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TSUNAMI HAZARD ASSESSMENT STUDY: NEAR-SOURCE EFFECTS

PROGRESS REPORT

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1.0 INTRODUCTION

This phase of the AID-funded tsunami hazard assessment study (contract #AID/SOD/PDC-C-0404) centers on the wave effects up and down the South American coast near the source areas of possible tsunamigenic earthquakes. The rationale for the study, the choice of potential earthquake sites, and the general approach to the problem have been discussed in detail in a previous SAI Report (Hebenstreit, 1981). The purpose of this Technical Note is to discuss the progress made during the first two months of the study and outline the steps remaining for completion.

2.0 THE NUMERICAL MODEL

This phase of the hazard assessment study differs from the far-field work also being carried on at SAI in that we are concerned with the tsunamis as they travel along the coast away from the source. The far-field work addresses on the problem of the evolution of the tsunamis when they leave the source and enter the deep waters of the central Pacific. The deep water (and resulting high propagation speeds) in which the waves travel allowed us to use a relatively unsophisticated numerical algorithm for obtaining solutions to the linear long wave equations (see Hebenstreit, 1981, for details). This algorithm is not quite as suitable for modeling wave propagation in shallow water. Instead, we chose to modify a numerical code, SSURGE, which has been used at SAI's Bryan, Texas office to simulate the response of coastal waters to severe storms and atmospheric pressure disturbances. Most of the computational work has been

carried out in Texas by Dr. R. E. Whitaker, who developed the model and is most familiar with its workings.

2.1 SSURGE

SSURGE, like the SEAWAVE model code used in the far-field work, is based on the well-known Platzman-type grid lattice staggered in space. Unlike SEAWAVE, however, SSURGE calculates all quantities at every time step. The spatial lattice is depicted in Figure 2.1. Note that surface elevation values are defined for integer values of j, k; u values at integer k and integer-and-a-half j; v values at integer j and integer-and-a-half k; and h at integer-and-a-half values of both j and k.

Computations are carried out according to a modified alternating-direction scheme. At time $t = (n+\frac{1}{2})\Delta t$, values of η, u, and v are obtained by implicit calculations on η and u and explicit calculations on v; at $t = (n+1)\Delta t$, values are obtained by implicit calculations on η and v from the previous half-time-step and explicit calculations on u from the same half step. A full time step consists of two half-time-step operations. This more sophisticated algorithm allows the computations to remain stable over long time periods at the fine spatial and temporal resolution needed for this problem. We chose a grid interval of $1/6^{o}$ in latitude and longitude and a time step of 60 sec.

We have purposely not reproduced the fine details of the numerical scheme in this note. The interested reader is referred to Leenderste, 1967 for more information.

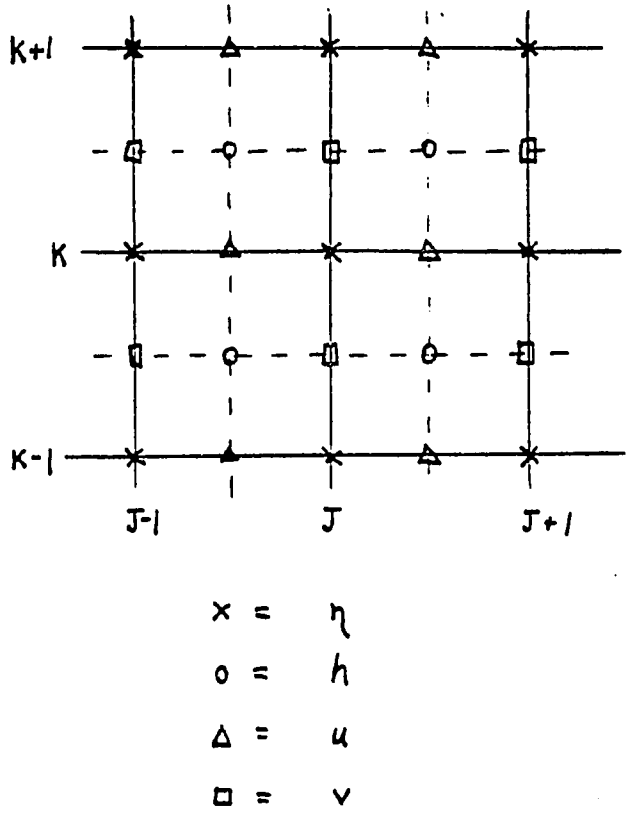

Figure 2.1 The space-staggered lattice which forms the computational grid for the near-source model.

2.3 BOUNDARY CONDITIONS

The condition at the sea-land boundary of the model was chosen to totally reflect waves approaching from offshore. This is in keeping with our decision not to simulate coastal flooding zones, but instead to concentrate on identifying near-shore regions in which wave energy is strongly focused. We feel strongly that this approach will provide sufficient information to be of value to disaster planning authorities while reducing the possibility that results of this study will be too heavily relied upon for specific hazard predictions.

The open sea boundaries of the model should allow for the transmission of outgoing waves through the boundary with minimal reflection due to numerical effects. In order to accomplish this the model combines the classical radiation boundary condition with a modification (Mungall and Reid, 1978) to allow for the radial spreading of the wave front as it leaves the source. Use of the modification at least partially compensates for the tendency of the classical condition to allow reflections if the wave fronts approaching the boundary are not plane (i.e., if the front has some curvature) or are not propagating in a direction nearly perpendicular to the boundary.

3.0 A MODEL TEST CASE

Each step in the modification of SSURGE was accompanied by tests to ensure that no errors had been introduced. These tests, usually applications to a situation with a known solution, will not be reported here. It is sufficient to say that all tests were conducted satisfactorily.

