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DIGITAL ELEVATION MODEL VISIBILITY INCLUDING EARTHS'S CURVATURE AND ATMOSPHERE REFRACTION

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RESUMO-NOTAS/ABSTRACT-NOTES

There are some instances in which the Earth's curvature and the atmospheric refraction, optical or eletronic, are important factors when Digital Elevation Models are used for visibility calculations. This work deals with this subject, suggesting a practical approach to solve this problem. Some examples, from real terrain data are presented. The equipment used was an IBM-PC like computer with a SITIM graphics card.

OBSERVAÇÕES/REMARKS

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RESUMO

Há casos em que a curvatura da Terra e/ou a refração atmosférica, ótica ou eletrônica, são fatores importantes quando Modelos Digitais de Elevação são usados para cálculos de visibilidade. Este trabalho trata deste assunto, sugerindo uma abordagem prática para sua solução. Alguns exemplos, a partir de dados de um terreno real são apresentados para ilustração. O equipamento usado foi um computador compatível com um IBM-PC, com uma placa gráfica SITIM.

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DIGITAL ELEVATION MODEL VISIBILITY INCLUDING EARTH'S CURVATURE AND ATMOSPHERE REFRACTION

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Abstract

There are some instances in which the Earth's curvature and the atmospheric refraction, optical or eletronic, are important factors when Digital Elevation Models are used for visibility calculations. This work deals with this subject, suggesting a practical approach to solve this problem. Some examples, from real terrain data, are presented. The equipment used was an IBM-PC like computer with a SITIM graphics card.

KEY WORDS: Digital Elevation Models, Earth's Curvature,
Atmospheric Refraction, Visibility.

1. INTRODUCTION

When Digital Elevation Models (DEM) are used for site selection of FM radio or TV stations transmission towers, in addition to the Earth's curvature, the atmospheric refraction also has to be taken into account. This is due to the fact that VHF (very high frequency - 30 Mz to 300 MHz) radio waves are refracted by the Earth's atmosphere because the atmospheric density varies with height causing the radio waves to bend towards the ground. Even when the location of visual observation forest fire control posts have to be choosen, the above discussed effects also have to be considered, with the use of an optical refraction index. To develop a computer software that, using, a DEM, is capable of calculating the visibility for a given observer situated at a certain height above the ground, with Earth's curvature and atmospheric refraction effects, was the main objective of this work. Such a software, running on MS-DOS on a IBM-PC-XT clone computer, with a SITIM graphics card, is an addition to the Geographic Information System developed at the Institute for Space Research-INPE, Brazil (1,2). The SITIM card was also developed at INPE.

The software is flexible enough to allow the user to change the Earth's radius and the refractive index, K. It should be noticed that a possible application, not attempted on this work, is the use of this software for visibility calculations on planets and/or satellites with a different radius and/or different atmosphere.

2. FLAT EARTH, NO REFRACTION

The method to determine the visibility here presented is based on Yoeli (3),with XO and YO as the observation point coordinates, TO as the observer height above the ground, DX and DY as the intervals betweeen columns and lines, respectively, then the observation point altitude, ZO, is the interpolated altitude HO, plus TO.

The interpolation used for the observation point is:

$$HO= \sum_i (Hi/D_i^2)/\sum_i (1/D_i), \text{ and } ZO= HO + TO$$

where, i=1, ..., 4 are the four cell vertexes, D_i the distance of the point to each of the vertexes, H_i the altitude at each vertex. The DEM x and y coordinates are given by:

$$XP= XO + DX\ (I-1), \text{ and } YP= YO + DY(J-1)$$

with I = 1,...,N (column number), and J = 1,...,K (line number).

The visibility will be determined only for the DEM points, in order to simplify the calculations. The observer point is O and the point to be observed is P.

For visibility determination the following algorithm is applied:

a) If all the intermediate point between O and P have smaller altitudes than the end points, P is visible.

b) If at least one of the intermediate points between O and P have a higher altitude than the end points, P is invisible.

c) If the steps a) and b) could not determine the visibility, calculate the tangent with respect to the horizon, between O and P, and O and all the intermediate points. If at least one of the tangents is larger than the tangent between O and P, the point P is invisible, on the contrary P is visible.

The visibility is determined for all points of the region, and the result is stored on a binary matrix: 1-visible, 0-unvisible. Each matrix element corresponds to a DEM cell. The matrix is then displayed graphically, along with a legend for the parameters used.

3. CURVED EARTH, REFRACTION

Since the Earth is not flat, its curvature effect have to be included. Form geometry, the target P sinks by a value e:

$$e = d^2/(2R)$$

where d is the distance between O and P and R is the Earth's radius.

