BRL-TR-3374

AD-A253 141

TECHNICAL REPORT BRL-TR-3374

BRL

A VARIABLE RESOLUTION TERRAIN MODEL FOR COMBAT SIMULATION

JOSEPH K. WALD
CAROLYN J. PATTERSON

JULY 1992

U.S. ARMY LABORATORY COMMAND

BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

NOTICES

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	July 1992	Final, Jan 92 - Apr 92

4. TITLE AND SUBTITLE
A Variable Resolution Terrain Model For Combat Simulation

5. FUNDING NUMBERS
PR: 1L162618AH80

6. AUTHOR(S)
Joseph K. Wald and Carolyn J. Patterson

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US Army Ballistic Research Laboratory
ATTN: SLCBR-DD-T
Aberdeen Proving Ground, MD 21005-5066

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
BRL-TR-3374

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
In this paper we present a method for variable resolution terrain modeling. This methodology depends strongly on the concepts of self-similarity and minimum desired resolution. Among the possible areas of application are combat simulation and the programming of training devices.

14. SUBJECT TERMS
Nested System of Battlefield Simulation Models (NSOM)
Monte Carlo Method, Combat Simulation, Variable Resolution, Terrain Models, Fractals, Self-Similarity

15. NUMBER OF PAGES
28

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

INTENTIONALLY LEFT BLANK.

TABLE OF CONTENTS

Page

INTENTIONALLY LEFT BLANK.

LIST OF FIGURES

Figure | Page

INTENTIONALLY LEFT BLANK.

1. INTRODUCTION

Due to the unpredictable nature of the current world political situation, we no longer have the luxury of spending large amounts of resources in the study of potential combat situations on a few very specific pieces of terrain. Our combat simulation models must be able to handle a wide variety of scenarios in a wide range of potential theaters of operation, and hence on a wide variety of terrains. Moreover, when analyzing the employment of an existing weapon system or a new weapon concept, any single piece of terrain may contain peculiarities that can skew simulation results.

To help solve such problems, it would be nice to be able to repeat simulation runs using slightly different samples of a particular terrain type. It would be even nicer if we could change terrain slightly from replication to replication within a single run of a Monte Carlo combat simulation.

These facts, together with the current emphasis on variable resolution modeling, suggest that there is a need for a flexible, efficient, variable resolution terrain model for combat simulation.

The variable resolution terrain model introduced in this paper was developed under the umbrella of the Nested System of Battlefield Simulation Models (NSOM). The NSOM is conceived as a fully integrated, fully automated set of event sequenced, Monte Carlo, combined arms computer simulations, each of which models the battlefield at a distinct command level[1]. The key feature of the NSOM is the "time history injection process" which links simulations at adjacent command levels by providing the commander at the higher command level with the ability to interact, during the execution of the higher level simulation, with the dynamically unfolding lower level battle.

At the higher command levels, terrain is used in the modeling of such features as the positioning of large formations of troops, selecting approximate locations for observation posts, and the estimation of likely avenues of approach of large enemy formations. For these purposes, a relatively low resolution is required.

At the lower command levels, terrain is used in the modeling of such features as the positioning of individual weapon systems, the creation of overlapping fields of fire for small units, and the calculation of lines of sight in the (short range) direct fire battle. For these purposes, higher resolution is necessary.

In the NSOM, we need the ability to model a large battlefield at low resolution and still retain the option of looking at smaller portions of the battlefield, as necessary, at higher resolution. Hence, the development of a variable resolution terrain model is essential.

2. A STATISTICALLY SELF-SIMILAR TERRAIN MODEL

2.1 Self-similarity in Combat Modeling. An object is *self-similar* if it is invariant with respect to scale. Some examples of self-similar mathematical objects are the logarithmic spiral and the Cantor ternary set. There are also numerous examples of self-similarity in fields ranging from physics to psychology[2].

In combat modeling, as in many applications, self-similarity is only approximate and exists on a limited scale. However, a number of elements of military organization and operations exhibit self-similar characteristics. For example, at every command level from battalion upward, there are staff officers with the same responsibilities, e.g., intelligence (S2), operations (S3), and

[1] Wald, Joseph K., "*Time History Injection in a Nested System of Battlefield Simulation Models.*" BRL-TR-2984, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, March 1989.
[2] Schroeder, Manfred, **Fractals, Chaos, Power Laws.** New York: W. H. Freeman and Company, 1991.

logistics (S4). Command and control processes exhibit similar characteristics at all scales of combat. In particular, general troop leading procedures are virtually identical across command level and functional area. Also forms of maneuver, such as a frontal attack, an envelopment, or a turning movement can be found at many command levels.

2.2 A Power Law for Terrain Modeling. Self-similar entities (fractals) have been used for some time to produce pictures of terrain features such as islands, mountains, and coastlines[3]. In order to have a variable resolution, self-similar terrain model suitable for use in Monte Carlo battlefield simulations, however, we need to develop a practical method of simulating a general terrain type, e.g. deserts, mountains, or rolling hills. Given that we can statistically characterize a particular type of terrain by parameters such as the shape and height of a typical terrain feature, which for simplicity we will call a "hill", we proceed to construct a model which will generate examples of that type of terrain to any desired resolution.

Let s denote a dimensionless scale factor associated with a hill. As indicated in figure 1, the effect of varying s is to change the size of the hill without changing its shape. When s is doubled, the height of the hill is doubled, its surface area is quadrupled, and its volume is octupled. The same effect can be obtained by thinking of the four pictures in figure 1 being identical, but the scale of the coordinate axes being varied. [Although not shown explicitly, the coordinate systems in the four pictures of figure 1 are identical.]

Now let D denote the areal density of hills as a function of s. Then we set

$$D = Ks^{-2}, \; s>0 ,$$

where K is a constant (with dimension $length^{-2}$) that depends on terrain type. The choice of this power law to define the hill density per unit area as a function of s insures the self-similarity of the terrain. To see this, note that if there are (on average) n_0 hills for which s lies in the interval (s_1,s_2) in, say, a 10 kilometer by 10 kilometer square, then there are also (on average) n_0 hills for which s lies in the interval $(s_1/10,s_2/10)$ in any 1 kilometer by 1 kilometer square contained in the larger square. Thus, if we magnify any such smaller square to the size of the original 10 kilometer by 10 kilometer square the result will be (statistically) indistinguishable from the original. Hence we have statistical self-similarity.

Of course, every time we reduce s by an order of magnitude, the corresponding number of hills per unit area increases by two orders of magnitude. In the limit, we would have an infinite number of infinitely small hills. This does not sound very practical. Fortunately, corresponding to each command level there is a maximum useful terrain resolution (i.e., minimum useful value of s), depending, as noted above, on the features being modeled at that command level. For a given command level let us denote by s_0 the value of s corresponding to that maximum resolution. With just this piece of information and the power law we can compute the number of hills we must construct for a given area and develop a very simple formula that will give us the proper distribution of hill sizes. In particular, the total number of hills per unit area is obtained by integrating the power law from s_0 to ∞, i.e.,

$$\int_{s=s_0}^{s=\infty} Ks^{-2}ds = \frac{K}{s_0},$$

and the cumulative areal distribution of hills as a function of s is given by

$$\int_{t=s_0}^{t=s} Kt^{-2}dt = K(\frac{1}{s_0} - \frac{1}{s}).$$

[3] Mandelbrot, Benoit B., **The Fractal Geometry of Nature.** New York: W. H. Freeman and Company, 1983.