Once the modifications were completed the next step was to apply the model to a reasonably simple case which contains many of the elements of the actual planned simulations. We chose the case of an earthquake which occurs on the continental slope in a region with bottom topography which varies only in the direction normal to the shore. Thus isobaths (lines of constant depth) run parallel to the shore. The long axis of the uplift zone also runs parallel to the shore.

In order to approximate the type of conditions we intend to simulate, we chose the uplift pattern to match that of one of the test earthquakes - a source roughly 220 km long (long-shore axis) by 110 km wide with a uniform uplift of 5.8 m. This source is located NW of Lima, Peru. The bottom topography was obtained by digitizing from the appropriate bathymetric chart for the source area. A side view of the source area is shown in Figure 3.1. The location of the uplift zone is shown also, with the uplift greatly exaggerated in the vertical.

For ease in evaluating test results the source area was centered on the equator. The northern end of the grid was at 3.33°N, the southern end at 3.33°S. Because of the staggered grid the source motion could not be centered on the equator; instead it was centered 1/2 grid step ($\frac{1}{12}$°) north of the equator.

3.1 RESULTS

Figures 3.2 - 3.7 show the positive surface wave height elevations in the model grid at one hour intervals

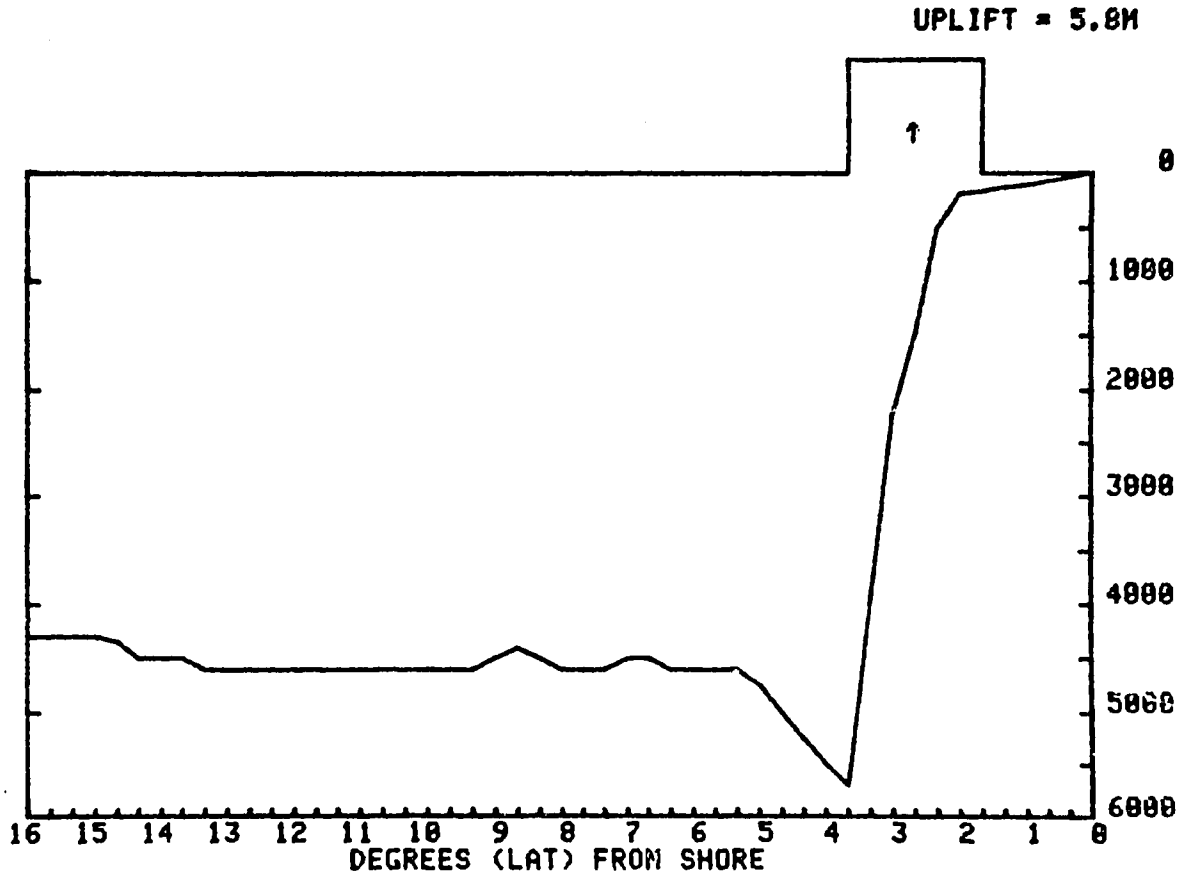

Figure 3.1 Side view of the test area. The right side is the continental shore. The vertical axis denotes depth in meters below MSL, the horizontal axis is distance in degrees of longitude from the shore. The uniform displacement, greatly exaggerated in the vertical, is superimposed on the h=0 axis.