On the other hand, the electromagnetic radiation bends down, the value of the bending depends on the refraction index, K. For visible light the average value for K, in Brazil, is 0.13 (4), while for microwaves is 0.25 (5), and for VHF 1.3 (6). The vertical value that has to be added to the altitude of P due to refraction is r:

$$r = d^2 * K/(2R)$$

where K is the refraction index.

Based on the above , the correction on the DEM becomes:

$$ZP = ZO - d^2 * (K-1)/(2R)$$

Then the DEM altitude matrix may be corrected to include the Earth's curvature and/or the refraction.

4. EXPERIMENTAL RESULTS

It was chosen an area near Campinas, SP, Brazil to test the software. The size of the region is 8x8 kilometers, with a DEM of 161 lines x 161 columns with 50 meter horizontal and vertical resolution. Figure 1 presents a perspective view of the region DEM, with a vertical exageration of 30 times.

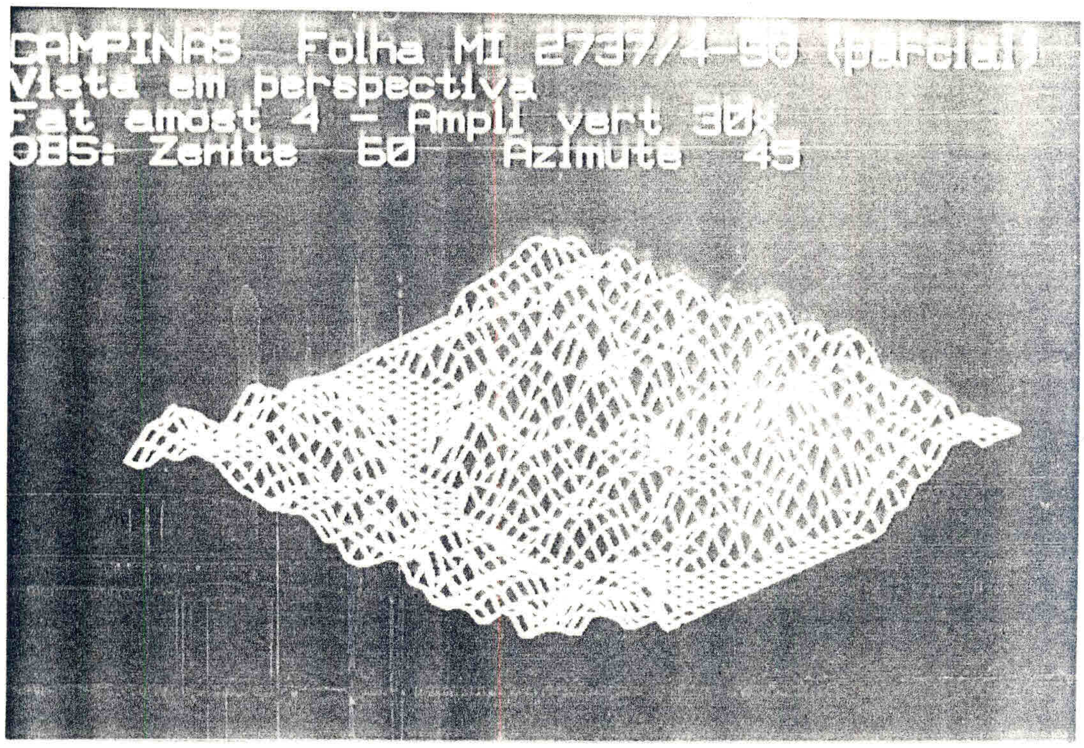
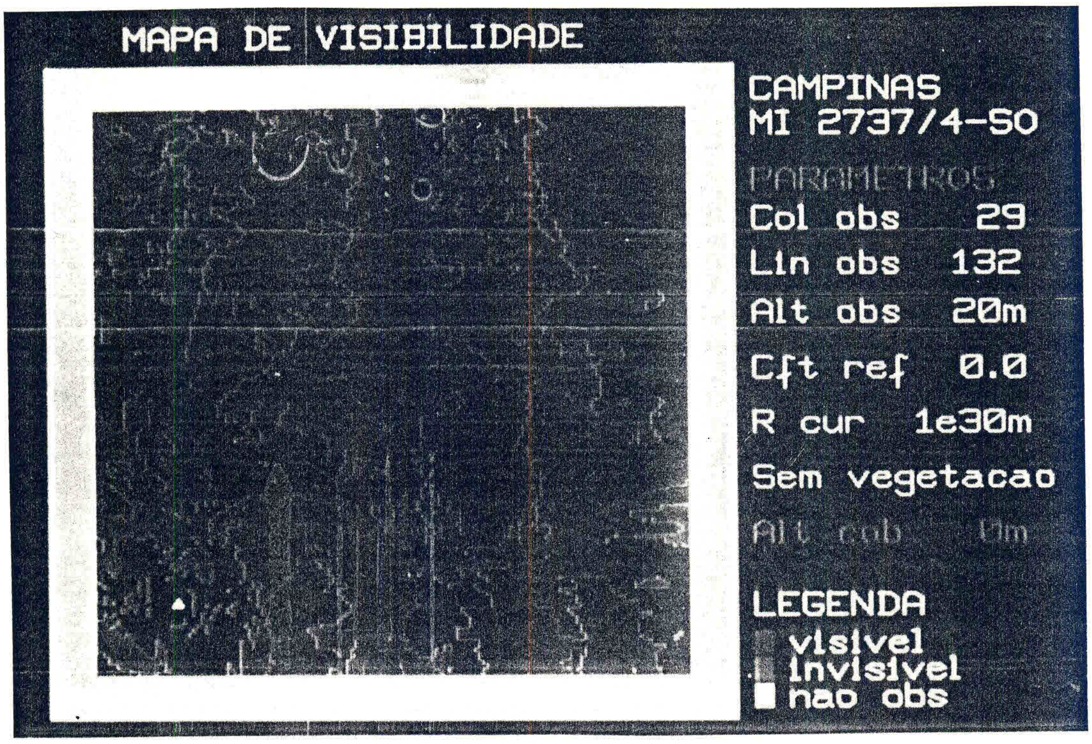