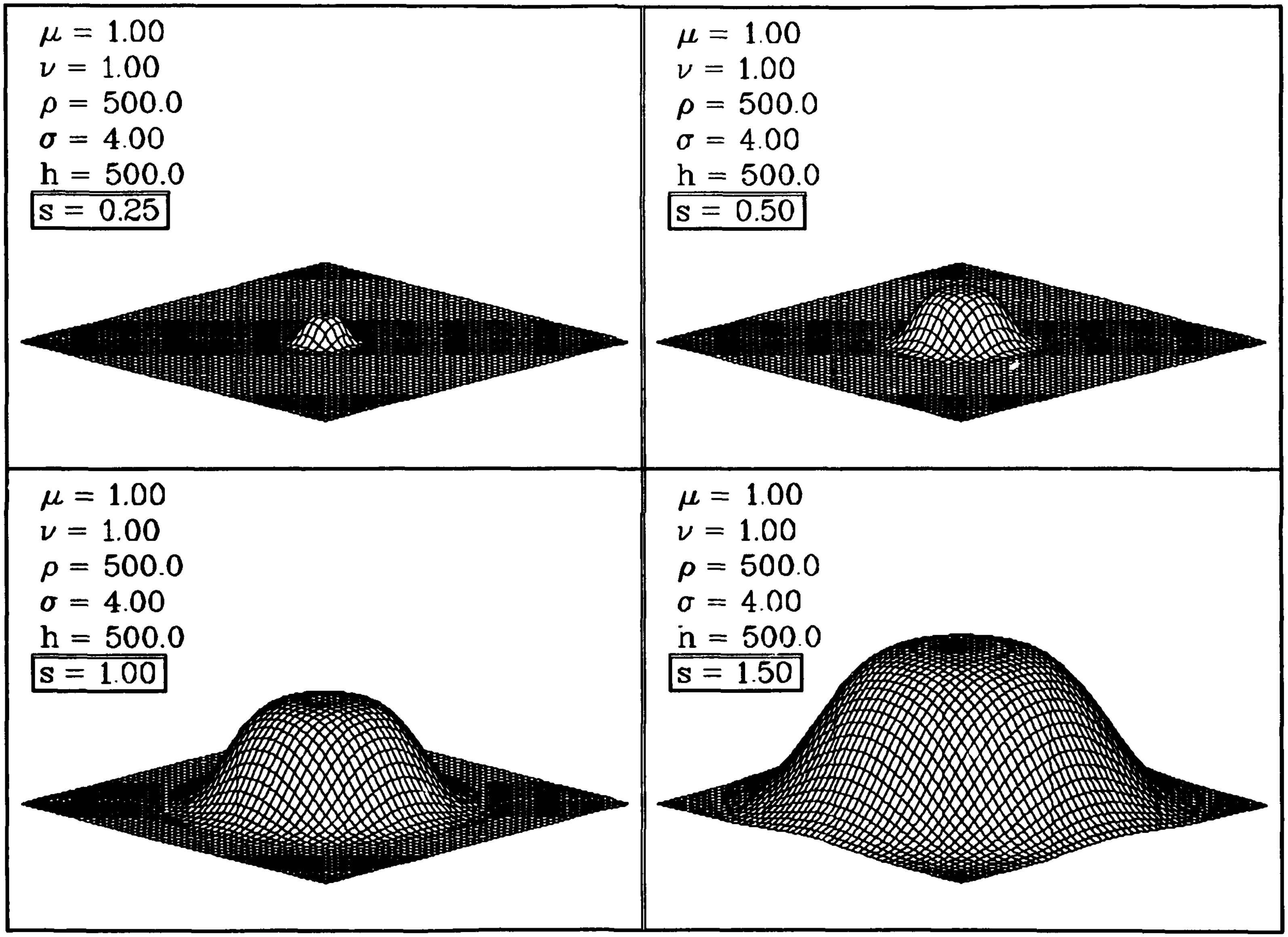

Figure 1. Varying the Parameters "s".

Thus, to build each hill, we need only draw a uniform random number, u, between 0 and K/s_0, and the value of s corresponding to that hill will be

$$s = \frac{s_0 K}{K - u s_0} .$$

Note that this is equivalent to drawing a random number, r, from the interval (0,1), with the hill scale factor being

$$s = \frac{s_0}{1 - r} .$$

This formulation makes it clear that the size of the terrain feature depends only on s_0. The location of the hill is randomly chosen in the desired area. The complete terrain surface is defined by the superposition of all of the hills.

2.3 Exponential Hills and Valleys. In the development of the variable resolution methodology in section 2.2, the only information we required about our hill was a dimensionless scale factor. In fact, we have great freedom in choosing the mathematical description of a typical terrain feature as long as a continuously varying dimensionless scale factor is among the parameters. It would also be nice to have a single mathematical description that could model a variety of terrain types simply by changing the region in parameter space from which the specific realizations of terrain features are drawn. One family of continuous functions that has these properties (but certainly not the only possible alternative!) is defined by

$$f_k\,(x,y,\zeta_k,\eta_k,\mu_k,\nu_k,\rho_k,\sigma_k,h_k,s) = s h_k \, exp(-\left\{ \frac{1}{s\rho_k} \left[\left(\frac{x-\xi_k}{\mu_k} \right)^2 + \left(\frac{y-\eta_k}{\nu_k} \right)^2 \right]^{\frac{1}{2}} \right\}^{\sigma_k}),$$

where the parameters ξ_k, η_k, μ_k, ν_k, ρ_k, σ_k, and h_k are randomly selected from appropriate intervals of real numbers, and s is the scale factor. For $h_k > 0$, this function has a single relative maximum, with height h_k, located at the "center", (ξ_k,η_k), i.e., a hill. Similarly, for $h_k < 0$, we have a valley. If μ_k, and ν_k are equal, then the horizontal cross sections are circles; otherwise they are ellipses. The other parameters control the relative sizes of the cross sections and the slope of the hill or valley. Figures 1 through 5 show examples of some of the effects one can obtain by varying the parameters. These "hills" are the building blocks of a piece of terrain. In figure 3, note that for the choice of parameter $\sigma = 1$ the surface is not differentiable at the center of the hill. In fact, only for choices of σ_k greater than 1, is f_k everywhere differentiable. Moreover f_k is analytic when, and only when, σ_k is an even positive integer.

Note that additional flexibility (and complexity) can be achieved by further augmentation of f_k. For example, if we were to add the term

$$2\lambda_k \frac{(x-\xi_k)(y-\eta_k)}{\mu_k \nu_k} \qquad |\lambda_k| < 1$$

to the quantity within the square brackets, we would have the ability to orient the elliptical cross sections in any desired direction.

2.4 More Complex Terrain. By putting together these building blocks in a statistically self-similar manner, we can create examples of widely differing terrain types. The terrain can be purely self-similar or can be a self-similar "background" complementing one or more unique terrain features. Figure 6 depicts a self-similar mountainous region, while in figure 7 we see a self-similar landscape of low rolling hills. In figure 8 we have a rocky seacoast in which we have tilted the underlying plane and introduced "sea level" by replacing the height associated with each point at negative elevation with a height of zero. Each of these landscapes was plotted from a set of 40401 data points (a 201 by 201 grid) generated from the continuous model. The typical cpu times for the creation of this amount of digitized terrain are about 10 seconds on a Cray XMP.

