MODIFICATION OF DEFENSE MAPPING AGENCY AEROSPACE CENTER (DMAAC) DIGITAL RADAR LANDMASS SIMULATOR (DRLMS) DATA BASE

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SUMMARY

A planar approximation for data compression of DRLMS data base is provided by General Electric. The data considered were the terrain elevation slope between adjacent points within a 1^0 X 1^0 rectangle. Because of the heterogeneity such a large area, smaller areas 1/1600 of the 1^0 X 1^0 rectangle were considered and the planar approximation applied to each of the smaller rectangles. To substantiate the need for a reduction of the 1^0 X 1^0 area, a roughness index for each of the 1600 blocks in the area in question was calculated.

The Grumman modification of the General Electric "Trig" (Triangle Generation) algorithm which implements this planar approximation reduces computational time and enhances the fidelity of the simulated video signal.

DISCUSSION

The Digital Radar Landmass Simulator (DRLMS) simulates the ground mapping of all modes of the AN/APQ-156 Radar. It is required that this simulator be realistic enough to the ground training environment to permit substitution of simulator time for flight training time. A combined effort of General Electric and Defense Mapping Agency Aerospace Center (DMAAC) produced a system, currently incorporated in A6E-WST, in which DRLMS computes radar video signals for each resolvable element of the earth's surface illuminated by the radar antenna. The DMAAC off-line digital data base contains terrain relief data that was digitized as the elevation values at the intersections of a grid and also the cultural descriptive data that likewise was digitized onto a grid. Stored terrain and cultural data from the DMAAC data base is used for computing the radar receiver output and this information is used to drive the radar display. It is specifically the terrain file to which this report addresses itself. The DRLMS employs three range dependent on-line data bases to simulate radar images; these are:

- o Long Range (75 n. mi. - 150 n. mi.)
- o Medium Range (27.5 n. mi. - 75 n. mi.)
- o Short Range (5 n. mi. - 27.5 n. mi.)

To generate the data base for the DRLMS, the grid terrain model is defined by DMAAC and a planar approximation, used for data compression, is provided by GE. The planar technique for terrain modeling is a variable compression method -- planar segments being very large in areas where the world is flat and such segments being small where the terrain is rugged. With this variation, such an approach should allow placement of the data where it is needed.

A. General Electric Basic Trip Algorithm

The planar approximation, implemented in G.E.'s "Trig" (Triangle Generation) Algorithm, adjusts range dependent parameters not only to satisfy the overall terrain elevation but also to be self-adaptive to the memory system capacity. A major disadvantage of this technique is that the parameters are only range dependent and not terrain quality dependent. It is to rectify this insufficiency that the Grumman modification was initiated.

A typical GE selected data base represented 1.6 X 10^6 square miles, or 1600 31 element X 31 element arrays. The actual terrain elevation for each array position (DMAAC) is compared with the elevation on the plane (GE derived) for the same X-Y location, and the absolute value of this difference is calculated. Then, the mean deviation of these differences is computed. If the absolute difference of any X-Y location exceeds some input parameter, α, or if the mean deviation of the planes exceeds the input parameter, ε, the model is rejected, and a new model is constructed. While the (α, ε) parameters were selected for 31x31 blocks, 1600 such blocks representing a one by one degree area, were compiled and investigated in their entirety. Only one parameter set applied to the block conglomerate. Such a philosophy is adequate if the terrain of these 1600 blocks is homogeneous. For areas of heterogeneity, however, the data compression technique produces a compromised data base that does not meet the subjective requirements for smooth areas within the heterogeneous area.

If the original 31x31 word array is rejected, a new model is formed by dividing the 31x31 array into four 16x16 subarrays with two planes for each.

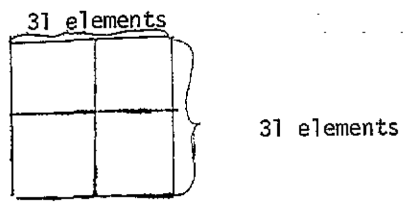

Figure 1: 16x16 subarrays

Again, each of the 16x16 element subarrays is investigated to determine its passing the α, ε criterion. If failure exists, each subarray is further subdivided and again tested. If less than three of the quadrants fails, the array is subdivided into nine mini-arrays (Fig. 2) and then twenty-five mini-arrays (Fig. 3). If, then, any of the twenty-five mini-arrays fail the tests, the entire subarray structure is abandoned as it would have been if three or four of the subarrays shown in Figure 2 had failed.

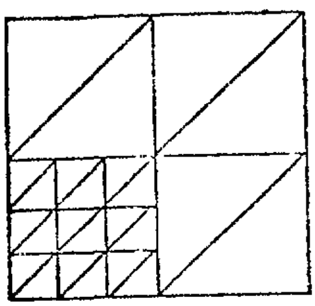

Figure 2: Nine Mini-Arrays

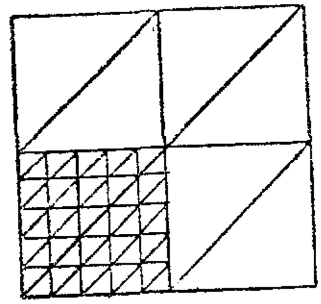

Figure 3: 25 Mini-Arrays

At this point the basic 31x31 array would be divided into nine subarrays each with two planes defined by its corners and diagonal as shown in Figure 4.

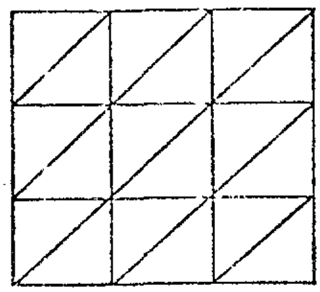

Figure 4: Nine Subarrays

Further subdivisions are illustrated in Figures 5 and 6.