Fig. 1 - Perspective view of the test area DEM. Vertical exageration is 30 times. Area size is 8x8 km.

A visibility map of the test area is presented in Figure 2, with the obsever at the pixel line 132 column 29, with a height above the ground of 20 m, witout refraction, flat Earth. In order to produce a flat Earth a radius of 1E30 meter was used.

In Figure 3, using the same parameters from Figure 2, except the observer height that now is 1,8 meter, it is seen that the visible region has shrink. In Figure 4, the curvature was exagerated (R=4000 km), while keeping the other parameters constant.

Finally, Figure 5 shows the same parameters, as Figure 2, execpt the curvature, in which the real Earth's radius value was used (R = 6372 km), and the refraction index K = 0,13 (for visible light).



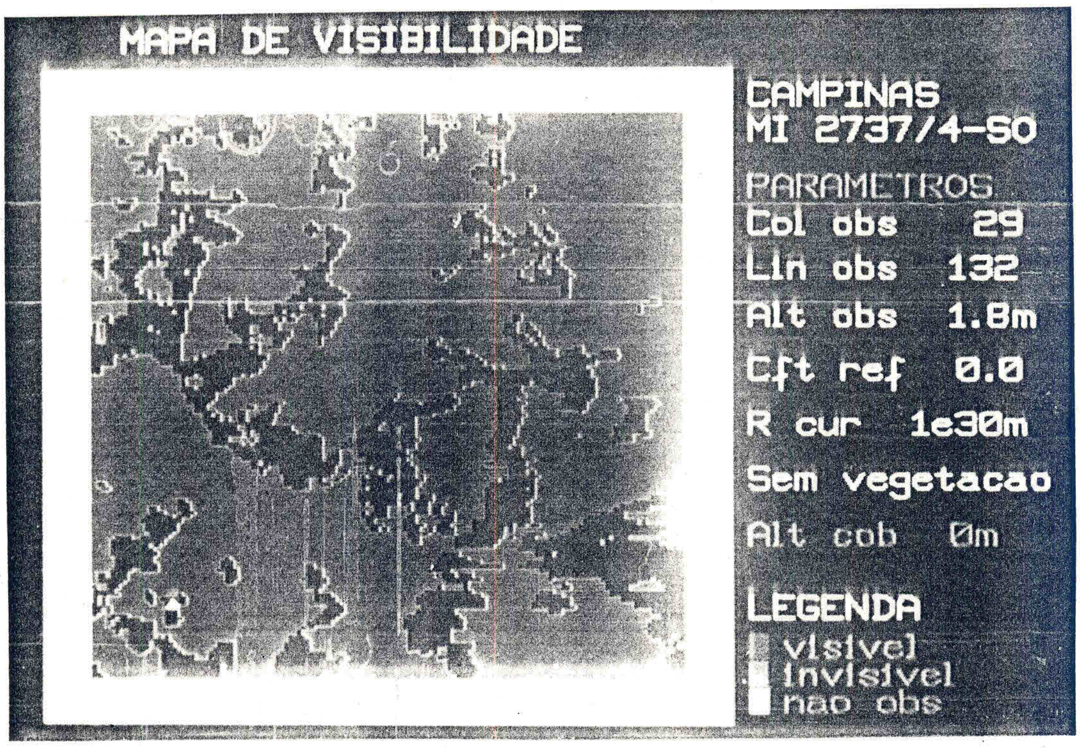
MAPA DE VISIBILIDADE

CAMPINAS
MI 2737/4-SO

PARAMETROS
Col obs 29
Lin obs 132
Alt obs 20m
Cft ref 0.0
R cur 1e30m
Sem vegetacao
Alt cob 0m