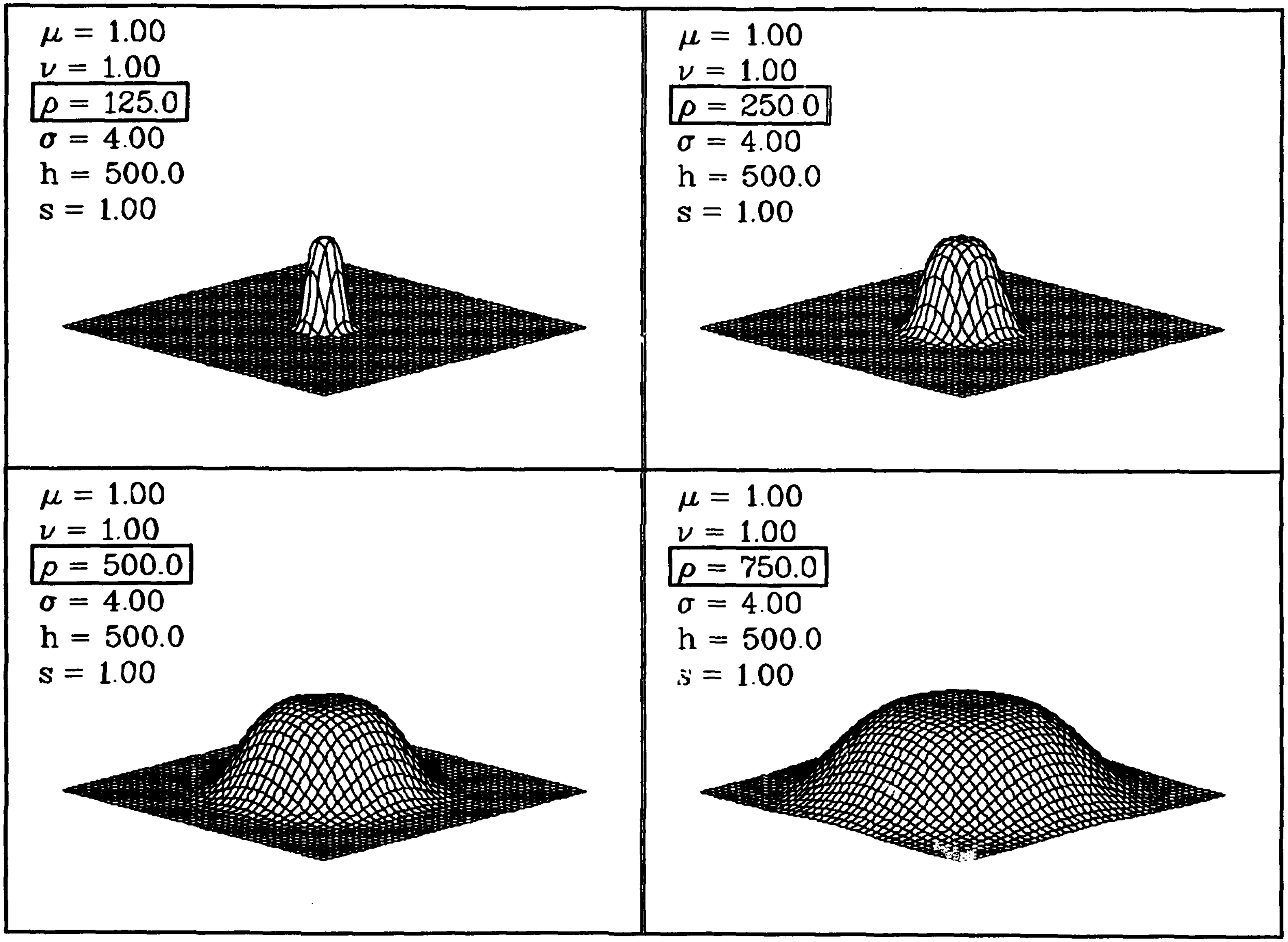

Figure 2. Varying the Parameter "ρ".

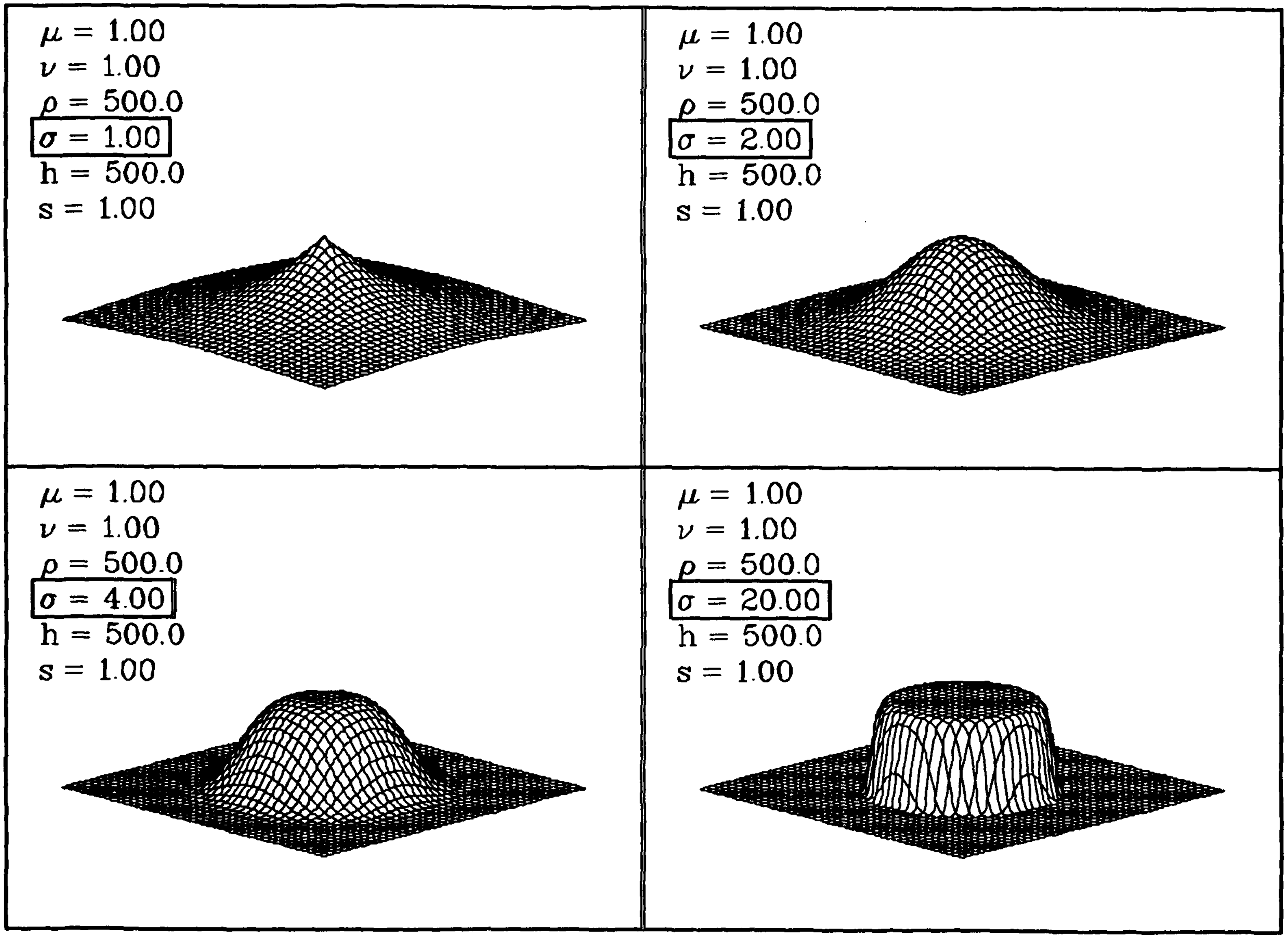

Figure 3. Varying the Parameter "σ".