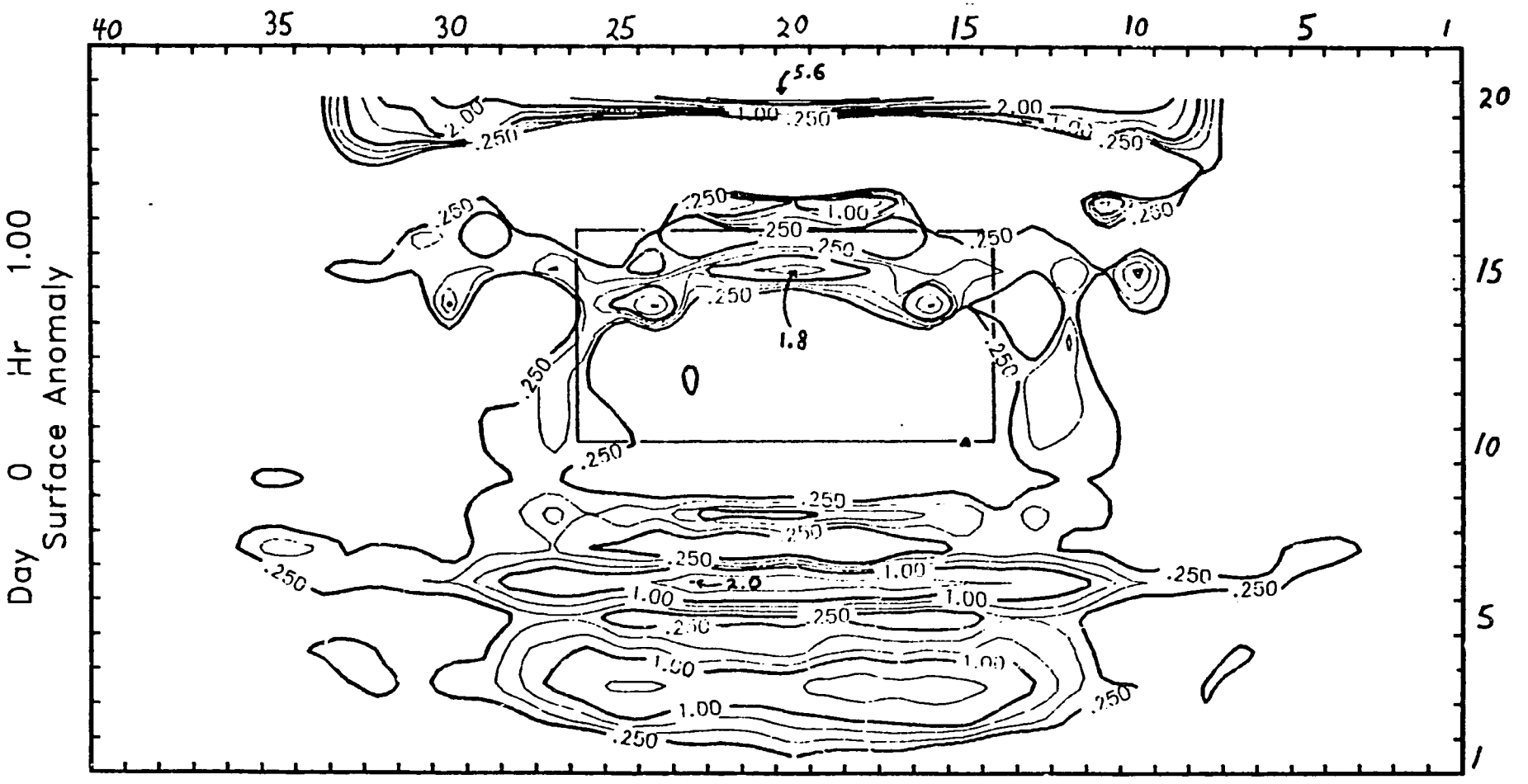

Figure 3.2 Contours of surface wave elevation one hour after the generating event. A rectangular (non-Mercator) grid is used. Model grid points fall between tic marks. The top of the plot is on the coast line, the bottom is in deep water. The left edge of the slot is north of the source. Contour levels are indicated in the text.