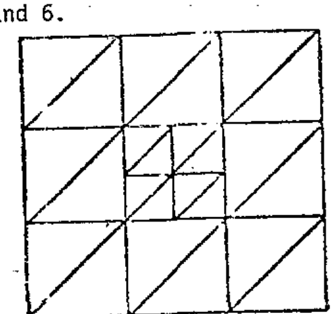

Figure 5: Four Mini-Arrays

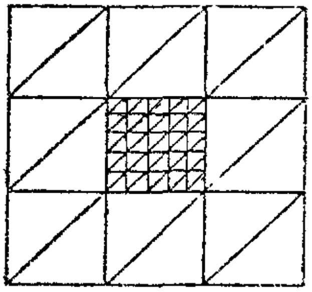

Figure 6: 25 Mini-Arrays

The subdivisions are evident but the conditions for these subdivisions should be stated. If less than five of subarrays fail, further subdivision is performed as in Figure 5. If any of the planes defined by the four mini-arrays of Figure 5 occurs the subarray is replaced by 25 mini-arrays as in Figure 6. No further reduction occurs. If more than five of the nine subarrays of Figure 4 occurs, the basic 31x31 array is configured into 25 subarrays as in Figure 7. If, then, any subarray fails it is replaced by four mini-arrays as in the left center of Figure 8. If any mini-array fails the test, the four mini-arrays will be replaced by nine mini-arrays as shown at right center of Figure 8. No additional reduction will occur.

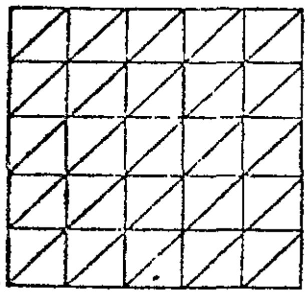

Figure 7: 25 Subarrays

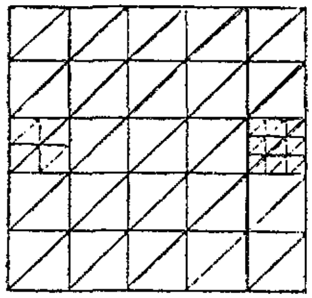

Figure 8: 25 Subarrays with 4 and 9 Mini-Arrays

Needless to say, such data manipulation is time consuming with apparently little statistical rigor. Grumman proposed to modify the GE "Trig" Algorithm by incorporating the Air Force roughness index equation. Considering roughness, or terrain characteristics, of each 31x31 word array, an α,ϵ can be assigned to each block of 961 elements.

B. Grumman Modification of Trig Algorithm

To accommodate terrain heterogenity within a $1^{\circ} \times 1^{\circ}$ block, the roughness equation proposed by the Air Force for the DRLMS requirements for the B1 was incorporated and proposed as a patch to the existent software routine. This equation will be used so that the selection of α,ϵ for the TRIGEN routine may be optimized. A statement of the equation, appears in Specification CP001-07878-139A dated 3 September 1976. From work done with DMAAC, probable ranges of α,ϵ for the variable α,ϵ study were proposed.

1. Air Force Roughness Equation Statement

Roughness index is a measure of terrain variation and the equation for calculation is:

$$R=\frac{1}{(n-2)^2}\sum_{i=2}^{n-1}\sum_{j=2}^{n-1}\frac{\{|2e_{i,j}-(e_{i,j+1}+e_{i,j-1})|k+|2e_{i,j}-(e_{i+1,j}+e_{i-1,j})|\}}{4} \qquad (1)$$

where n = 31

R = Terrain Roughness (Elevation Variation) Index

$e_{i,j}$ = element of an nxn terrain elevation matrix whose elements are spaced in equal increments of latitude and longitude.

$e_{1,1}$ = elevation of SW corner of matrix (meters)

$e_{n,1}$ = elevation of NW corner of matrix (meters)

$e_{1,n}$ = elevation of SE corner of matrix (meters)

$e_{n,n}$ = elevation of NE corner of matrix (meters)

K = meridian convergence term for entire matrix

$$K = \left[\frac{\cos\ (\text{latitude of } n^{th} \text{ row})}{(2)\ (Z)} + \frac{\cos\ (\text{latitude of first row})}{(2)\ (Z)}\right]^{-1} \qquad (2)$$

where Z = 1 for latitudes $\leq |50|$
= 1/2 for latitudes |50-70|
= 1/3 for latitudes |70-75|
= 1/4 for latitudes |75-80|
= 1/6 for latitudes |80-90|

2. Interpretation of Roughness Equation

A. Roughness Equation

In a 31x 31 block, the elevation of all the points except the corner points are considered. For each j (point along the y axis), keeping i constant, the sum of the elevations of the (j+1) st and the (j-1) st terms is subtracted from 2 times the j^{th} point.

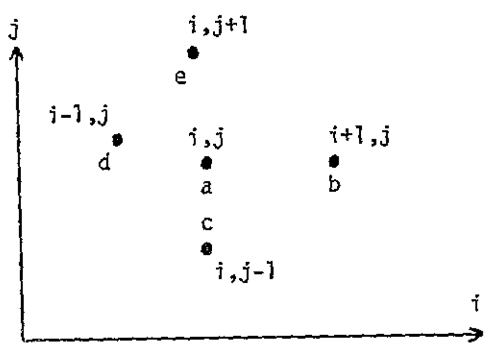

Fig.9: Identification of a Point & Its Neighbors

For example, consider the point i, j-

In reading equation (1), we first sum according to j. Multiply the the elevation of the point a by 2 and subtract from it the sum of the elevations of points e and c. The absolute value of this difference is then multiplied by a meridian convergence factor (see eq. 2) and added to an elevation term in which j is kept constant. This term is formed by multiplying point a by 2 and subtracting from it the sum of the elevations of b and d. Once all the points with constant i are considered, i is advanced to the next integer and a similar computation is effected, the result of which is added to the previous composite sum. There will be $(n-2)^2$ such calculations comprising the roughness index calculation. The meridian convergence term (k) is introduced to standardize the distance between consecutive readings.