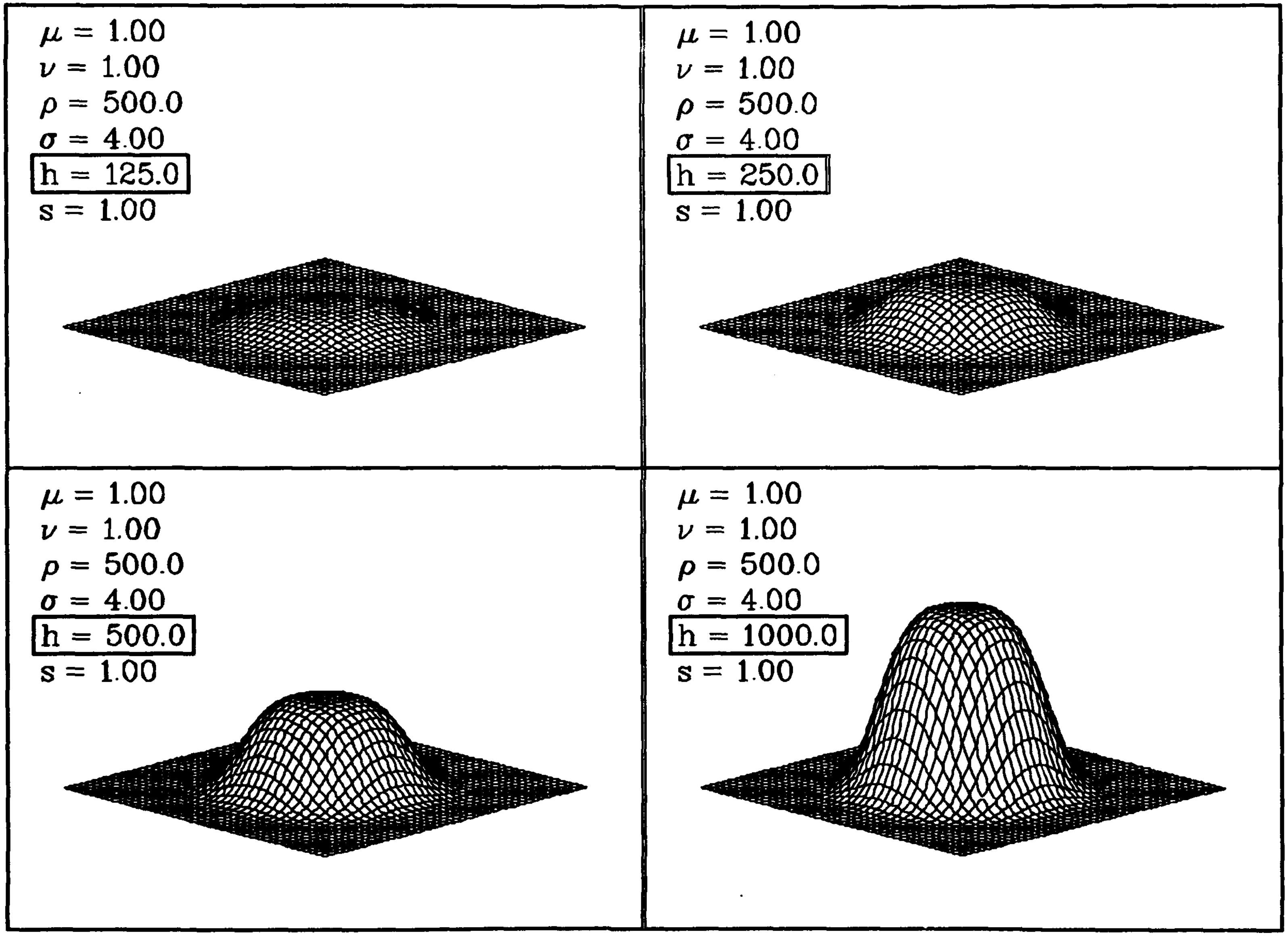

Figure 4. Varying the Parameter "h".

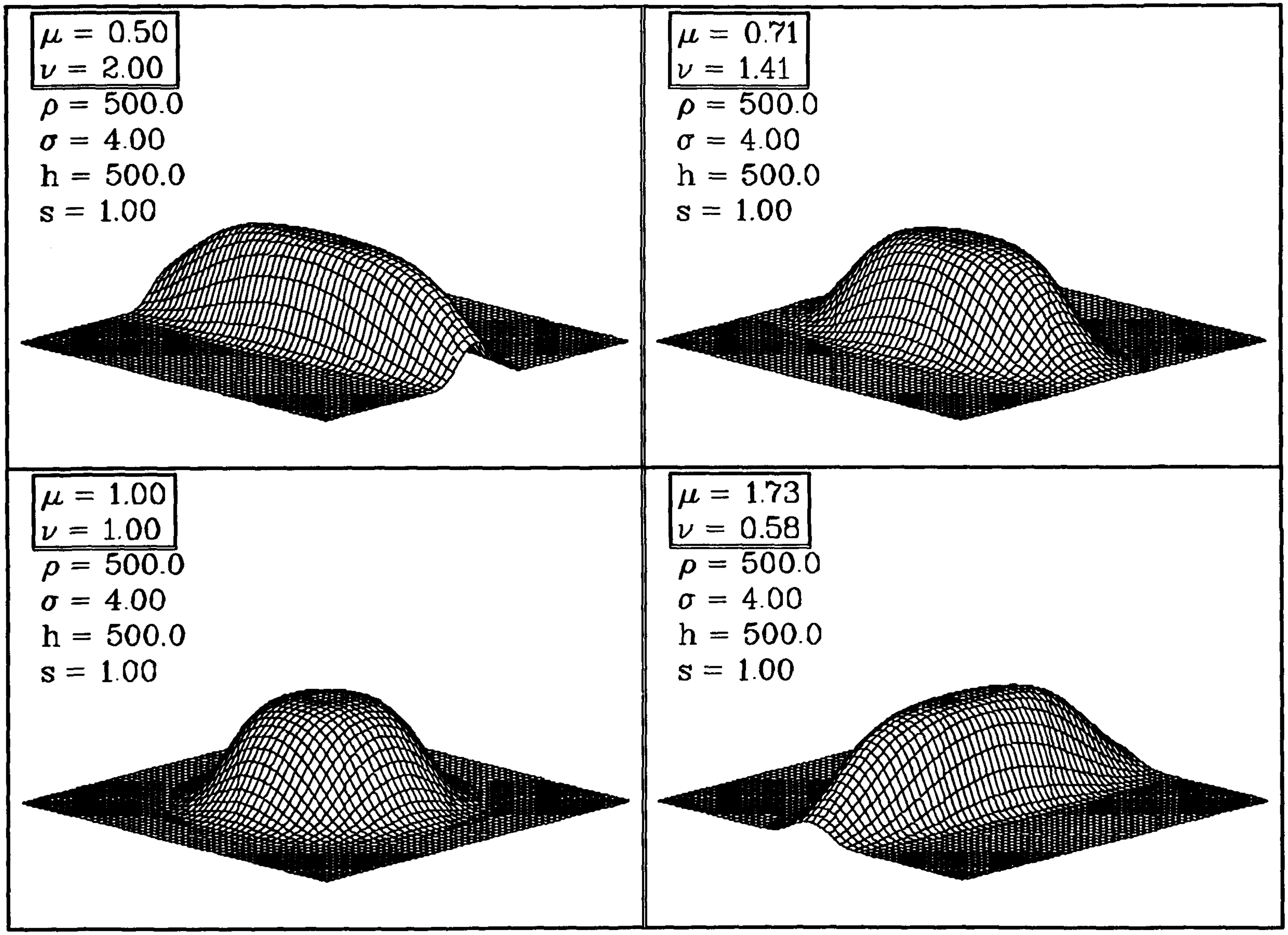

Figure 5. Varying the Parameters "μ","ν".