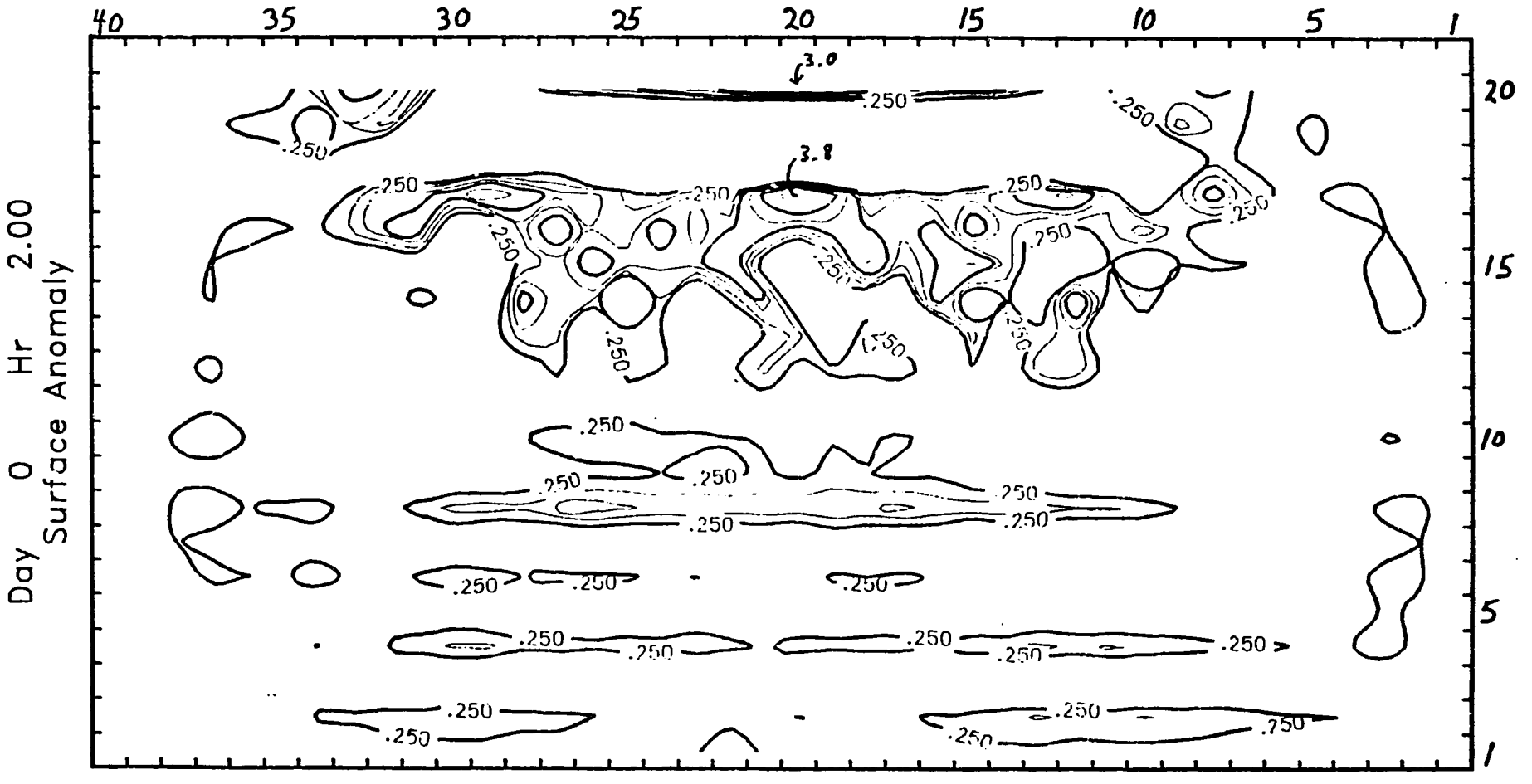

Figure 3.3 Same as Figure 3.2 but at 2 hours.

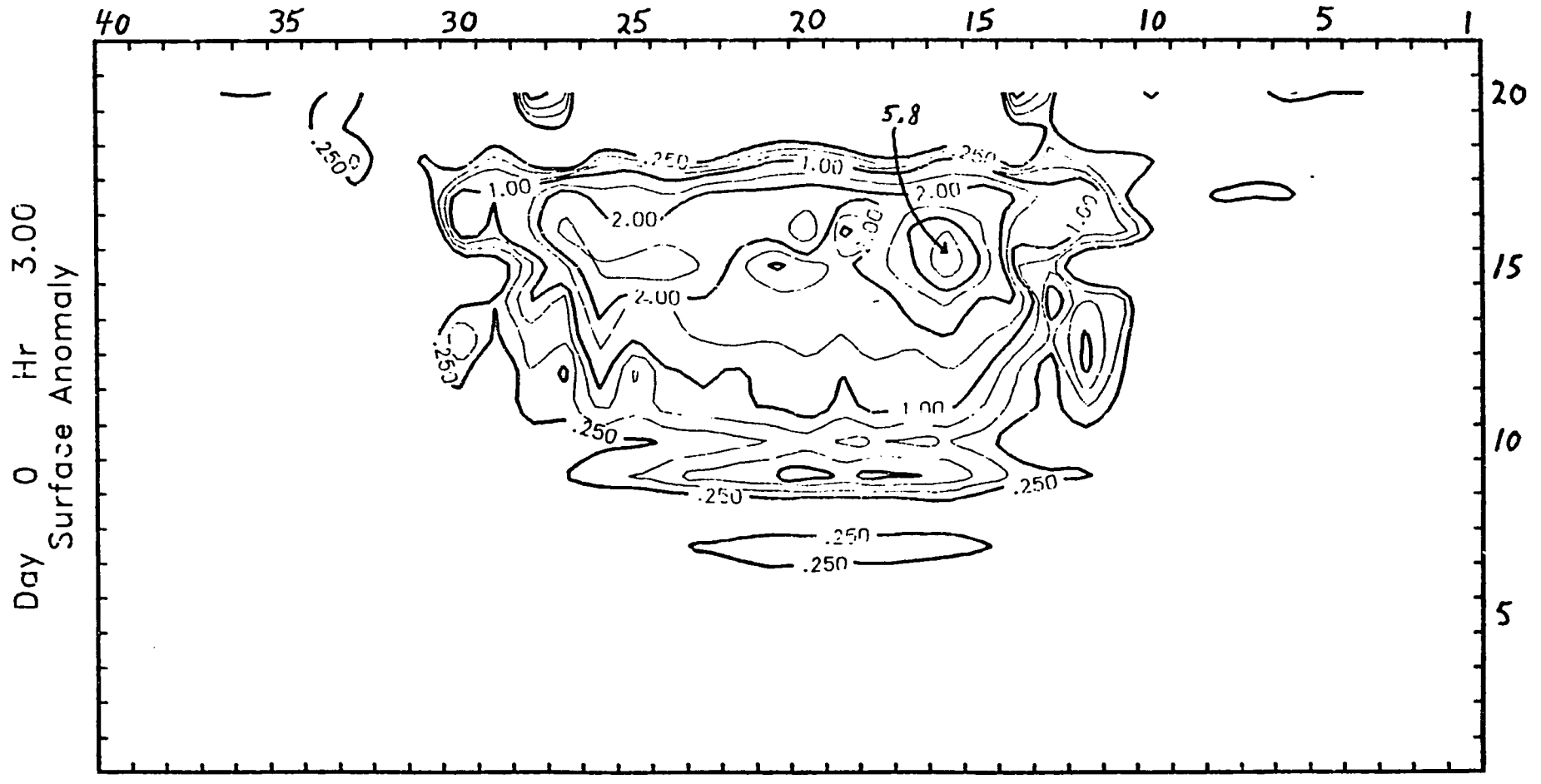

Figure 3.4 Same as Figure 3.2 but at 3 hours.

