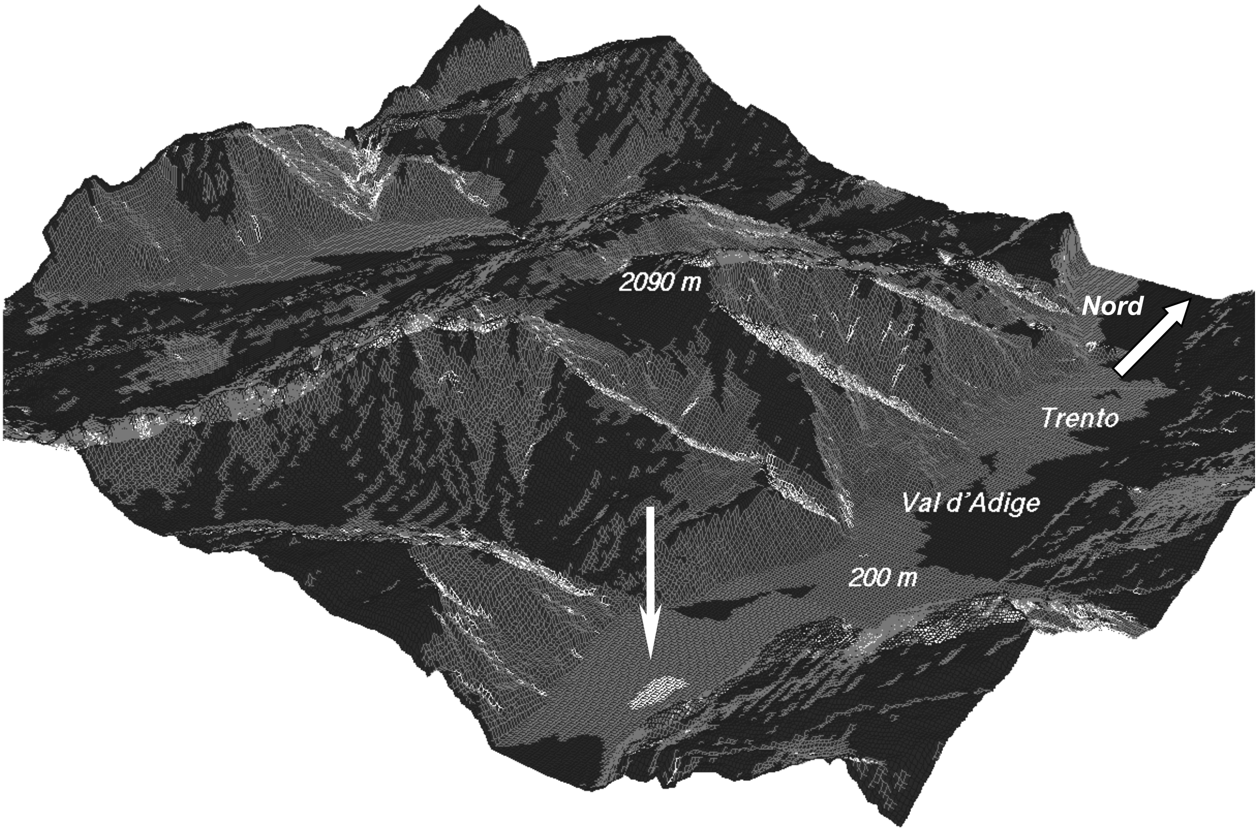

Figure 9 Satellites visibiliy map for Trento area: 21-07-'99 - 12.00 GPS Time
To show map in grey scale visibility has been subdivided in three categories:
white → < 4 satellites grey → 4-6 satellites black → 7-9 satellites

Conclusions

The applications described here clearly show the broad applicability of the GRASS system to general environmental problems. Moreover, the great flexibility of the system allows the realisation of fairly complex models environmental risks assessment. The GPS visibility application is a new and original features in a GIS and will be further developed, hopefully leading to the realisation of a new GRASS module.
The GRASS raster management capability ease custom maps realisation, whereas vector applications are not so flexible. Fortunately often the information used in environmental problem have an aerial nature, thus raster maps are most used.

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