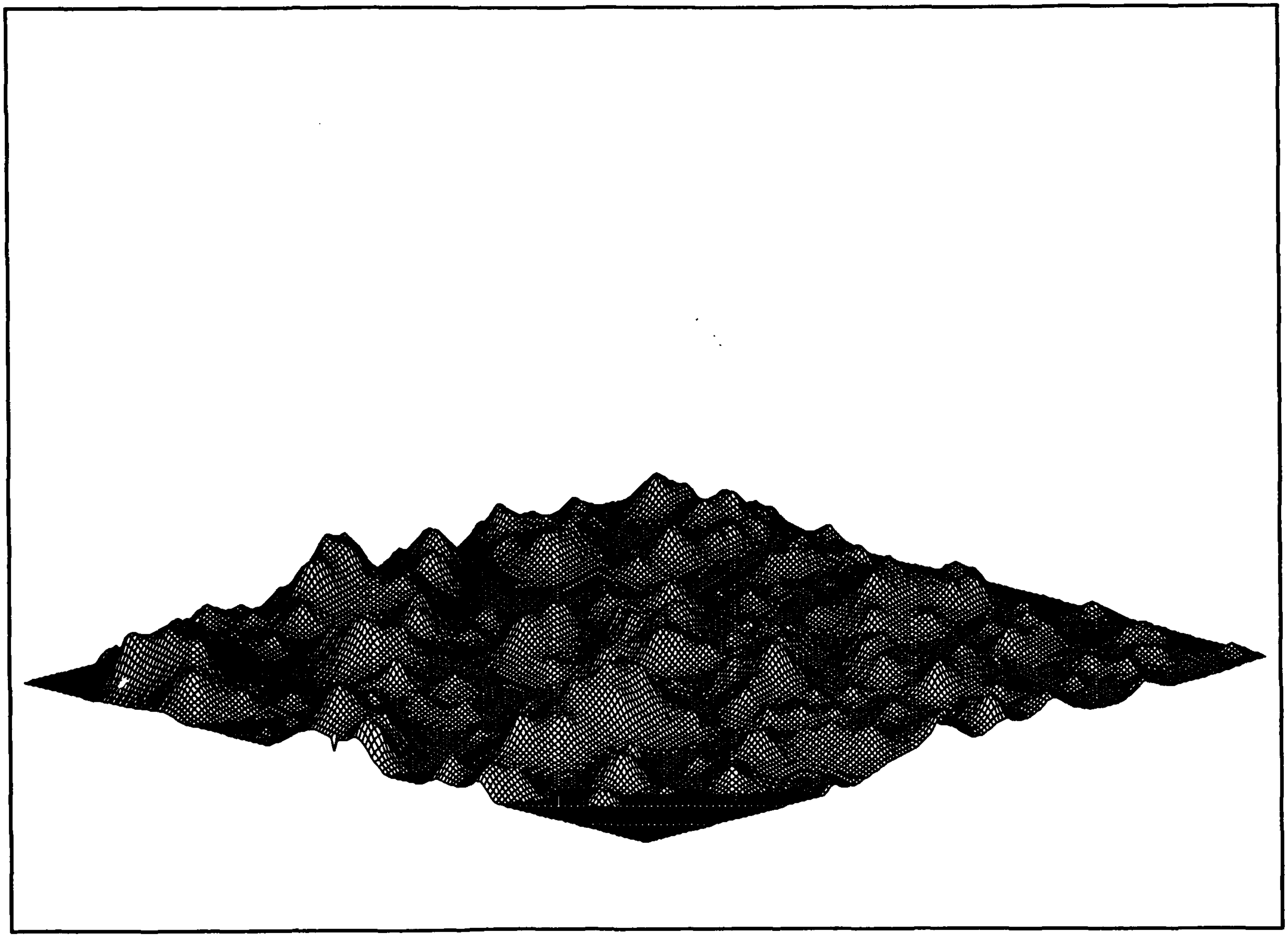

Figure 6. <u>Self-similar Mountains</u>.

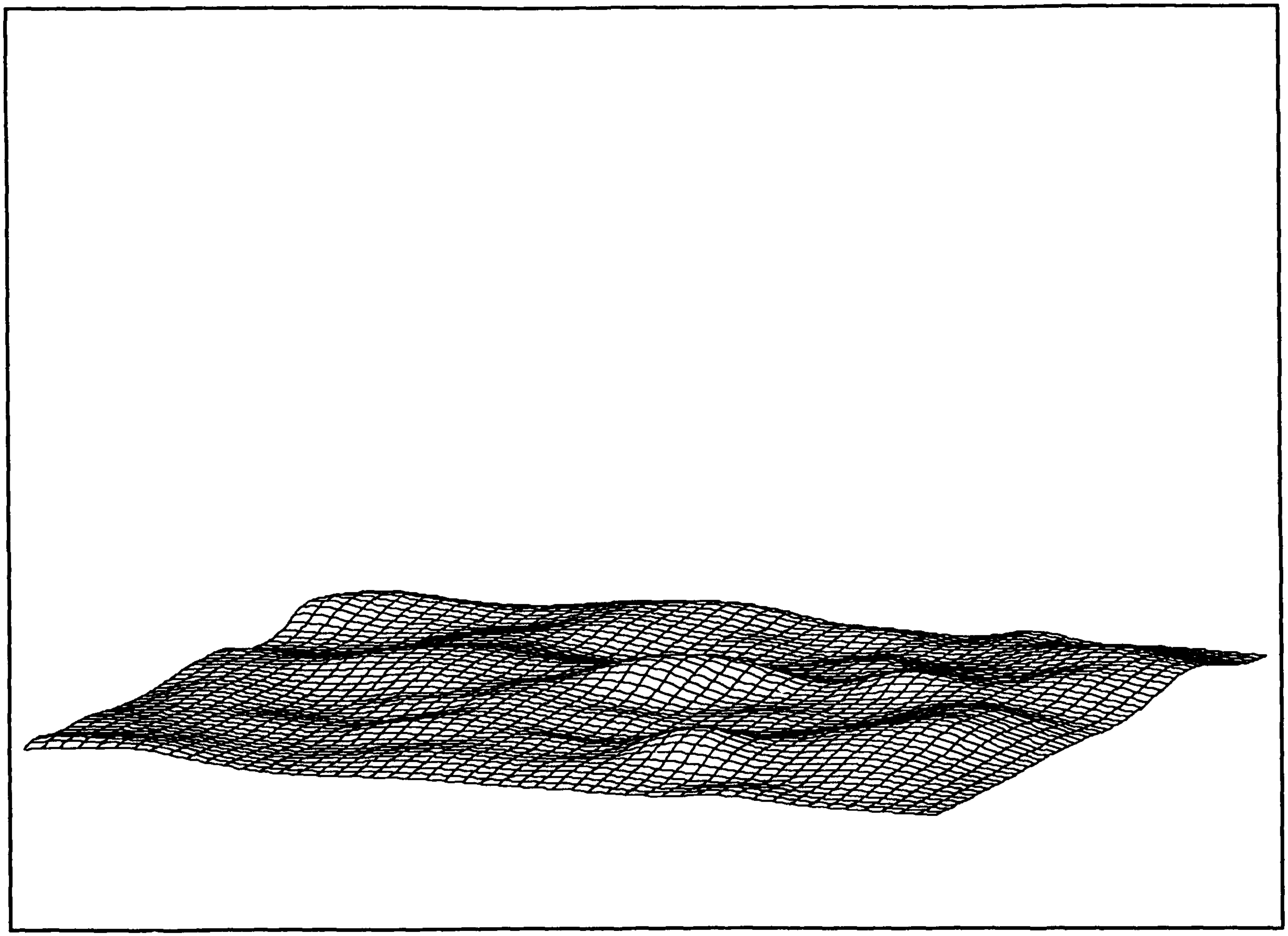

Figure 7. Self-similar Low Rolling Hills.

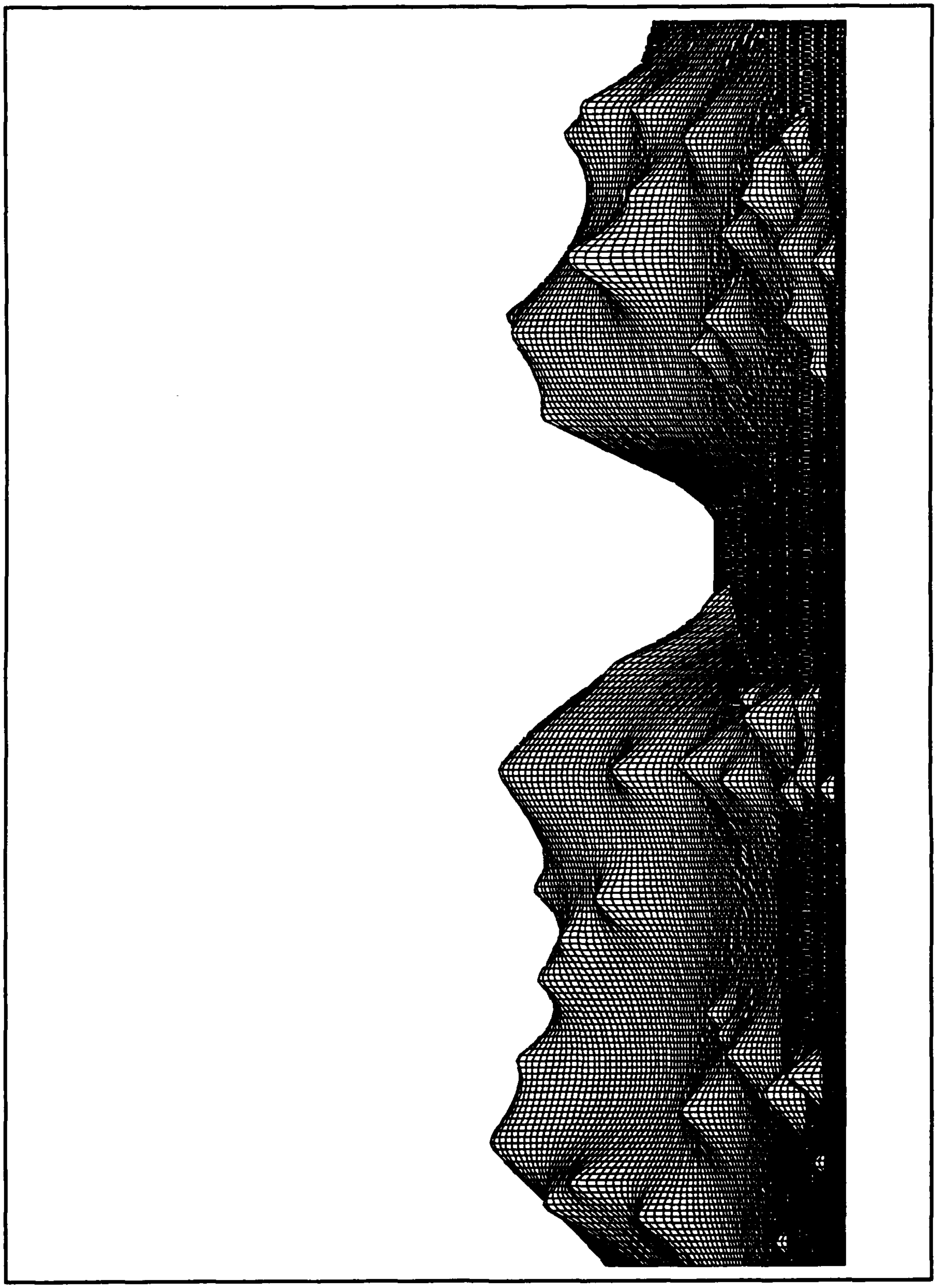

Figure 8. Rocky Sea Coast.

