Nat. Hazards Earth Syst. Sci. Discuss., 1, C1320–C1324, 2013
www.nat-hazards-earth-syst-sci-discuss.net/1/C1320/2013/

Natural Hazards and Earth System Sciences
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Interactive Comment

Interactive comment on "A wavefront orientation method for precise numerical determination of tsunami travel time" *by* I. V. Fine and R. E. Thomson

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Received and published: 2 October 2013

General comments This paper describes a method to improve the accuracy and efficiency on computing the Tsunami Travel Time of oceanic wide tsunamis. The comparison of the new method's results is done both against a synthetic case of an ocean with 4000 m constant depth and the outputs of a known code in the field, the TTT SDK by GEOWARE. Although the maximum differences in travel time between the two methods range from < 0.5 % to 1 %, the proposed method has the merits of both efficiency and another C262one in terms of accuracy that is not explored in the text (see 'Final comment').

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Specific comments 1. At the introduction, line 5 page 898, it is made a reference to the "pattern of neighbouring points" but the explanation what this concept of 'pattern' has not been introduced yet and the reader gets lost. The concept must be explained before its usage.

RESPONSE The reviewer has a valid point and we appreciate the comment. The term "pattern of neighbouring points" is not a common phrase. We have modified the sentence so that it is more informative at the introductory stage of the text.

Was: A critical step in the calculation is defining the pattern of neighbouring points.

Change to: A critical step in the calculation is defining the spatial pattern or template of neighbouring grid points upon which the travel time estimates are to be determined.

2. First paragraph of section 2.1 (pages 898-899), describes the so called "conventional method" with the help a figure (Figure 1) and says that "the program computes the travel time for points 1 to 3, and points 20 to 32". I don't understand this statement. As I understand the TTT functioning, all travel paths displayed by node connected lines in Figure 1 are computed.

RESPONSE We understand the confusion and have attempted to address this in the revision. Basically, the method does not use those travel paths for which the resulting travel time is greater than the time already computed during previous time steps. Those travel paths are excluded from the analysis.

One other important point that lacks in the explanation is how the travel times are actually computed. It is necessary to explain how the velocity varies along the path. The TTT algorithm interpolates the velocity linearly between its end values.

RESPONSE The reviewer not correct. If the TTT program were to use only the end-points to compute the travel time between two points, it would create large travel time errors, especially for large spatial pattern templates. For example, suppose that there is a thin barrier of land between the end points. Waves simply can't jump through this

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barrier so the program will create significant errors. Another example is if there is a shallow region between the two deep water end points. If the program were to use just the endpoint values (which in deep water and therefore have high propagation speeds), the program would strongly underestimate the travel time between points. To avoid this problem, the TTT program calculates travel time along the line connecting the points taking into account the variable depth between the points. Specifically, TTT calculates the travel time along straight lines connecting the end points as the sum of the travel times within each of the grid cells which the line crosses. This significantly increases the algorithm complexity but helps to to avoid serious errors. To calculate travel time Inside each grid cell, the TTT algorithm interpolates the inverse celerity not the velocity per se, so the computed time between neighbouring points corresponds to the travel time using the inverse celerity for a region with uniform depth (thus, the depth used is always closed to the shallower point). We do the same thing in our algorithm. Moreover, because of the short spatial template (distance between neighbouring points), each inner-cell computation is limited to just one cell, and we use the average inverse celerity to compute travel time in the cell.

Furthermore, it also takes into account the variation of the gravity acceleration in function of latitude.

RESPONSE Thank you for pointing this out. Although variable g adds only a minor correction, we omitted to take this into account. We have corrected our results using the same approach as TTT, and accordingly corrected the figures, tables and text.

3. Lines 5-7, page 899, discuss the errors in the conventional method due to the fact that not all propagation paths are considered. A pictorial example of such cases would help the reader a lot. I can only imagine that those are points beyond those of the N = 32 pattern displayed in Fig 1, since the other non-visited points will be when the current source node moves into another position. In this regard, I do not understand the statement (lines 9-10, page 899) of the big gaps being along the grid axes. That is true when the source node is at O, but the next to right B1 will be visited when the

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source node is at that position.

RESPONSE The term “big gap” refers to the case where there is no direct connection between points, as for example between point (6,1) and point (1,1). Computing travel times between such points based on two-segments lines increases the path length and corresponding computed travel time in comparison with the theoretical value. The gap in the directions will not fill when the source moves from point O to point B1, and will remain forever. As a result, the isochrone line will always be an n-vertex polygon.

4. Lines 15 herein until the end of 2.1 section discuss how directional errors can be estimated analytically. Again, if I did not know what is being discussed I think I would have difficulties in understanding the point. All would be much clearer with and helping little figure

RESPONSE We have added a figure to illustrate the analytical estimation and to address this concern.

Final comment As I mentioned in the introductory note, the proposed method has a good pro point that has not been explored by the authors and which is related to the approximation that the TTT type codes do regarding the velocity variation along the travel path. As referred, TTT does linear interpolation between the velocities and the end nodes. But this does not take into account how velocity actually varies along the path. Longer the path (higher N's pattern, ironically where method's geometrical accuracy is better), cruder the approximation. The authors could not 'capture' this effect because their analytical solution used a very simplified constant depth ocean and therefore of constant velocity. The TTT algorithm does take into account how the velocity (actually, the inverse velocity) varies along the path, as we discussed above in our reply to comment 2.

RESPONSE Our analytical solution uses a uniform depth approach (which corresponds to an average inverse celerity), which also means that the travel time is a linear function of the coordinates. We believe it is fair to assume that the travel time

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function is a locally linear function of the coordinates. The gradient of that function is a local inverse celerity (slowness) vector. Of course, this approach assumes small depth changes inside each cell. Once again, this is a common assumption for any kind of numerical modeling, including travel time calculations. The same approach, though implicit, is used by the TTT algorithm. For variable depth, the wave beam will not follow a straight line, excluding the special case when the velocity gradient is directed exactly along the line which connects the points. In all other cases, the wave beam will go along some curve, which was not taken into account, neither by our method nor by the TTT software. In fact, both methods have the same interpolation approach.

In practical terms, the actual bathymetry often varies more rapidly than is assumed in numerical grids. This raises the question of whether any method is accurately representative of real situations. If the water depth (or, more to the point, the wave celerity) varies several times between neighbouring points, the travel time error can be of the order of the computed values themselves (which in turn strongly depends on the type of interpolation used between points). In the deep ocean, the travel time between points can be small, and accordingly, the error will be small. Unfortunately, the biggest change in water depth usually occurs in shallow areas, where the travel time between points is long and, accordingly, the errors are especially large. The only way to avoid such errors is to increase the grid resolution.

Interactive comment on Nat. Hazards Earth Syst. Sci. Discuss., 1, 895, 2013.