LEGENDA
visivel
invisivel
nao obs

Fig. 2 - Visibility map, observer height = 20 m, flat Earth (R= 1 e 30 m), no refraction



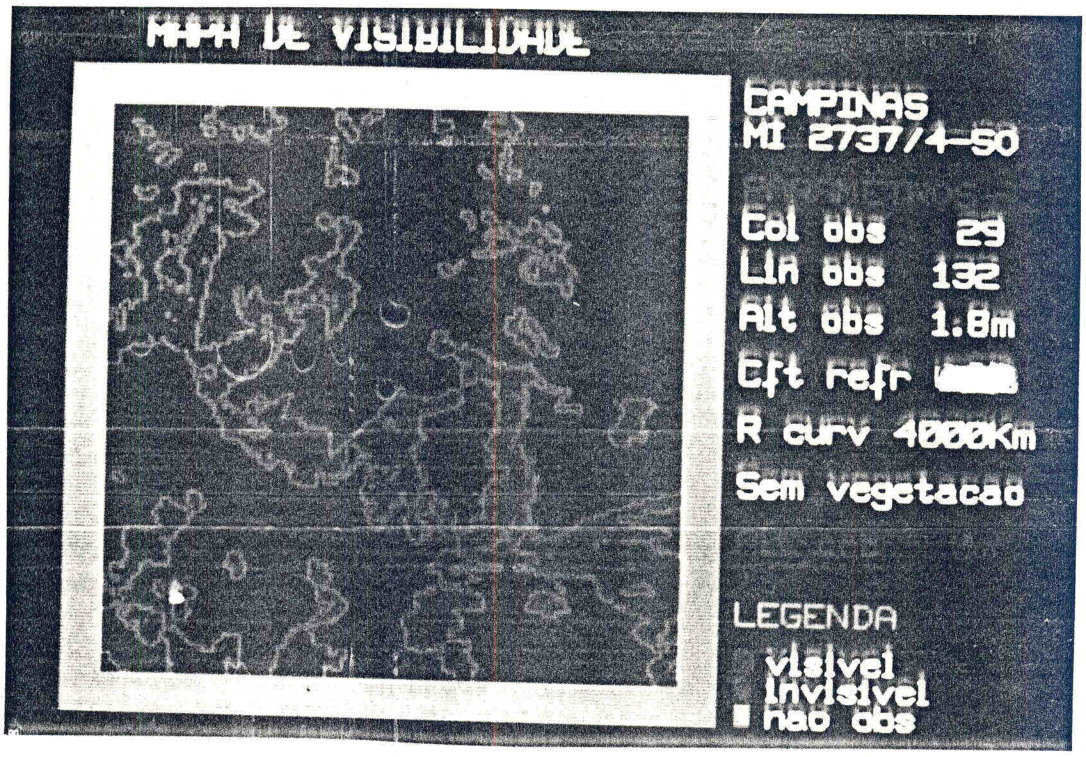
MAPA DE VISIBILIDADE

CAMPINAS
MI 2737/4-SO

PARAMETROS
Col obs 29
Lin obs 132
Alt obs 1.8m
Cft ref 0.0
R cur 1e30m
Sem vegetacao
Alt cob 0m

LEGENDA
visivel
invisivel
nao obs

Fig. 3 - Visibility map, observer height=1,8 m, flat Earth (R= 1 e 30 m), no refraction.



MAPA DE VISIBILIDADE

CAMPINAS
MI 2737/4-SO

Col obs 29
Lin obs 132
Alt obs 1.8m
Cft refr [illegible]
R curv 4000Km
Sem vegetacao

LEGENDA
visivel
invisivel
nao obs

Fig. 4 - Visibility map, observer height= 1,8 m, curved Earth (R= 4000 km), no refraction.

MAPA DE VISIBILIDADE

CAMPINAS
MI 2737/4-SO

PARAMETROS
Col obs 29
Lin obs 132
Alt obs 1.8m
Cft ref 0.13
R cur 6372Km
Sem vegetacao
Alt cob 0m

LEGENDA
visivel
invisivel
nao obs

Fig. 5 - Visibility map, observer height= 1,8 m, curved Earth (R= 6372 km), refraction index K= 0,13

5. CONCLUSIONS

It was noticed that the proposed software worked as expect, indicating that even a simple IBM-PC based system, with a graphic card, can be used effectively for the generation of visibility maps including Earth's curvature and atmospheric refraction. The computer running time to do all calculations and display was less than 10 minutes, for the test area. If a much larger region is to be studied the running time may become prohibitive. However, the visibility algorithm was not optimized, which would reduce the running time even more.The authors would like to thanks INPE and IBM Rio Scientific Center for the support, since this work was part of a joint project from both institutions.

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