B. Interpretation

The salient points that the roughness index will quantify for each area of topography subjected to the test, are the degree and direction that the slope between two points is changing. For example, the western desert areas, with a constant grade covering large areas, will exhibit a RI of zero the same as if it were a body of water. In a similar manner, those western areas in which the terrain has dramatic changes due to crests and ridge hills exhibit a significantly high RI. (Test results indicate a value of 10.9 for 48/121 region). Basically the RI is a point-to-point measurement of the change rate in slope between adjacent data points.

Roughness index will assume only positive values. A roughness index of 0 indicates that the elevation slope from the central point to each of its neighbors is zero, or constant in magnitude and direction. A roughness index greater than zero indicates the slope changes from the central point to each of its neighboring points. Let us assume that the points a,b,c,d and e (Figure 9) all have equal elevations (EL1), then each term of the summation will be 2(EL1)-(EL1+EL1) or zero. Again, referring to Figure 9 if the (elevation of point a - elevation of point b) =- (elevation of point a - elevation of point d), and (elevation of point a - elevation of point e) =- (elevation of point a - elevation of point c), the roughness index calculates to be zero. To illustrate, consider point a_1 of the contour map.

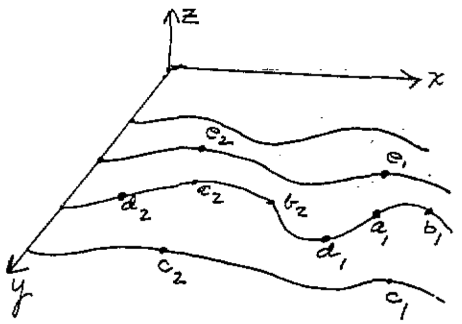

Figure 10: Contour Map Illustrating Roughness

Although points $b_1 c_1 d_1 e_1$ are not equal in elevation to a_1, the slope of the terrain around it is constant. Therefore, point a_1 is the average of the elevation of its equally distant neighbors b_1 & d_1; as well as c_1 and e_1. This point thereby adds zero to the roughness calculation for the area.

On the other hand point a_2 is at the peak of a hill, and is not the average elevation of its neighbors b_2, c_2, d_2 and e_2; thereby, making a positive contribution to the roughness calculation. Since absolute values are used in the calculations, a depression of equal magnitude to the peak at point a_2 would contribute an equal amount to the roughness calculation.

Regardless of range, the sample size for roughness calculation will be (n-2) where n = 31. For short range at latitude of 40^o there is an interval of 200 feet in longitude and 300 feet in latitude between points, in medium range a difference of 1000 feet in longitude and 1500 feet in latitude between points, and in long range a difference of 2000 feet in longitude and 3000 feet latitude.

3. Results of Roughness Index Calculation

Figures 11-16 inclusively, illustrate the results of the roughness index calculation for 1.5x1.5 min. blocks in areas of latitude, longitude combinations of 34/77, 36/77, 47/120, 47/121, 48/120, 48/121, respectively. East coast terrain is relatively flat in comparison to that of the west coast Reference to maps for each of the specified areas will illustrate the fidelity of the roughness indices to the actual terrain roughness. Each of the Figures 4-10 represents a $1^o \times 1^o$ block at short range. The specified location is that of the Southwest corner of the area under consideration.

Typical roughness maps can be used to establish an α, ε for each 31x31 word array (1.5x1.5) min. This will serve several purposes among which will be the reduction of time necessary to form subarrays, when statistical variation within a block is pronounced and also a computational time reduction for recalculation when the memory system capacity is exceeded.

This effort justified the need for modifying the GE "Trig" Algorithm.

DATE 120F77 PAGE 24

******************* U N C L A S S I F I E D *******************

*** START TERRAIN EXTRACT ***

PHASE I STARTS AT 012444 ON 120877

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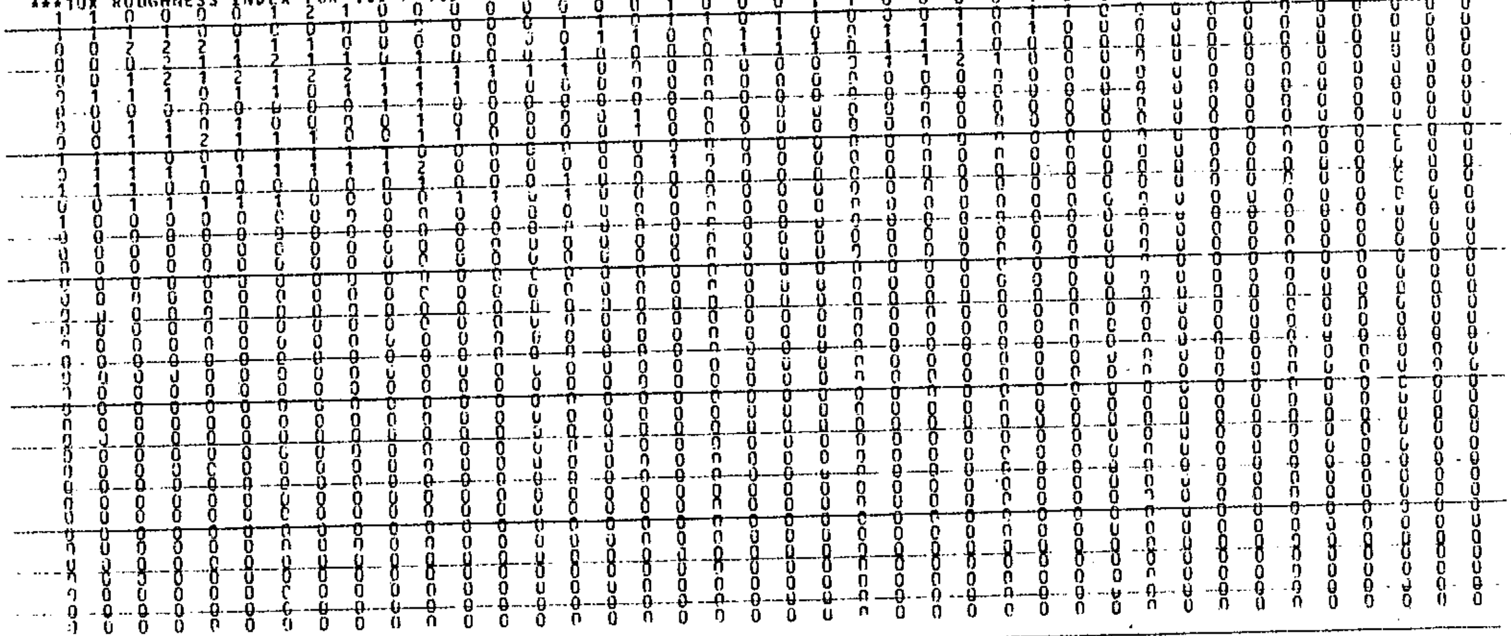
THIS TAPE FROM ZONE 1