More complex terrain structures can be created by superimposing two or more of the basic building blocks. We can simulate an impact crater by superimposing a valley on a slightly wider but shallower hill. Using this as the basic terrain feature, we created a cratered landscape (figure 9); or is it a "moonscape"? Also, it is not necessary to restrict ourselves to a uniform distribution of terrain features. For example, figure 10 depicts a pair of parallel mountain ranges which are uniformly distributed in one direction and normally distributed in the other direction, while the island in figure 11 was constructed from two bivariate normal distributions of hills. In both of these cases, however, self-similarity is preserved.

3. APPLICATIONS

As mentioned in the introduction, it is sometimes necessary to investigate a small portion of a battlefield at higher resolution. This typically occurs when subunits on each side meet and direct fire combat ensues. On such occasions we define a new (higher) maximum resolution and corresponding hill scale factor, s_1, with $s_1 < s_0$, valid for the "mini-battlefield" in question. Since we have already modeled this mini-battlefield to resolution s_0 (as part of the larger battlefield), it remains to add details by superimposing on the terrain hills and valleys for which s ranges between s_1 and s_0. Using the same methodology as in section 2, we see that there should be

$$\int_{t=s_1}^{t=s_0} Kt^{-2}dt = K(\frac{1}{s_1} - \frac{1}{s_0})$$

additional hills and valleys per unit area. The scale factor for a given hill will be

$$s = \frac{s_1 K}{K - us_1},$$

where u is a uniform random number between 0 and $K[(1/s_1) - (1/s_0)]$.

There is a slight twist here. Whereas in creating the terrain for the larger battlefield there was no restriction on the proportion of hills to valleys, when modifying the mini-battlefield we should endeavor to avoid altering its mean altitude. One way to do this would be to construct as many valleys as hills.

In addition to creating terrain from scratch, one can use this methodology to interpolate more detail in between the points of a coarse set of digitized terrain data. One can even imagine dynamically altering the terrain during the battle, e.g., creating shell craters during an artillery barrage or digging foxholes or trenches as dictated by events on the battlefield.

Another application for this methodology is in the area of training devices. A number of such devices use digitized terrain in the simulation of a scenario in which a soldier or an entire unit participate. Usually there are a number of quite different scenarios available, but no way to slightly vary a single scenario to provide repetitions of the exercise for the students. Using our methodology, one could quickly and cheaply generate a number of different but similar examples of a given terrain type simply by varying the random number stream in the model. The four pieces of terrain in figure 12 were generated in this manner.

4. SUMMARY AND FUTURE WORK

We have proposed a basic methodology for the construction of a variable resolution terrain model and have suggested a specific form for that model. The key feature of the approach is the concept of self-similarity. This is an idealization and can be relaxed somewhat for practical applications. For example, it may be argued that, at least for certain terrain types, smaller hills erode faster than larger ones. If that is the case, one can introduce a scale-dependent decay factor that smooths out the smaller hills and fills in the smaller valleys.

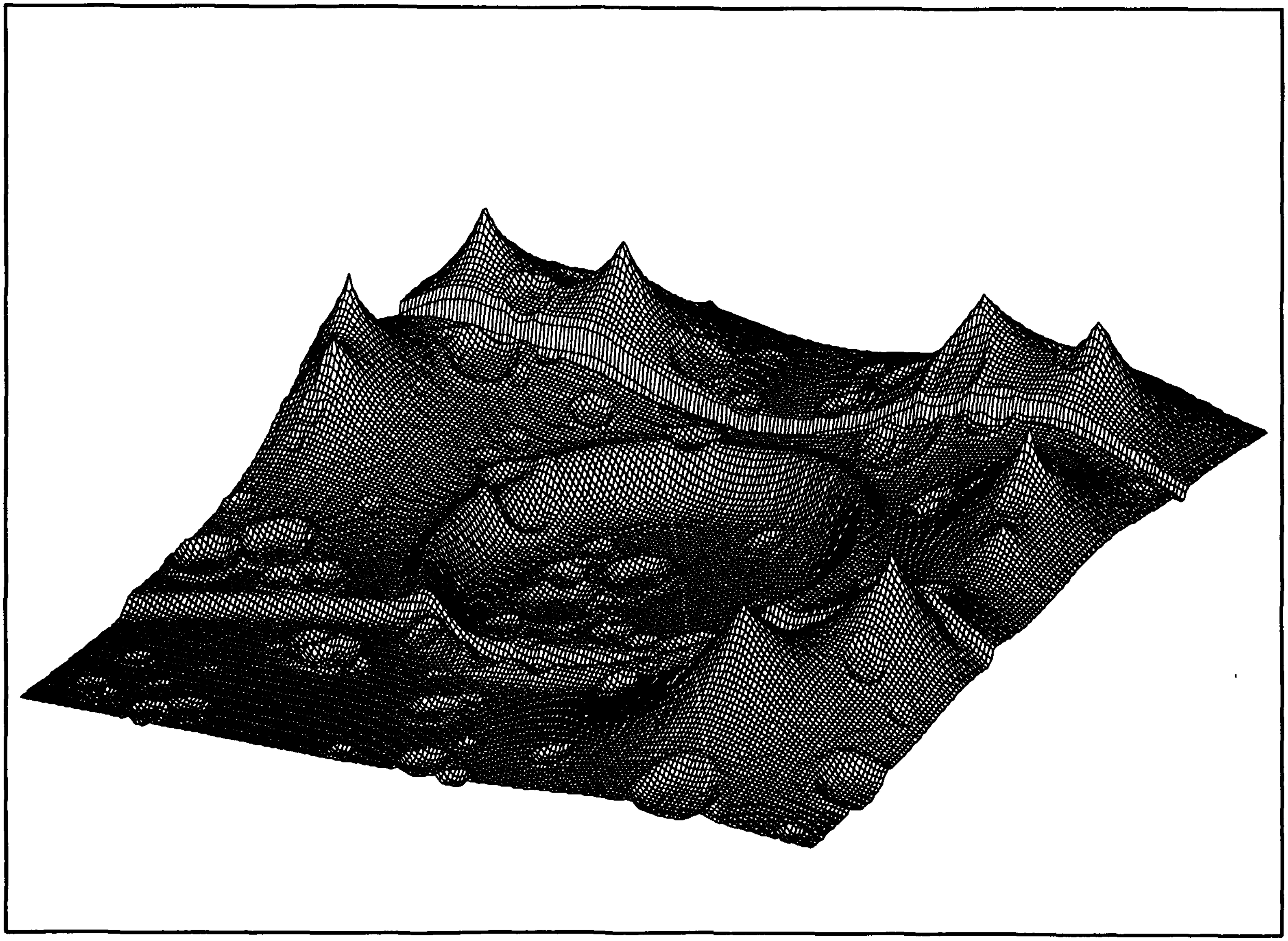

Figure 9. Cratered Landscape / "Moonscape".