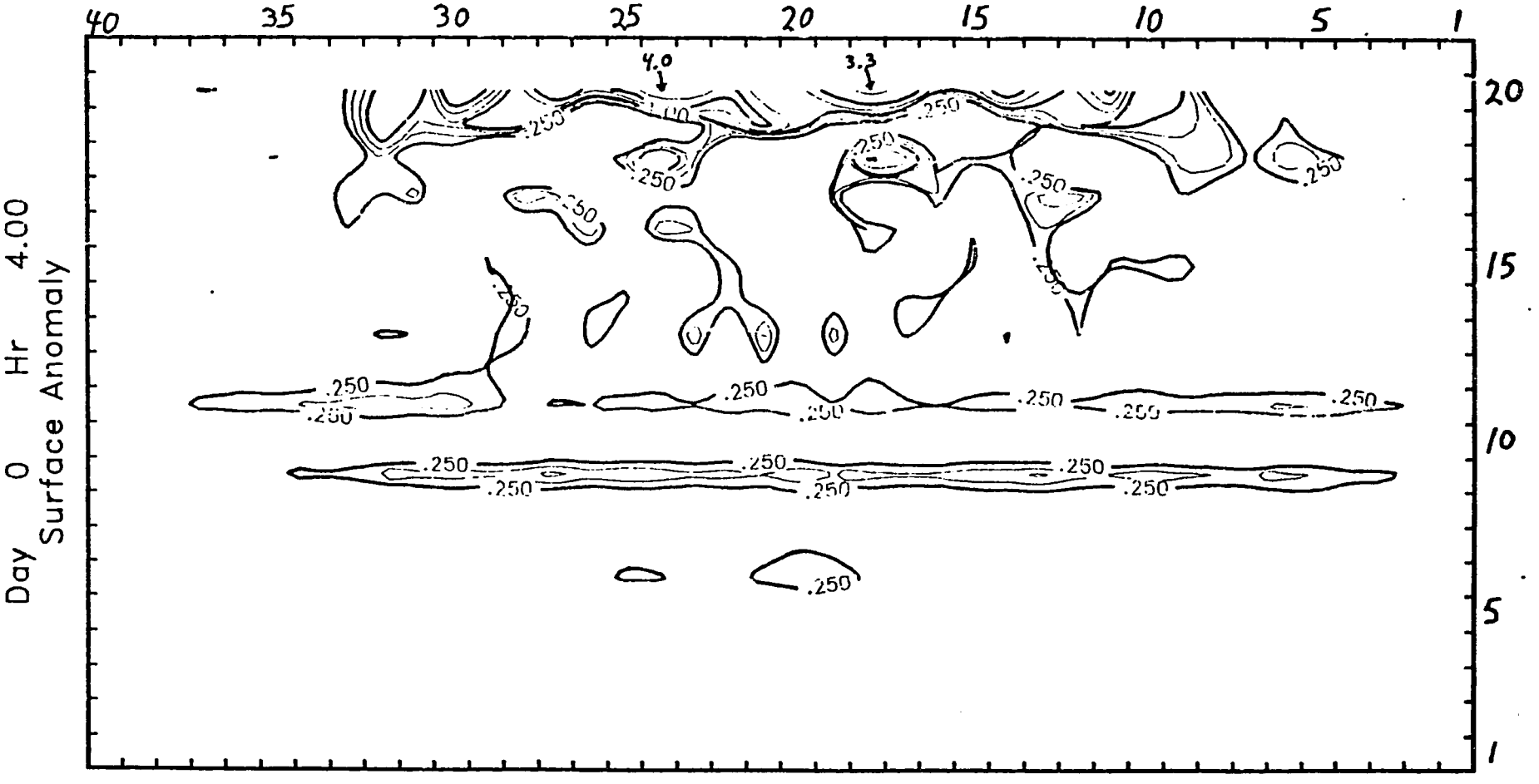

Figure 3.5 Same as Figure 3.2 but at 4 hours.