***10X ROUGHNESS INDEX FOR 1.5 X 1.5 MIN BLOCK ** *



*** THE AVERAGE ROUGHNESS FOR THE 1 X 1 DEG IS .02.

PHASE I ENDS AT 020407 ON 120877

****
*
* SUPS THIS RUN: TOTAL = 658.345 CPU = 128.103 I/O = 530.242 (INCLUDES CC/ER)
*
****

@ADD,P TERRAIN-D

@FREE 1.

@FREE 4.

@XQT T-TRIANGLES

ROUGHNESS INDEX MAP FOR 34°N LAT, 77°W LONG

FIGURE 11

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******************* U N C L A S S I F I E D *******************
*** START TERRAIN EXTRACT ***                                                   DATE 120877        PAGE   24
**PHASE 1 STARTS AT 101414 ON 120877**
*** NAMELIST CARDIN -- RANGE = 1, ICOUNT = 5000
THIS TAPE FROM ZONE   1
****10X ROUGHNESS INDEX FOR 1.5 X 1.5 MIN BLOCK ** *
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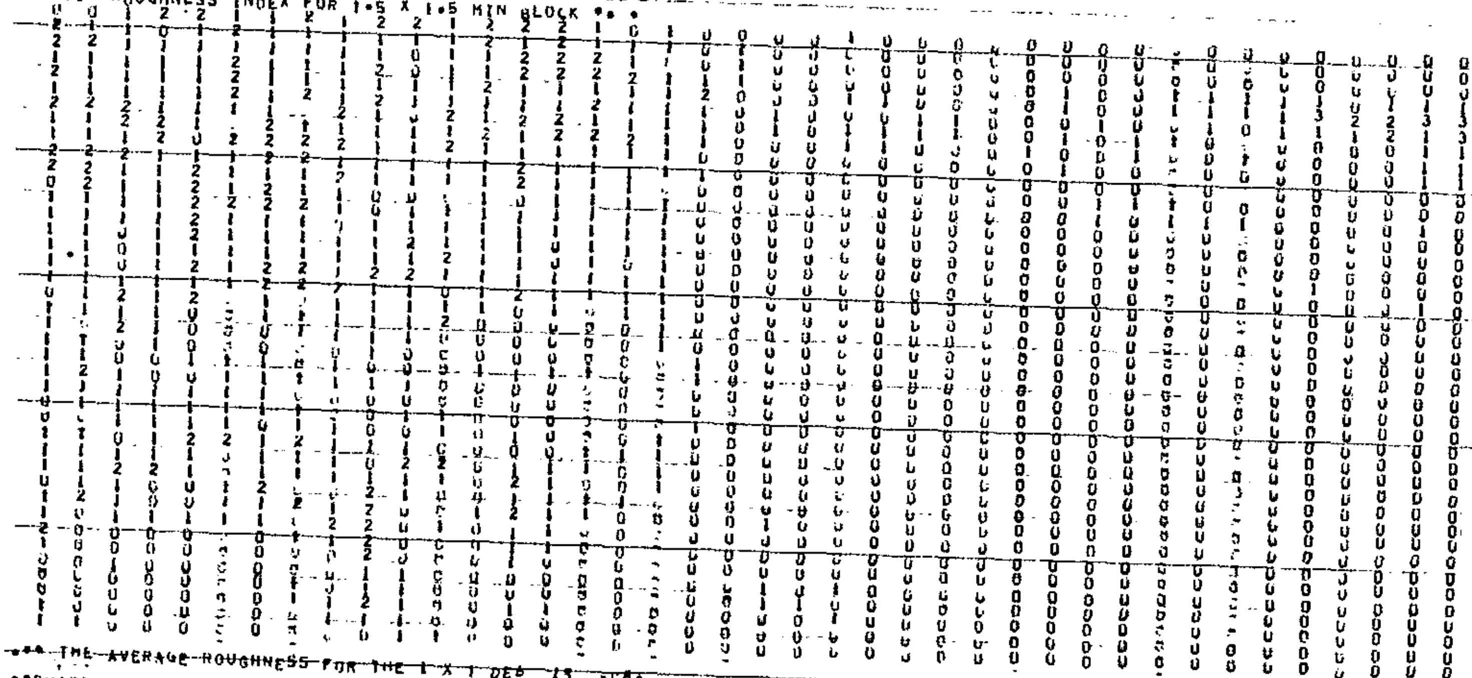

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*** THE AVERAGE ROUGHNESS FOR THE 1 X 1 DEG IS .18*
**PHASE 1 ENDS AT 103802 ON 120877**
*************************************************************************
* SUPS THIS RUN: TOTAL = 659.167    CPU = 129.574    I/O = 529.693 (INCLUDES CC/ER)
*************************************************************************

@ADD,P   TERRAIN-D

@FREE   1.

@FREE   4.

@XQT    T-TRIANGLES
```

ROUGHNESS INDEX MAP FOR 36°N LAT, 77°W LONG

FIGURE 12

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******************** U N C L A S S I F I E D ********************          DATE 120777          PAGE 24

*** START TERRAIN EXTRACT ***

**PHASE I STARTS AT 075936 ON 120777**

*** NAMELIST CARDIN -- RANGE = 1, ICOUNT = 8996
THIS TAPE FROM ZONE   1

***10X ROUGHNESS INDEX FOR 1.5 X 1.5 MIN BLOCK ***
 27 38 34 26  7 11 10  5  3  3  6 12 10 11 16 10  8  4  5  6  2  2  2  3  3  2  1  2  2  2  2  4  1  1  2  2  2  7  7 15
 26 27 32 34 35 12 12  7  7  3  5  6  5 10 10 11  7  5  7  ...
[illegible]

*** THE AVERAGE ROUGHNESS FOR THE 1 X 1 DEG IS .53.

**PHASE I ENDS AT 072429 ON 120777**
*******************************************************************
* SUPS THIS RUN: TOTAL = 650.248        CPU = 136.693        I/O = 522.555 (INCLUDES CC/ER)
*
*******************************************************************

@ADD,P TERRAIN=0
@FREE 1.
@FREE 4.
@XQT T-TRIANGLES
```

ROUGHNESS INDEX MAP FOR 47°N LAT, 120°W LONG

FIGURE 13

******************* U N C L A S S I F I E D ******************* DATE 120877 PAGE 25

*** START TERRAIN EXTRACT ***

PHASE I STARTS AT 062040 ON 120877

*** NAMELIST CARDIN -- RANGE = 1, ICOUNT = 13164
THIS TAPE FROM ZONE 1

***IDX ROUGHNESS INDEX FOR 1.5 X 1.5 MIN BLOCK ** *

36	31	48	46	50	42	56	23	37	49	40	42	42	34	44	42	23	24	30	28	25	16	33	30	37	43	34	42	23	17	22	9	23	30	34	34	31	31	33	26
44	43	30	37	47	53	46	41	15	33	27	41	37	23	34	35	41	23	24	33	31	20	25	33	43	50	59	36	29	33	34	20	10	21	24	21	34	25	22	21
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6	13	11	10	5	11	7	6	13	13	28	15	13	10	6	9	18	25	18	24	11	26	23	13	25	16	37	25	7	10	29	24	56	44	50	32	18	11	12	21
22	17	17	20	23	15	17	5	11	12	15	6	5	10	3	3	3	9	13	17	20	30	19	17	24	24	22	13	26	21	34	33	33	45	28	25	35	35	25	15
30	32	30	20	19	24	26	15	7	3	7	6	12	3	3	3	3	3	4	3	3	5	9	16	20	13	22	30	29	26	14	47	53	33	44	49	44	30	38	10
29	37	17	14	24	28	20	32	27	21	6	1	1	3	3	1	2	3	3	2	2	2	4	9	8	5	10	24	30	22	17	34	43	33	33	28	18	28	17	9
25	16	14	16	5	7	16	15	28	24	13	4	0	9	22	9	4	9	6	3	3	3	4	3	7	5	4	14	26	39	21	34	45	36	30	21	14	21	14	9
13	6	18	13	22	20	25	18	28	20	21	11	3	3	1	7	4	2	3	3	3	4	3	3	2	5	10	10	28	29	16	2	21	35	36	23	21	21	23	13
10	10	15	21	20	18	2	25	10	20	23	22	7	4	3	2	2	2	2	2	2	3	3	3	2	2	3	9	14	18	17	15	24	25	22	19	10	13	9	12

*** THE AVERAGE ROUGHNESS FOR THE 1 X 1 DEG IS 2.74.

PHASE I ENDS AT 063412 ON 120877

****
*
* SUPS THIS RUN: TOTAL = 659.776 CPU = 123.110 I/O = 536.666 (INCLUDES CC/ER)
*
****

@ADD,P TERRAIN-D

@FREE 1.

@FREE 4.

@XQT T-TRIANGLES

ROUGHNESS INDEX MAP FOR 47°N LAT, 121°W LONG

FIGURE 14.

******************* U N C L A S S I F I E D *******************

*** START TERRAIN EXTRACT ***

PHASE I STARTS AT 175733 ON 120577

*** NAMELIST CARDIN -- RANGE = 1, ICOUNT = 11736
THIS TAPE FROM ZONE 1

***10X ROUGHNESS INDEX FOR 1.5 x 1.5 MIN BLOCK ** *

15	23	23	31	24	23	25	19	25	39	44	5	30	9	14	19	21	20	12	19	23	12	1	14	13	12	20	16	10	5	7	10	15	17	12	9	8	16	19	13
24	16	22	28	33	34	14	26	32	39	34	8	24	21	23	19	18	16	20	24	19	17	3	10	11	9	9	11	8	5	8	16	10	9	10	8	12	13	11	32
27	26	15	12	24	19	11	13	12	28	62	37	13	12	24	21	16	13	15	16	21	14	4	5	14	12	12	19	9	10	7	8	7	12	13	7	8	9	18	30
22	24	15	12	15	19	14	12	19	20	17	18	29	13	13	22	18	22	13	12	7	18	2	24	22	21	16	8	11	8	7	9	11	9	10	7	14	9	12	19
12	17	11	14	13	16	11	14	15	19	25	15	17	27	29	5	21	17	15	12	18	16	2	15	15	18	13	16	12	12	8	12	13	5	9	7	8	10	9	23
18	20	19	12	20	13	16	19	23	21	19	21	18	16	13	26	20	9	14	14	15	13	8	2	15	13	12	9	18	15	8	16	15	14	12	5	11	11	7	26
29	24	23	23	17	15	19	22	27	27	19	24	25	13	16	17	10	10	13	10	11	14	10	0	12	11	10	5	7	7	5	7	5	12	10	10	12	14	10	16
27	21	24	27	29	20	16	14	16	21	23	23	26	25	21	22	16	13	12	5	9	12	11	3	18	10	15	13	17	3	6	4	7	9	11	9	14	15	13	10
17	18	21	22	20	18	14	17	25	20	15	24	19	19	19	20	7	7	8	6	5	15	8	2	22	9	13	17	5	17	16	19	10	10	17	21	13	12	13	12
16	8	21	19	17	21	25	19	21	19	25	27	21	18	18	23	6	8	10	13	14	16	9	2	13	10	10	10	3	8	9	12	13	14	17	10	8	11	5	5
23	12	13	20	23	24	23	23	26	23	17	26	25	14	26	20	19	4	3	6	10	14	24	9	14	4	5	8	8	9	10	17	21	11	18	12	9	7	8	10
15	14	14	16	24	33	33	37	29	23	17	18	18	22	15	18	16	9	5	5	7	5	6	6	10	8	10	11	7	10	14	21	15	17	10	11	16	9	4	10
11	13	22	37	30	25	38	37	29	32	30	35	21	25	11	15	22	14	8	4	5	5	10	15	13	13	13	15	11	13	13	9	17	18	11	11	10	10	6	14
20	19	29	36	35	19	16	24	31	19	13	22	24	14	9	15	15	13	14	14	12	7	25	15	10	14	7	10	10	16	9	12	8	7	15	17	17	21	16	15
21	24	30	34	32	28	26	21	26	17	10	22	21	15	9	16	16	20	13	15	9	10	16	10	9	14	10	11	9	13	11	13	12	6	7	8	11	13	8	11
27	23	28	27	30	33	25	31	20	26	20	25	23	25	10	11	17	14	16	9	11	21	10	15	8	8	6	9	12	21	10	9	15	10	6	8	8	7	8	13
22	32	29	26	16	15	11	25	25	23	25	30	37	22	12	13	14	10	13	8	14	13	10	13	14	17	13	11	7	12	9	7	11	10	12	9	9	10	17	12
14	19	27	20	12	12	14	14	20	19	22	21	21	21	17	16	6	20	6	10	13	16	8	7	4	5	7	11	14	16	16	13	12	15	11	10	19	21	14	14
23	20	32	19	15	15	15	19	13	22	21	12	12	17	15	17	7	14	12	13	11	15	23	11	8	4	4	4	12	17	10	14	13	9	8	10	14	11	21	8
21	21	22	24	25	26	10	13	13	22	31	20	11	8	11	10	14	11	15	5	24	8	13	15	10	9	5	4	3	6	10	19	19	16	20	19	17	18	10	7
24	24	20	21	20	30	26	13	16	22	25	25	11	8	13	10	10	5	3	5	9	22	13	16	14	15	14	10	4	5	14	5	10	10	15	19	16	9	7	9
28	26	17	23	18	30	16	22	16	17	23	21	22	13	14	13	11	8	2	2	4	9	18	15	13	14	17	17	17	18	19	9	16	11	13	17	11	14	4	9
40	33	23	14	21	24	25	22	20	23	27	14	23	18	21	16	17	2	2	6	2	4	10	11	8	10	14	22	13	16	19	19	15	12	9	4	10	11	10	14
30	25	22	18	21	16	16	17	23	19	21	17	22	13	22	19	12	4	3	3	5	6	9	7	7	14	19	15	7	7	13	14	15	17	8	1	3	13	25	19
29	29	29	16	12	16	9	9	11	21	8	14	22	15	19	11	9	7	3	4	5	5	11	12	9	4	6	8	11	11	6	7	8	13	16	13	14	20	16	15
28	29	22	16	9	14	18	17	15	16	20	12	14	23	19	9	5	7	7	11	6	17	16	17	15	11	6	4	8	7	5	5	6	12	11	19	14	22	18	17
31	24	21	11	11	8	8	6	17	18	26	15	10	19	7	6	10	7	12	12	16	19	17	28	17	10	5	3	5	4	10	6	8	8	14	22	20	20	21	20
18	28	19	21	13	12	7	4	8	21	19	14	6	4	7	7	9	8	6	7	6	16	14	14	20	15	16	11	16	11	17	13	5	6	5	8	12	16	12	22
21	14	13	14	7	13	9	5	12	6	17	8	8	15	12	9	9	3	6	5	4	6	22	8	12	13	12	9	10	13	13	12	8	15	9	6	21	15	16	13
21	20	19	9	8	13	13	16	15	18	11	7	12	13	11	9	7	1	1	2	1	1	5	13	7	8	14	13	10	6	18	10	11	16	18	19	18	14	23	11
20	7	6	12	9	11	17	12	16	13	10	5	14	9	6	10	5	4	4	3	3	2	0	6	8	4	8	12	10	14	9	13	16	10	14	9	11	12	13	12
17	11	11	10	6	9	7	17	14	9	12	4	9	12	6	9	7	3	2	3	0	2	1	4	9	4	10	16	5	6	10	9	11	7	10	4	6	14	12	7
21	14	15	8	7	8	5	15	9	17	9	5	5	9	6	6	2	2	1	4	1	1	1	2	9	3	6	16	16	20	16	20	15	10	14	12	19	15	14	9
18	14	15	23	14	10	12	20	12	5	10	1	3	7	7	7	6	3	2	3	1	1	3	5	7	6	4	14	10	11	16	10	17	16	22	22	18	21	20	16
12	15	19	17	10	13	18	9	15	5	5	3	6	7	5	7	4	1	1	2	9	5	4	5	5	9	8	4	13	9	10	6	14	12	15	21	17	17	14	18
13	17	14	9	11	9	17	17	15	5	3	4	2	4	4	10	4	1	1	3	8	6	6	4	2	3	11	10	7	7	10	7	5	9	17	13	11	9	11	10
16	13	16	10	11	14	12	6	15	15	4	1	1	7	4	8	3	5	9	15	13	11	9	4	3	7	8	9	11	13	5	10	11	8	13	8	5	8	13	10
24	14	13	13	9	10	9	8	9	11	18	15	2	5	6	5	7	4	8	12	7	16	13	11	13	10	8	9	10	3	0	11	8	3	3	2	1	7	10	12
30	20	12	7	8	13	9	3	6	5	7	12	7	7	7	6	7	8	8	4	4	2	5	9	11	12	15	14	6	2	2	3	6	6	3	2	5	10	8	11
25	32	23	3	2	14	0	7	2	2	6	8	9	7	8	8	10	9	4	1	2	3	4	2	2	1	7	2	2	2	2	2	2	2	4	2	3	8	10	6