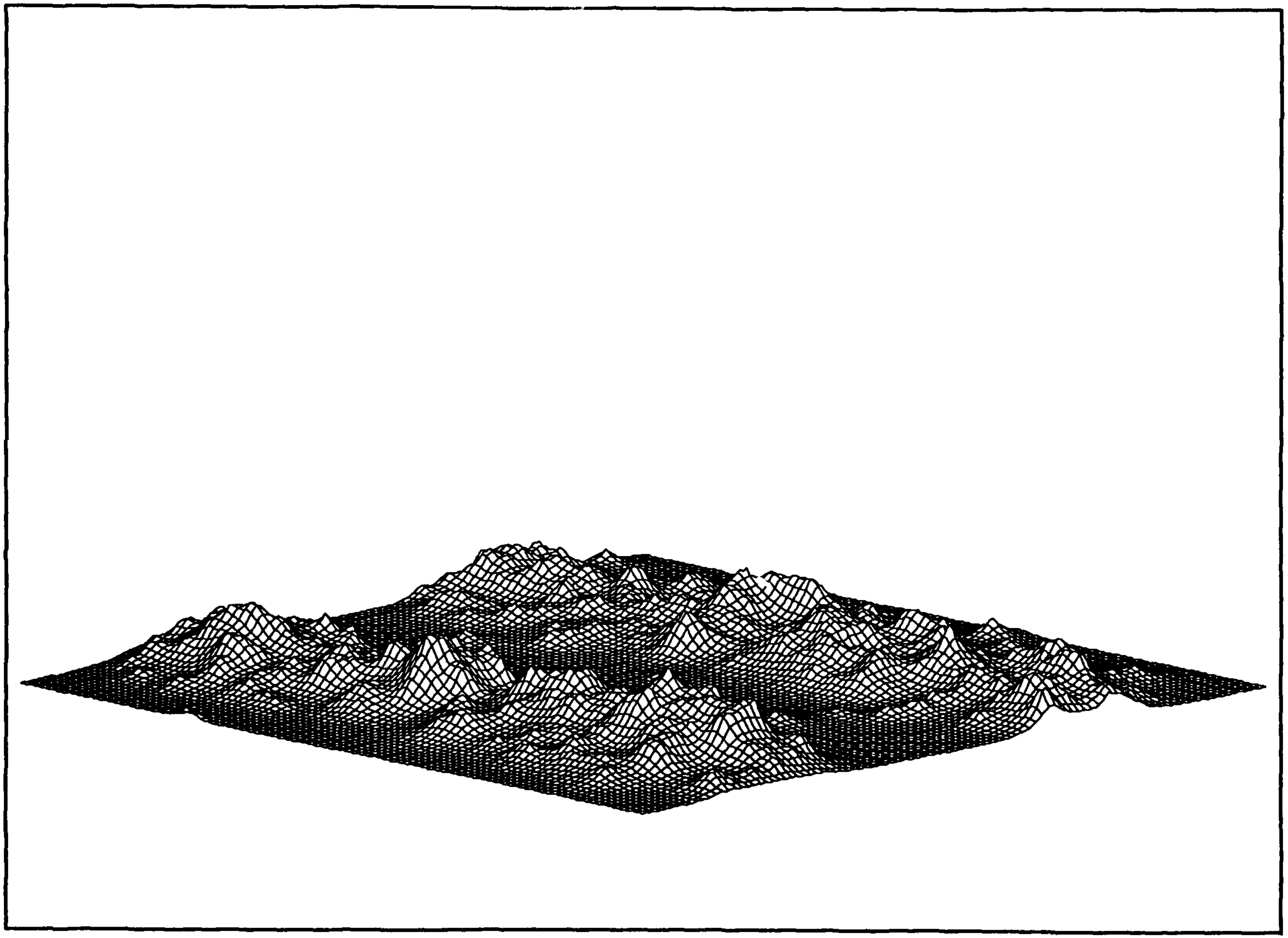

Figure 10. Parallel Mountain Ranges.

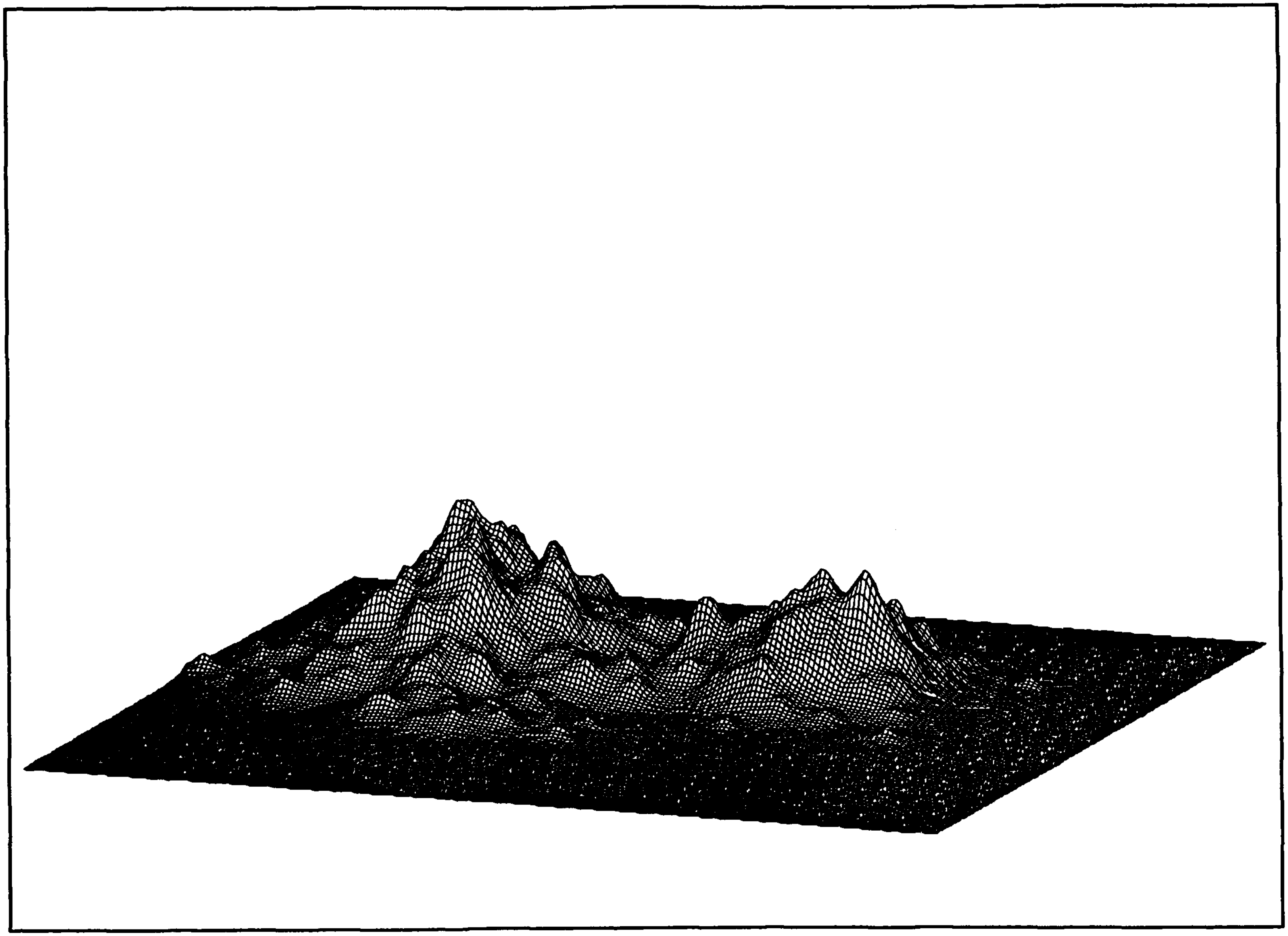

Figure 11. Volcanic Island.