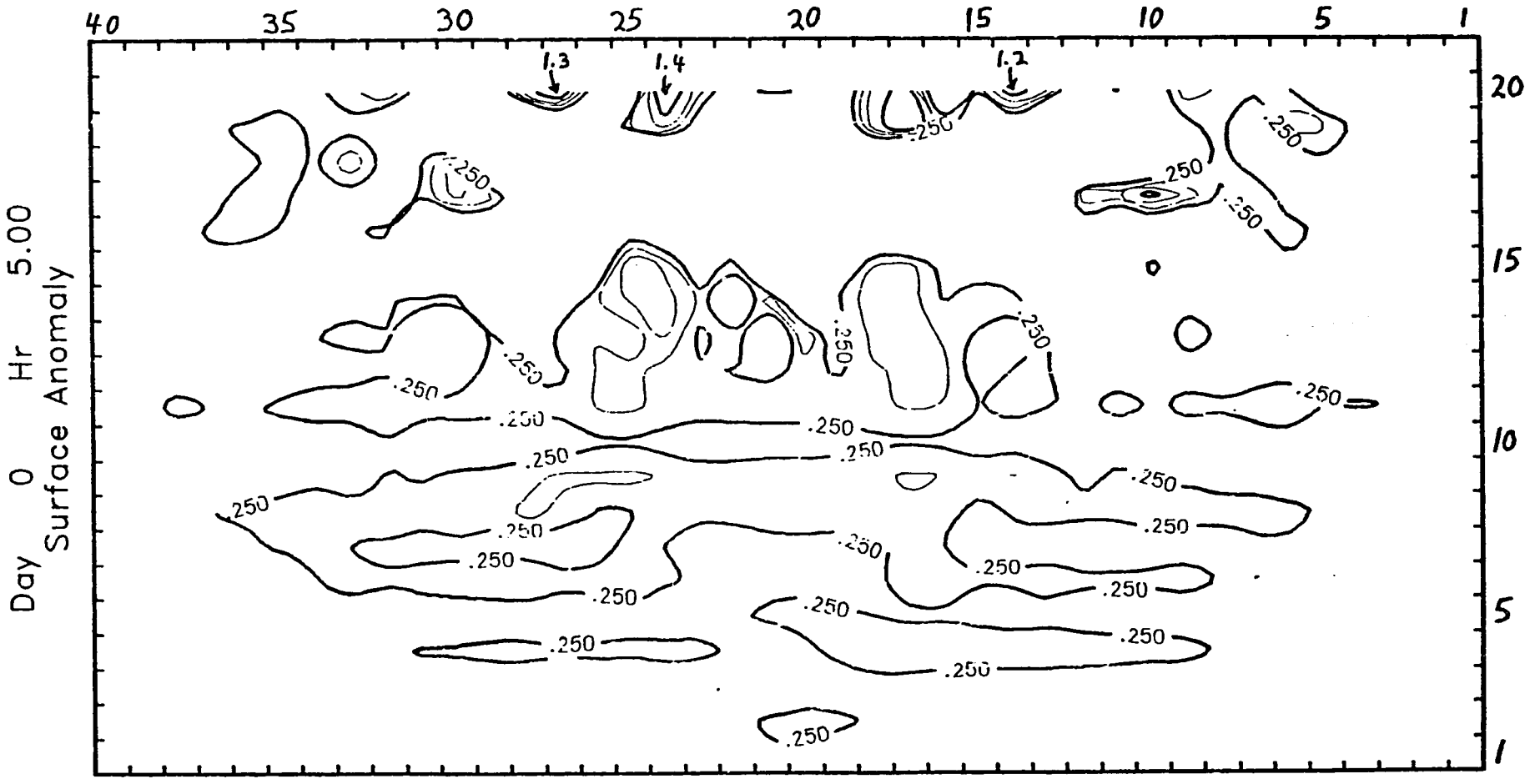

Figure 3.6 Same as Figure 3.2 but at 5 hours.

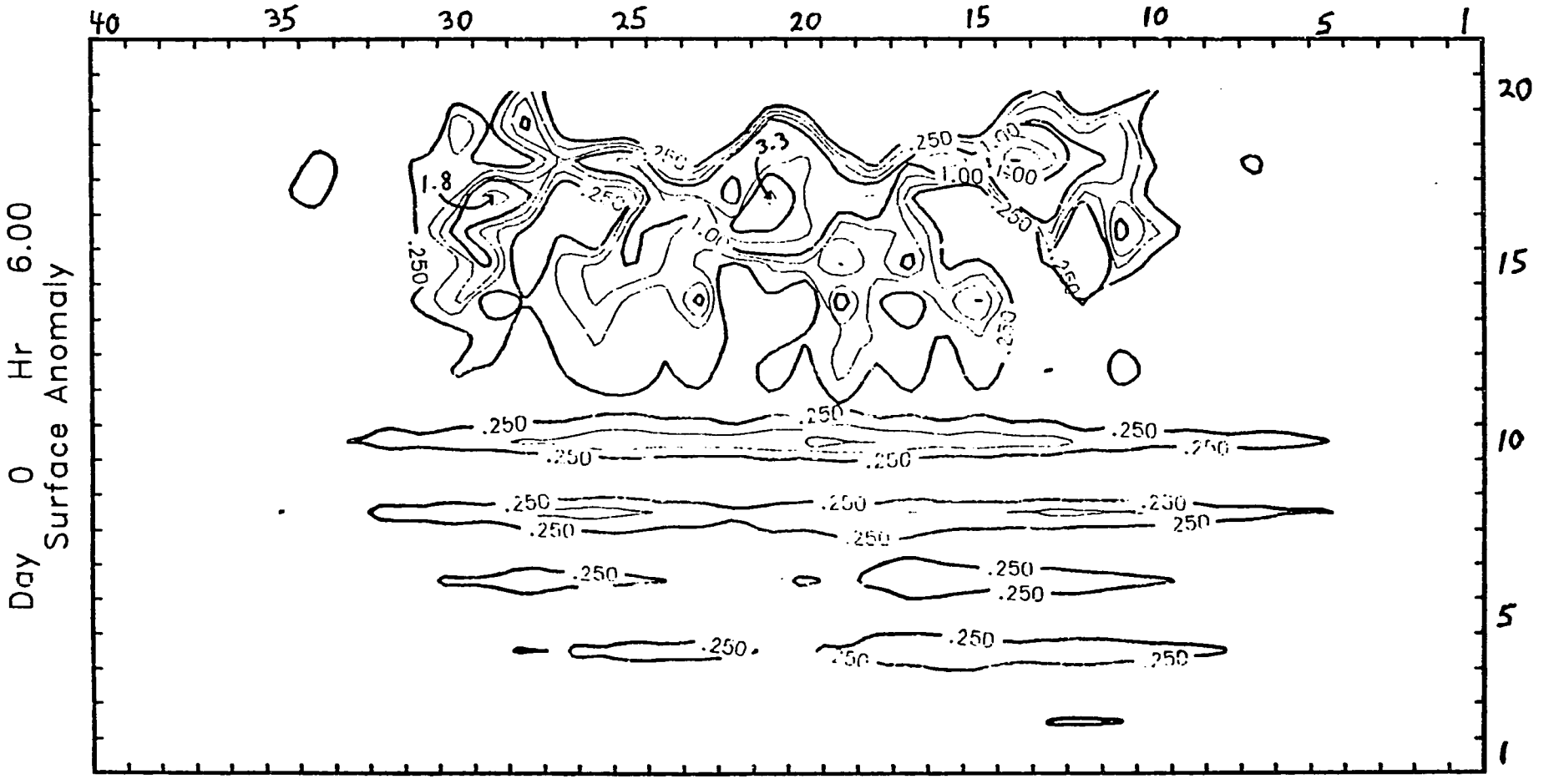

Figure 3.7 Same as Figure 3.2 but at 6 hours.

after the beginning of the simulations. Heavy lines denote lines of equal elevation at 0.25 m, 1 m, 2 m, 4 m, 7 m, and 10 m. Light lines denote intermediate elevations.

The figures are oriented so that the upper portion lies along the coast. The left side is north of the equator. The contours are plotted in rectangular coordinates, with no attempt to transform to Mercator coordinates.

After one hour the wave has spread out rapidly from the source area (the rectangle in Figure. 3.2). The leading seaward propagating waves have apparently left the basin and secondary waves are approaching the boundary. The shoreward propagating waves have just about reached their maximum values at the shoreline and the first reflected waves will begin to spread seaward. Waves are also moving northward and southward at a slow rate along the shelf.

After two hours the first reflected wave is approaching the edge of the shelf. A second reflection is beginning at the shore.

By the sixth hour the initial effects of the uplift have cleared the basin. A significant amount of wave activity is still apparent in the source region. This is presumably due to edge waves trapped on the shelf, the gradual damping of oscillations from the initial displacement, and, to some extent, numerical noise.

Figure 3.8 shows time series of waves at four points up and down the coast from the center of the basin.

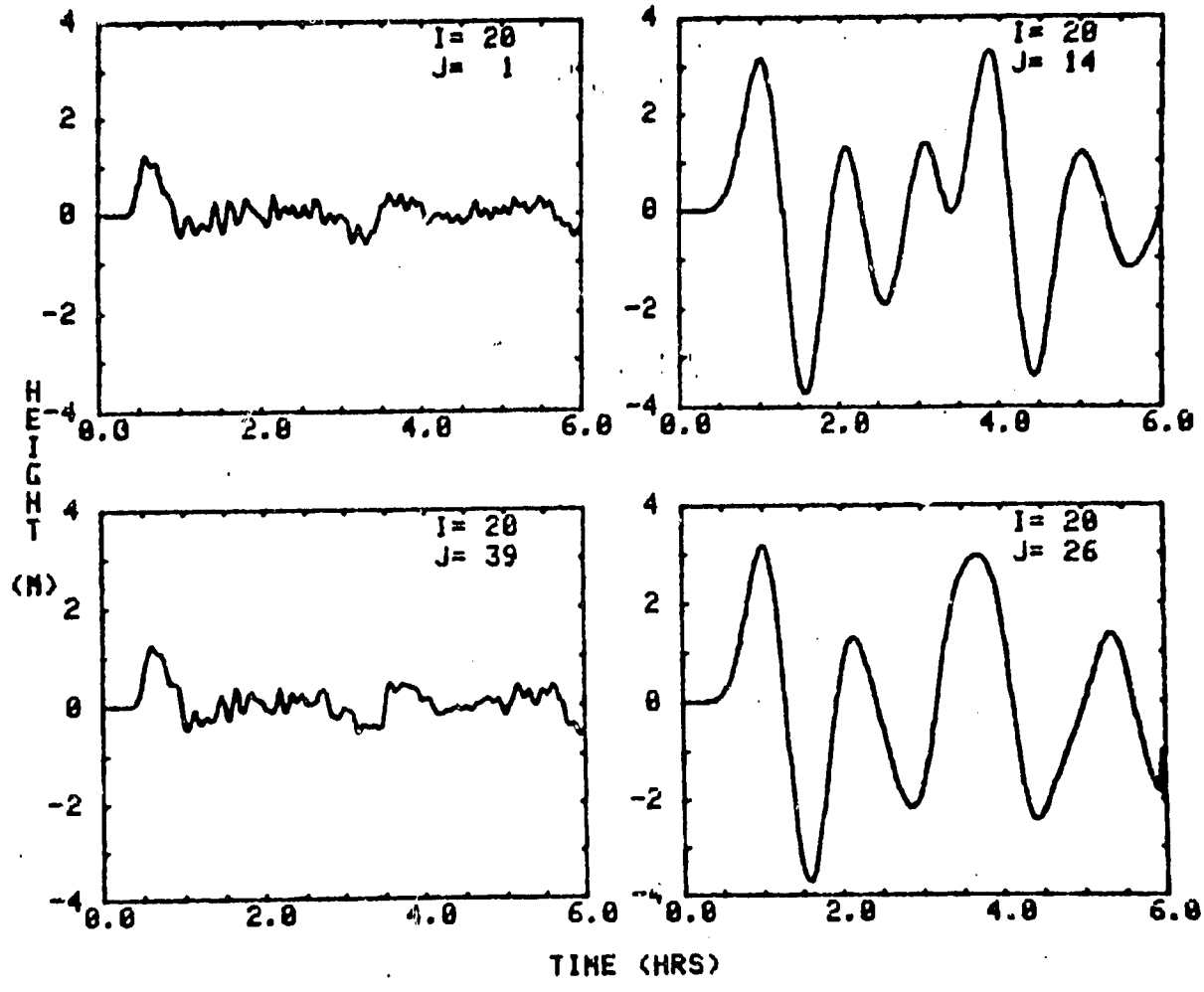

Figure 3.8 Time series of wave elevation at 4 points along the shore. Numerical smoothing has been performed to reduce short wavelength numerical noise. The "center" of the grid along the coast is at I=20, J=20.

Note the continued presence of waves, even after six hours. The peak amplitudes, which occur within an hour or two of the event, are a significant fraction of the initial uplift. Later waves show much lower amplitudes.

Figure 3.9 shows the peak wave height calculated at each point along the coast. Again, points fall between tic marks rather than at tic marks. Along the top of the plot we have noted the time after the event at which each peak was recorded. Time is recorded in military fashion, so that 0352 denotes 3 hours and 52 minutes rather than 352 time steps. The points farthest away from the source recorded maximum elevations approximately one-half hour after uplift, while points closer in to the source experience significant waves for quite a while longer. Again, this is evidence of the intense wave activity in the vicinity of the initial disturbance.

3.2 TEST CONCLUSIONS

The purposes of this test case were to examine the model's behavior under conditions close to those required for the near source study, and to merge SAI's capability for producing graphic output into the routine simulation procedure. We are now satisfied that the model is ready for application with only two relatively minor changes. The first is that the graphics will be modified to allow, for example, for continental outlines to be superimposed on the contour plots so that the user can quickly orient himself. The second is that the code for solving the equations will be modified slightly to smooth out some of the short

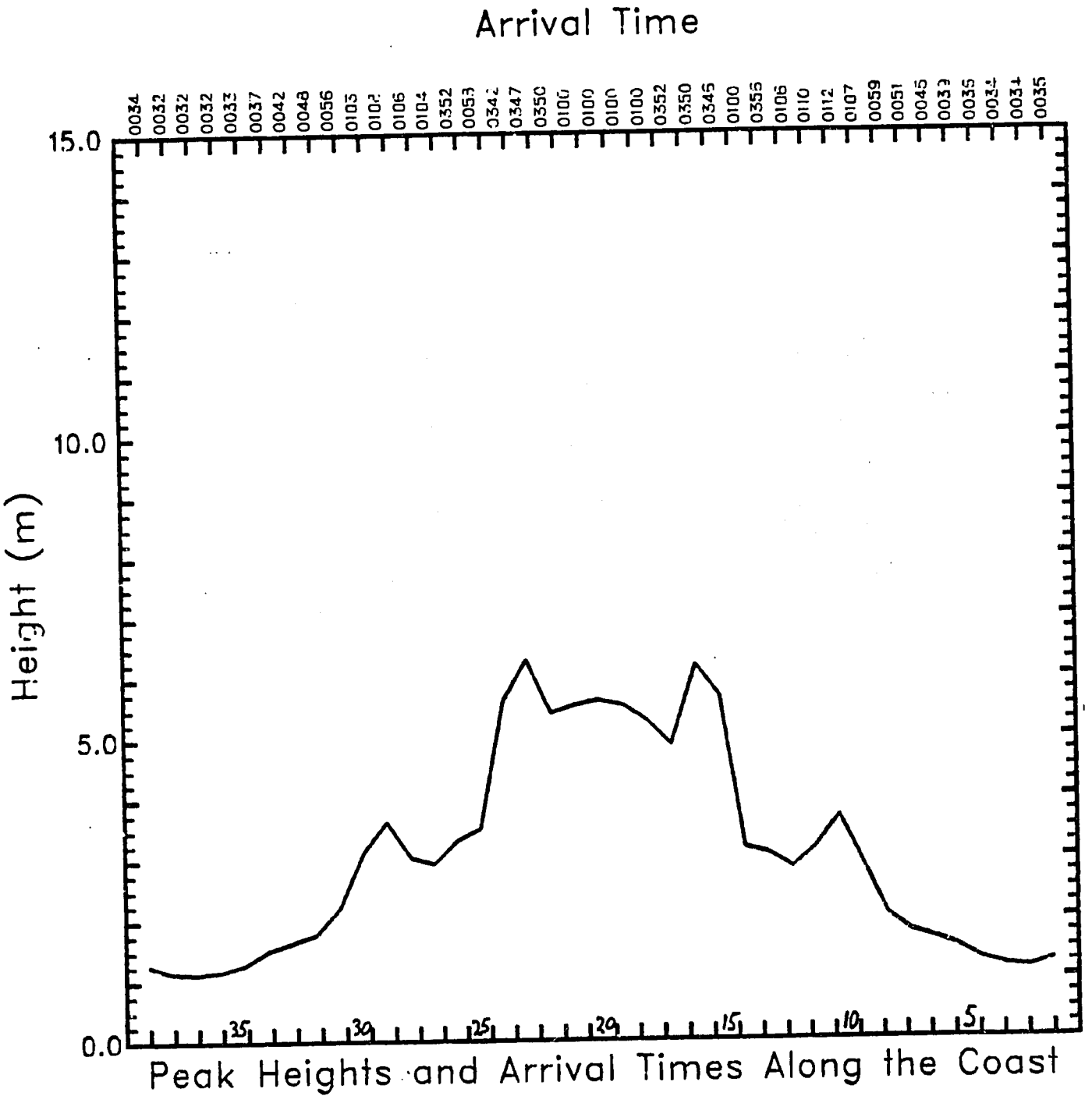

Figure 3.9 Peak wave heights at each point along the coast. The time of arrival is noted along the top of the plot.

wavelength (2 grid intervals long) oscillations caused by numerical effects. This will be accomplished by adding horizontal advection terms to the equations of motion. This will be described in the project report.

4.0 IMPLEMENTATION OF THE MODEL

Now that the numerical code has been thoroughly tested, we can begin the task of simulating possible tsunamis. This task will consist of 5 steps:

1) Digitize the high resolution bottom topography needed for the simulations. This will consist of merging the 1/3° resolution data used previously (Hebenstreit, 1981) with higher resolution values digitized from charts of the region between the Peru-Chile Trench and the shore. This task is nearing completion at SAI/Bryan.

2) Add the numerical code for the Mansinha and Smylie displacement model. The code is already working as part of SEAWAVE and transfer to SSURGE should be straightforward.

3) Run the twelve simulations and analyze the results.

4) Compile available historical data on local tsunamis in the Peru-Chile area for qualitative comparison with model results.

5) Produce the final report and have it translated into Spanish.

We foresee few difficulties in completing the analysis by 31 October 1981. The English version of the final report and its Spanish translation should be delivered by approximately 1 December 1981.

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Leendertse, J.J., 1967: Aspects of a computational model for long-period water-wave propagation. Tech. Rept. RM-5294-PR, The Rand Corp.

Mungall, J.C.H. and R.O. Reid, 1978: A radiation boundary condition for radially-spreading non-dispersive gravity waves. Tech. Rept. 78-2-T, Dept. of Oceanography, Texas A & M Univ., College Station, TX.