*** THE AVERAGE ROUGHNESS FOR THE 1 X 1 DEG IS 1.38.

PHASE I ENDS AT 181456 ON 120577
****

*
* SUPS THIS RUN: TOTAL = 660.666 CPU = 129.959 I/O = 530.707 (INCLUDES CC/EF)
*
****

@ADD,P TERRAIN-D

@FREE 1.

@FREE 4.

@XQT T-TRIANGLES

ROUGHNESS INDEX MAP FOR 48°N LAT, 120°W LONG

FIGURE 15

****************** U N C L A S S I F I E D ****************** DATE 120°77 PAGE 25

*** START TERRAIN EXTRACT ***

PHASE I STARTS AT 022134 ON 120577

*** NAMELIST CARDIN -- RANGE = 1, ICOUNT = 14404
THIS TAPE FROM ZONE 1

***10X ROUGHNESS INDEX FOR 1.5 X 1.5 MIN BLOCK ** *

62	61	47	55	67	64	59	23	34	46	34	32	34	26	28	31	31	23	28	25	26	29	30	32	27	23	26	20	9	24	18	26	45	32	38	37	20	27	30	20
57	53	46	53	57	48	31	39	35	42	26	36	39	20	38	28	18	24	32	27	32	28	27	27	28	34	37	22	17	23	12	8	26	20	36	18	13	20	23	20
31	50	43	52	44	44	51	47	36	36	25	25	31	34	39	11	15	30	33	35	43	41	46	38	28	36	38	20	34	28	31	24	32	29	29	25	16	18	31	14
23	53	49	47	46	49	62	49	41	36	31	43	43	43	17	7	28	24	25	32	32	37	33	37	36	36	34	23	25	29	33	19	36	33	28	28	19	23	14	18
44	50	52	51	53	58	56	51	43	43	29	30	34	35	9	20	37	43	30	41	35	35	47	35	33	38	36	40	37	44	31	34	29	23	23	27	25	23	24	21
55	45	47	49	49	55	36	32	39	47	40	36	31	19	36	30	44	31	49	37	31	37	40	42	47	43	33	31	30	41	29	34	37	33	26	23	37	20	36	35
47	43	37	45	43	36	41	37	25	39	34	20	17	22	38	17	45	53	47	36	34	35	42	35	39	41	41	34	32	37	34	31	36	32	27	24	27	20	39	35
73	46	39	35	40	34	39	29	26	37	39	16	32	34	35	29	45	39	47	36	32	42	48	55	30	41	38	33	34	34	41	48	36	36	34	31	35	23	38	40
55	60	69	34	49	44	41	50	33	44	39	25	22	42	24	37	41	42	47	43	31	29	45	46	53	40	48	42	33	35	32	40	50	30	30	34	43	39	36	23
62	56	45	50	33	33	54	65	51	35	36	37	24	27	25	48	39	46	52	43	36	41	44	69	49	55	63	41	31	26	36	33	32	30	19	40	39	35	23	18
42	43	39	52	29	39	54	52	37	37	52	41	35	31	26	46	47	53	42	52	36	62	65	67	51	41	43	57	28	27	25	36	38	34	19	41	37	28	22	24
40	32	56	54	77	46	49	55	33	33	32	36	32	23	29	36	47	51	46	48	42	62	48	41	47	40	36	38	27	28	17	32	30	22	22	23	36	34	33	27
56	42	46	41	40	50	41	47	44	61	31	36	37	46	36	36	37	50	46	40	37	27	41	37	31	38	29	28	22	18	23	20	26	24	19	33	38	39	32	21
55	48	40	44	43	40	49	45	37	43	41	44	39	57	60	54	43	34	30	27	23	27	19	29	22	25	33	32	32	28	20	26	19	21	19	31	25	29	34	19
37	58	63	45	47	29	32	43	29	34	40	55	53	47	53	61	59	36	28	28	18	39	26	36	34	34	34	27	35	34	19	16	22	21	21	26	27	32	29	23
39	43	54	51	43	44	28	28	40	25	68	43	39	56	49	40	43	45	36	32	29	17	24	25	26	32	38	32	25	27	24	28	21	21	27	32	27	31	30	35
38	42	47	51	58	57	50	28	23	55	43	51	43	48	36	30	47	44	31	24	26	21	27	15	13	75	24	34	32	22	19	20	17	19	32	33	38	36	29	20
43	54	33	44	52	61	56	50	27	31	49	41	41	40	37	41	51	37	37	40	37	34	30	39	28	12	17	24	19	19	23	21	14	26	26	36	31	33	35	19
42	43	40	46	50	53	50	74	70	28	48	41	41	38	46	51	68	47	36	57	53	42	34	30	28	41	8	17	21	23	22	18	10	26	21	27	36	34	30	21
31	39	42	55	71	44	61	51	51	51	44	43	39	59	63	54	42	48	49	43	49	48	45	36	38	36	36	29	7	7	13	16	4	11	16	30	34	35	29	21
50	43	40	73	60	38	31	44	50	46	46	41	44	60	57	58	75	45	46	52	31	43	38	44	35	35	37	31	24	15	6	5	4	12	6	18	28	34	27	29
56	70	46	38	68	61	37	48	49	35	45	33	42	49	53	64	51	36	53	51	42	44	39	41	42	33	41	38	28	20	15	9	3	9	16	22	19	29	32	27
77	63	52	36	39	22	57	51	58	23	45	49	38	36	53	59	62	45	26	25	39	47	48	43	39	32	33	33	33	19	16	15	8	5	13	21	22	18	20	37
60	87	50	45	45	32	39	56	73	59	62	46	47	43	33	42	50	47	45	39	19	33	38	40	41	30	25	31	28	24	33	31	18	6	4	25	17	23	21	38
55	98	48	43	58	48	28	44	56	56	56	46	42	34	51	53	64	69	39	49	40	27	18	29	35	38	31	18	20	21	25	17	19	18	7	15	24	15	13	16
39	41	63	40	28	30	42	46	50	37	26	52	49	48	42	43	47	40	43	44	50	49	45	20	16	20	20	24	31	29	24	25	25	23	21	10	9	11	10	15
49	53	42	23	35	57	50	39	45	52	50	21	21	52	63	36	36	29	40	33	48	45	40	42	33	36	29	27	23	36	30	32	34	26	36	35	13	3	8	20
44	63	55	26	79	69	52	44	41	51	70	75	50	15	44	49	42	33	33	33	35	45	42	43	33	32	27	25	22	30	33	35	35	32	42	33	20	3	19	25
44	55	38	53	51	56	43	49	40	56	59	62	109	65	9	36	47	43	36	32	33	31	33	39	33	43	37	30	34	27	27	27	32	25	37	32	16	7	20	20
52	46	49	29	57	54	54	59	51	62	40	37	76	81	35	70	43	45	46	38	37	33	54	27	32	35	40	38	25	29	31	33	27	24	24	17	9	18	28	28
29	63	41	44	47	58	65	47	53	43	52	37	45	60	41	9	35	30	35	44	37	41	32	40	40	24	40	51	37	36	36	34	34	31	26	13	17	22	25	29
44	56	36	31	27	55	68	35	53	53	47	55	56	55	34	14	16	27	45	42	39	54	71	46	36	29	47	49	40	43	52	36	34	31	25	13	15	24	24	16
32	31	40	37	39	49	54	74	71	46	44	40	48	45	33	31	37	43	12	48	50	52	42	52	40	29	45	38	32	33	29	40	36	32	34	24	19	19	34	22
40	43	62	57	51	42	61	68	67	66	52	50	44	56	56	43	51	44	21	24	51	57	52	57	45	39	43	40	35	29	25	35	35	38	35	24	25	17	25	21
32	42	37	55	34	47	42	39	51	62	45	26	45	50	41	53	56	55	53	18	42	60	54	40	31	35	36	34	36	38	28	28	27	23	33	18	21	18	23	17
43	52	64	54	45	37	42	45	40	50	32	24	45	31	56	50	61	57	84	24	31	54	49	36	38	47	35	32	28	38	39	33	29	23	15	23	25	27	33	16
49	46	49	62	47	27	35	53	36	57	40	26	40	50	39	36	36	59	67	58	18	54	63	44	40	34	30	37	26	26	33	30	26	25	28	20	20	31	34	20
39	41	44	48	47	48	18	29	49	39	44	43	45	36	38	31	31	33	42	57	57	19	26	49	42	40	34	24	28	35	33	31	33	31	31	34	24	21	33	33
44	44	41	42	40	45	21	30	40	32	42	45	30	31	40	24	33	33	37	37	53	62	50	32	26	19	24	36	33	37	32	36	36	33	28	29	36	29	31	30
44	32	43	38	41	52	31	27	44	27	35	50	35	40	33	26	36	29	34	29	37	48	50	43	51	60	50	28	12	16	24	34	37	36	42	44	29	29	27	20

*** THE AVERAGE ROUGHNESS FOR THE 1 X 1 DEG IS 3.76.

PHASE I ENDS AT 025559 ON 120877
****
*
* SUPS THIS RUN: TOTAL = 460.455 CPU = 129.697 I/O = 530.868 (INCLUDES CC/ER)
*
****

@ADD,P TERRAIN-D

@FREE 1.

@FREE 4.

@XQT T-TRIANGLES

ROUGHNESS INDEX MAP FOR 48^{O}N LAT, 121^{O}W LONG

FIGURE 16

ABOUT THE AUTHOR

MS. FORTUNATA V. ALTMAYER is a Software Development specialist at Grumman Aerospace Corporation engaged in various aspects of avionics and computer systems specification analysis and software development. Work includes systems math modeling, algorithm development, hardware/software trade off studies, establishing programming conventions, evaluation of software routines in view of error analysis, timing, file and data base management, and software quality. Prior experience includes fundamental mathematical research and development on communication theory and fault isolation algorithms for diagnostic testing of digital systems and various avionics systems analysis. She holds an A.B. degree from Hunter College in physics and an M.S. degree from Polytechnic Institute of Brooklyn in applied mathematics. She also holds an M.S. degree in computer science from Stonybrook and has completed all course work for a Ph.D. in applied mathematics.