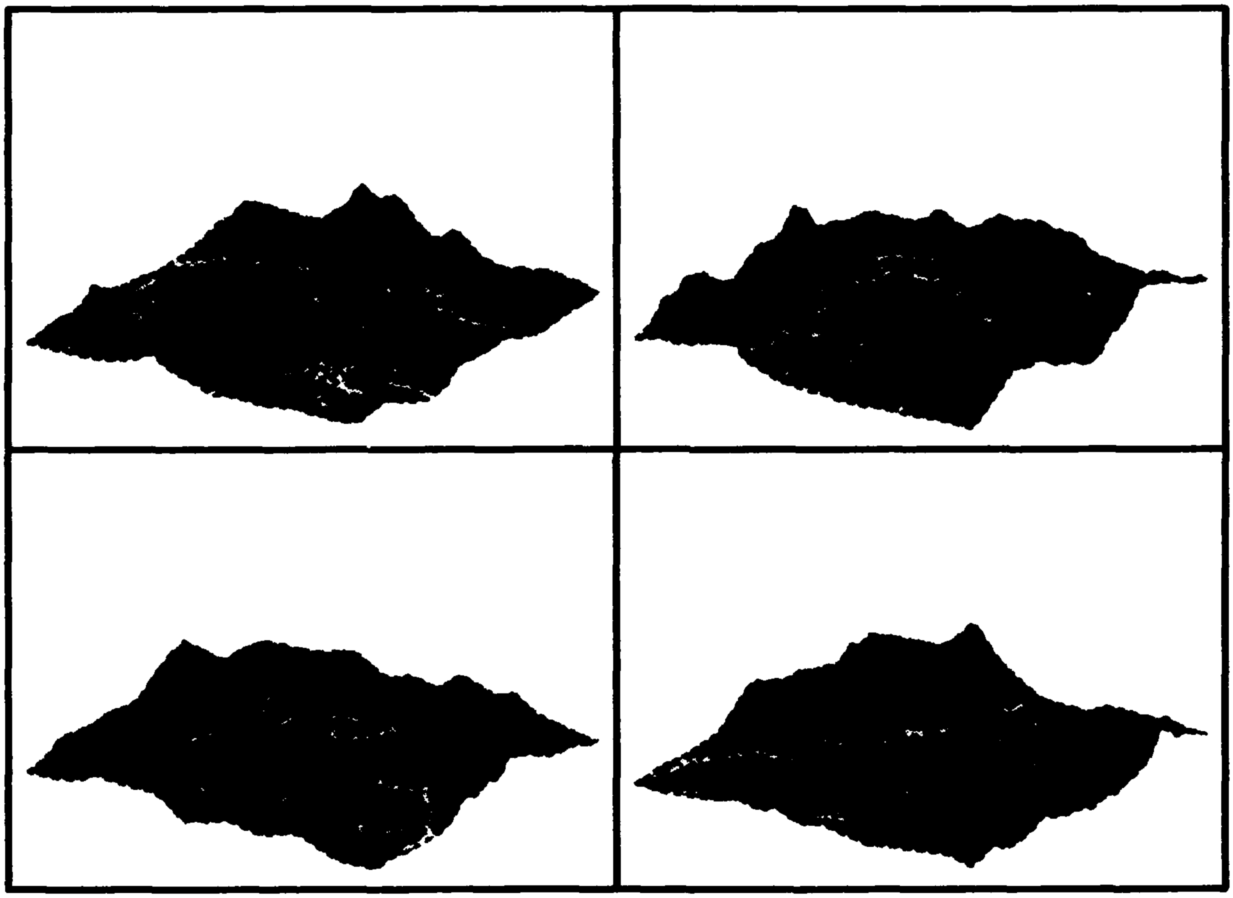

Figure 12. <u>**Four Mountain Lakes**</u>.

We noted in section 2.3 that, with certain limits on one of the parameters, the terrain surface is differentiable. This means that the directional derivatives exist at every point of the terrain surface. This information should be quite be useful in building routines to simulate road networks and troop movement.

In the introduction we asserted the need for a flexible, efficient, variable resolution terrain model. We believe that the proposed model clearly exhibits the traits of variable resolution and flexibility. The efficiency of the model will depend on the desired resolution and the minimum number of terrain features necessary to accurately model a given terrain type to that resolution. Also, simpler alternatives to the f_k functions might lead to increased efficiency.

The major practical problem remaining, of course, is to determine the parametric values that correspond to specific types of terrain. This can be accomplished by a thorough statistical analysis of existing terrain databases, with the help of some basic principles of physical geography. The same method of attack should also be helpful in modeling surface forms, both natural and man made, e.g., river systems, vegetation, and road systems.

INTENTIONALLY LEFT BLANK.

No. of Copies	Organization
2	Administrator Defense Technical Info Center ATTN: DTIC-DDA Cameron Station Alexandria, VA 22304-6145
1	Commander U.S. Army Materiel Command ATTN: AMCAM 5001 Eisenhower Ave. Alexandria, VA 22333-0001
1	Commander U.S. Army Laboratory Command ATTN: AMSLC-DL 2800 Powder Mill Rd. Adelphi, MD 20783-1145
2	Commander U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-IMI-I Picatinny Arsenal, NJ 07806-5000
2	Commander U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-TDC Picatinny Arsenal, NJ 07806-5000
1	Director Benet Weapons Laboratory U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-CCB-TL Watervliet, NY 12189-4050
(Unclass. only) 1	Commander U.S. Army Rock Island Arsenal ATTN: SMCRI-TL/Technical Library Rock Island, IL 61299-5000
1	Director U.S. Army Aviation Research and Technology Activity ATTN: SAVRT-R (Library) M/S 219-3 Ames Research Center Moffett Field, CA 94035-1000
1	Commander U.S. Army Missile Command ATTN: AMSMI-RD-CS-R (DOC) Redstone Arsenal, AL 35898-5010

No. of Copies	Organization
1	Commander U.S. Army Tank-Automotive Command ATTN: ASQNC-TAC-DIT (Technical Information Center) Warren, MI 48397-5000
1	Director U.S. Army TRADOC Analysis Command ATTN: ATRC-WSR White Sands Missile Range, NM 88002-5502
1	Commandant U.S. Army Field Artillery School ATTN: ATSF-CSI Ft. Sill, OK 73503-5000
(Class. only) 1	Commandant U.S. Army Infantry School ATTN. ATSH-CD (Security Mgr.) Fort Benning, GA 31905-5660
(Unclass. only) 1	Commandant U.S. Army Infantry School ATTN: ATSH-CD-CSO-OR Fort Benning, GA 31905-5660
1	WL/MNOI Eglin AFB, FL 32542-5000
	Aberdeen Proving Ground
2	Dir, USAMSAA ATTN: AMXSY-D AMXSY-MP, H. Cohen
1	Cdr, USATECOM ATTN: AMSTE-TC
3	Cdr, CRDEC, AMCCOM ATTN: SMCCR-RSP-A SMCCR-MU SMCCR-MSI
1	Dir, VLAMO ATTN: AMSLC-VL-D
10	Dir, USABRL ATTN: SLCBR-DD-T

No. of Copies	Organization
	Aberdeen Proving Ground
5	Dir, USAMSAA ATTN: AMXSY-A, Dwayne Nuzman Jack Meredith Bob Chandler AMXSY-C, Kenny Dalton AMXSY-G, Gary Comstock

USER EVALUATION SHEET/CHANGE OF ADDRESS

This Laboratory undertakes a continuing effort to improve the quality of the reports it publishes. Your comments/answers to the items/questions below will aid us in our efforts.

1. BRL Report Number BRL-TR-3374 Date of Report July 1992

2. Date Report Received ______

3. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which the report will be used.) ______

4. Specifically, how is the report being used? (Information source, design data, procedure, source of ideas, etc.) ______

5. Has the information in this report led to any quantitative savings as far as man-hours or dollars saved, operating costs avoided, or efficiencies achieved, etc? If so, please elaborate. ______

6. General Comments. What do you think should be changed to improve future reports? (Indicate changes to organization, technical content, format, etc.) ______

CURRENT ADDRESS

Name ______

Organization ______

Address ______

City, State, Zip Code ______

7. If indicating a Change of Address or Address Correction, please provide the New or Correct Address in Block 6 above and the Old or Incorrect address below.

OLD ADDRESS

Name ______

Organization ______

Address ______

City, State, Zip Code ______

(Remove this sheet, fold as indicated, staple or tape closed, and mail.)

DEPARTMENT OF THE ARMY
Director
U.S. Army Ballistic Research Laboratory
ATTN: SLCBR-DD-T
Aberdeen Proving Ground, MD 21005-5066

OFFICIAL BUSINESS

BUSINESS REPLY MAIL
FIRST CLASS PERMIT No 0001, APG, MD

Postage will be paid by addressee.

Director
U.S. Army Ballistic Research Laboratory
ATTN: SLCBR-DD-T
Aberdeen Proving Ground, MD 21005-5066

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES