行政院國家科學委員會專題研究計畫成果報告

亞洲海域國際聲學實驗(ASIAEX)－子計畫四：
三維模組反算聲速分布之模式建立

計畫編號： NSC 90－2611 －E－002 －041
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執行單位： **國立台灣大學工程科學及海洋工程學研究所**
國立中山大學海下技術研究所
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中文摘要

本計劃分三個年度進行，本年度為第一年，主要工作項目違建例正算模式既分析模式三為模組。以 ASIAEX **實驗地點之實測地形與水文為環境輸入條件，計算在地形變化及內波影響造成的三維效應及模組偶合效應，地形對模組偶合即傳穩時間之影響約為內波影響之數倍。然而內波影響也在可量測範圍，故反算水文變化仍為可行。**

英文摘要

A three-dimensional ocean environment is generated using measured ocean data from the ASIAEX South China Sea experiment. The experiment site is characterized as an active internal tide/solibore propagation region along the Northwestern shelf break of the South China Sea. The three-dimensional acoustic effects are studied using a wide-angle version of the parabolic equation code FOR3D. The differences of transmission loss and mode coupling matrices along with the travel time difference are shown to demonstrate the 3-D effects. Variations in topography of the shelf break and in the water column due to the internal solibore propagation cause significant mode coupling and 3-D effects in the acoustic field.

1 Introduction

The 3D effects on underwater acoustic propagation have been reported recently [1]. A number of 3D models have been investigated and reported by Tolstoy [2]. The selection of the FOR3D model [3] is not only for its accuracy but also for its capability of detecting 3D effect as evidenced by successful applications to a set of oceanographic data whose 3D effects were studied in Ref. [4, 5]. This paper begins with the description of experiment site in the ASIAEX South China Sea region, and a brief description of the theoretical derivation of MOdal Spectrum of 3-Dimensional PE Field (MOS3DPEF), then, a discussion on the computational results. Computational two-dimensional (Nx2D) and 3D results were compared, and clearly showed the 3D effect. The results of a 3D calculation without the variation in the water column, i.e., no internal waves, also were presented to show the effects from the variation in the water column comparing to the results of the 3D calculation with internal waves.

2 Asian Sea International Acoustic EXperiment (ASIAEX)

The Asian Sea International Acoustic Experiment (ASIAEX) was conducted last year (2001) in South China Sea (SCS) to study acoustic interaction with water column variation and in East China Sea (ECS) to study acoustic interaction with ocean bottom. The experiment site in SCS is on the shelf break as seen in Fig. 1. The experiment site is within a 50 km by 50 km box. There was two L-shape receiver arrays (composed of a VLA and a bottom-mounted HLA) anchored on the NW corner, two tomo sources (224 Hz and 400 Hz) anchored on the NE and SW corners respectively as seen in Fig. 1.

3 MOdal Spectrum of 3D PE Field (MOS3DPEF)

The theoretical derivation of the three-dimensional model analysis can be found in [9], and the three-dimensional model analysis is integrated on the three-dimensional PE field [10]. The derivation is briefly introduced as follows:

Eq. 3.1 shows that the acoustic field can be decomposed into different modes, i.e., summations of mode functions with modal amplitude as weighting functions

$$P_{PE}\left(r,\theta,z\right)=\Sigma_m\frac{1}{\sqrt{r}}P_m\left(r,\theta\right)Z_m\left(z;r,\theta\right)\ , \quad (3.1)$$

where $Z_m\left(z;r,\theta\right)$ is obtained by solving the local mode equation

$$\{\frac{\partial^2}{\partial z^2}+\left[k^2\left(z;r,\theta\right)-k_m^2\left(r,\theta\right)\right]\}Z_m\left(z;r,\theta\right)=0 \quad (3.2)$$

with respect to the boundary conditions

$$\left\{\begin{array}{l} Z_m\left(0;r,\theta\right)=0 \\ \frac{\partial Z_m(H;r,\theta)}{\partial z}=0 \end{array}\right. . \quad (3.3)$$

The modal amplitude $P_m\left(r,\theta\right)$ is obtained by

$$P_m\left(r,\theta\right)=\int P_{PE}\left(r,\theta,z\right)Z_m\left(z;r,\theta\right)dz\,. \quad (3.4)$$

For the three-dimensional cases, we have the equivalent version

$$P_{3D}\left(r,\theta,z\right)=\sum_m\frac{1}{\sqrt{r}}P_m\left(r,\theta\right)Z_m\left(z;r,\theta\right)\ , \quad (3.5)$$

$$\{\frac{\partial^2}{\partial z^2}+\left[k^2\left(z;r,\theta\right)-k_m^2\left(r,\theta\right)\right]\}Z_m\left(z;r,\theta\right)=0 \quad (3.6)$$

The $P_{PE}(r,\theta,z;\omega)$ can be expressed as following equation

$$P_{PE}(r,\theta,z;\omega)=\frac{1}{\sqrt{r}}u_{PE}(r,\theta,z;\omega)\,e^{ik_0r}\,. \quad (3.7)$$

We substitute this into Eq. 3.4 to obtain the modal amplitude

$$\begin{aligned} P_m(r,\theta;\omega) &= \left[\int u_{PE}(r,\theta,z;\omega)\,Z_m(z;r;\omega)\,dz\right]e^{ik_0r} \\ &= A_m(r,\theta;\omega)\,e^{ik_0r} \\ &= |A_m(r,\theta;\omega)|\,e^{i\Phi_m(r,\theta;\omega)} \end{aligned} \quad (3.8)$$

or

$$A_m(r,\theta;\omega) = \int u_{PE}(r,\theta,z;\omega)\cdot Z_m(z;r,\theta;\omega)\,dz\,, \quad (3.9)$$

and the modal phase

$$\Phi_m(r,\theta;\omega)=k_0r+Arg\left[A_m(r,\theta;\omega)\right]\,. \quad (3.10)$$

The modal travel time is then used the steady phase assumption to obtain from the phase equation.

4 Numerical Simulations and Conclusions

There are two sets of numerical simulations in this paper. The first set investigates the 3D effect that comes from the variation of bathymetry, thus a single sound speed profile is used. The second set use the method of MOS3DPEF to reveal the effect introduced by the internal waves which implies the variation in the water column.

The first simulation set includes two numerical cases. Case A simulates an acoustic source located on the shelf where the water depth is 70 m, while Case B simulates an acoustic source located on the shelf break where the water depth is 430 m. The source frequency is 400 Hz for both cases. The Nx2D and 3D calculations are done for both cases. The calculations are done for each 180-degree sector, all other parameters of the calculations are summarized in Table 1. Figure 2 shows the bottom depth contour within the 180-degree sectors of the two cases. We only use one single sound speed profile which is shown in Fig. 3 in the water column and bottom in the numerical calculations. The results are displayed in Figs. 4 - 8. Figures 4(a) and 5(a) are the TL contour at 70 m depth of 180-degree sector for 3D calculations, and Figures 4(b) and 5(b) are the TL difference contour at 70 m depth of 180-degree sector between 3D and NX2D calculations. The TL differences can be up to 10 dB for some regions. Figures 6(a) and 7(a) are the TL contour at mid-section of the 180-degree sector for 3D calculations, and Figures 6(b) and 7(b) are the TL difference contour at mid-section of 180-degree sector between 3D and NX2D calculations. The TL differences also can be up to 10 dB for some regions. Figures 8(a) and 8(b) are the TL contour of the 3D calculations and TL difference contour between 3D and NX2D calculations for the 10-degree section away from the left boundary of case A. The section is on the shelf, but the 3D effect is still prominent.

The second simulation set includes three numerical cases. Most parameters of the calculations which are summarized in Table 2 are the same for all three cases. In case IW3D, we consider full 3D environment including variations in topography and the water column. In case BG3D, the variation in the water column is eliminated by average. The difference between case IW3D and IWNx2D lies in that in the former we use 3D method while in the later Nx2D method was adopted. Figure 9 shows the bottom depth contour within the 135-degree sectors of the calculation domain. The sound speed profile with internal waves we use to generate a 3D environment in the water column in the numerical calculations is shown in Fig. 10. The results are displayed in Figs. 11 - 13. In Fig. 11, we compare the mode coupling matrices of the three cases. The effect of the internal waves can be told by comparing the first and the second matrices, and the 3D effect can be seen by comparing the first and the third matrices. Both effects are obvious and easily seen. Figs. 5 and 6 are the modal travel time difference plots, where we have picked the 31st track to draw the results. Fig. 12 shows the difference between case IW3D and IWNx2D, while Fig. 13 shows the difference between case BG3D and IW3D. In both plots, the three-Dimensional effects are clearly shown on the mode structures.

References

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Source Location	Frequency	Source Depth
E117 21.437 N21 56.350	400 Hz	124 m
$\Delta r = 0.7\text{m}, \Delta q = 1^\circ, \Delta z = 1\text{m}, q_{\text{total}} = 135^\circ$		

Table 1. Calculation parameters for simulation set 1.

Source Location	Frequency	Source Depth
E117 21.437 N21 56.350	400 Hz	124 m
$\Delta r = 0.7\text{m}, \Delta q = 1^\circ, \Delta z = 1\text{m}, q_{\text{total}} = 135^\circ$		

Table 2. Calculation parameters for simulation set 2.

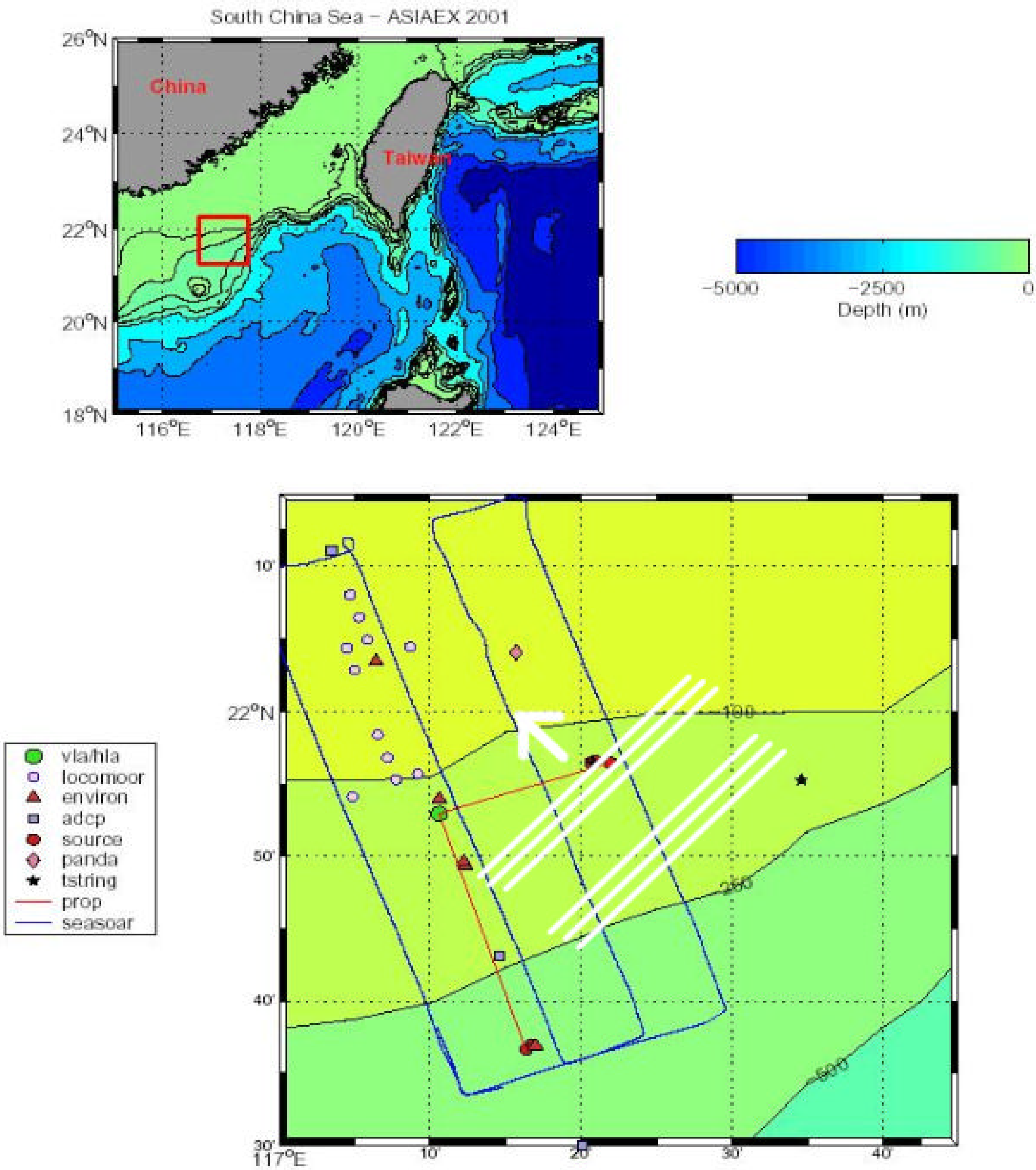

Figure 1. ASIAEX 2001 South China Sea area of study and mooring locations.

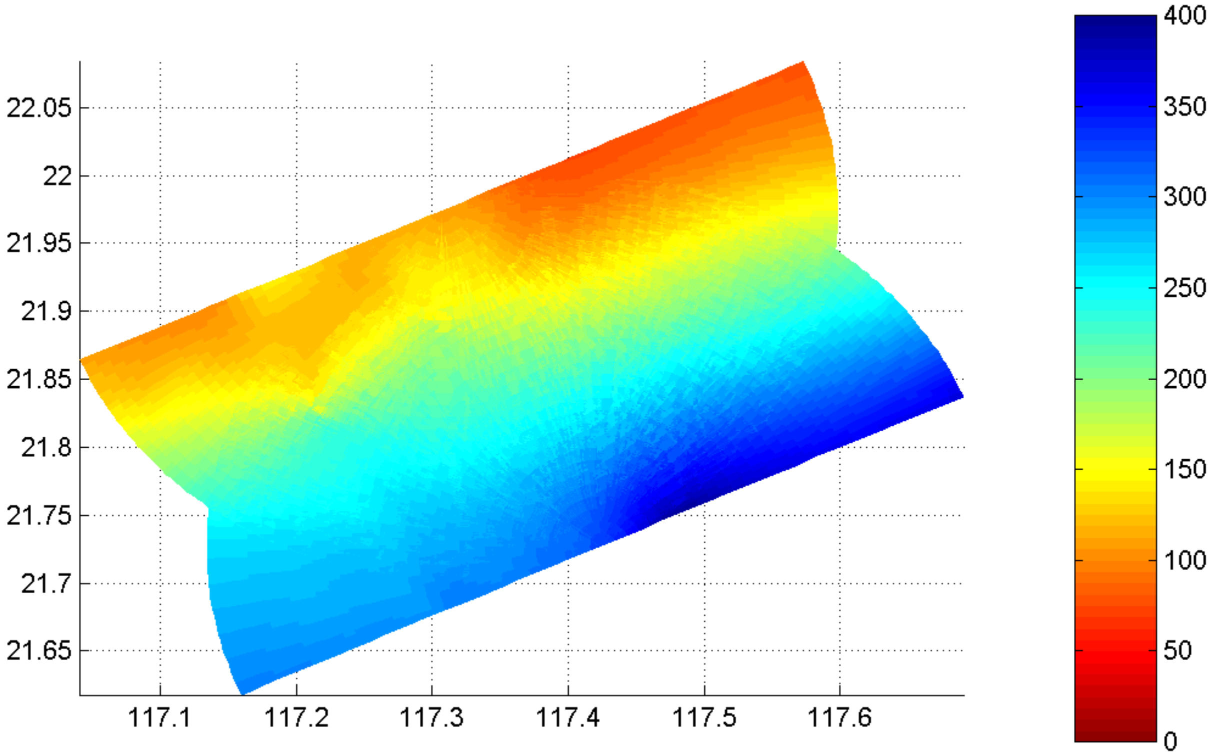

Figure 2. Topography of calculation area for simulation set 1.

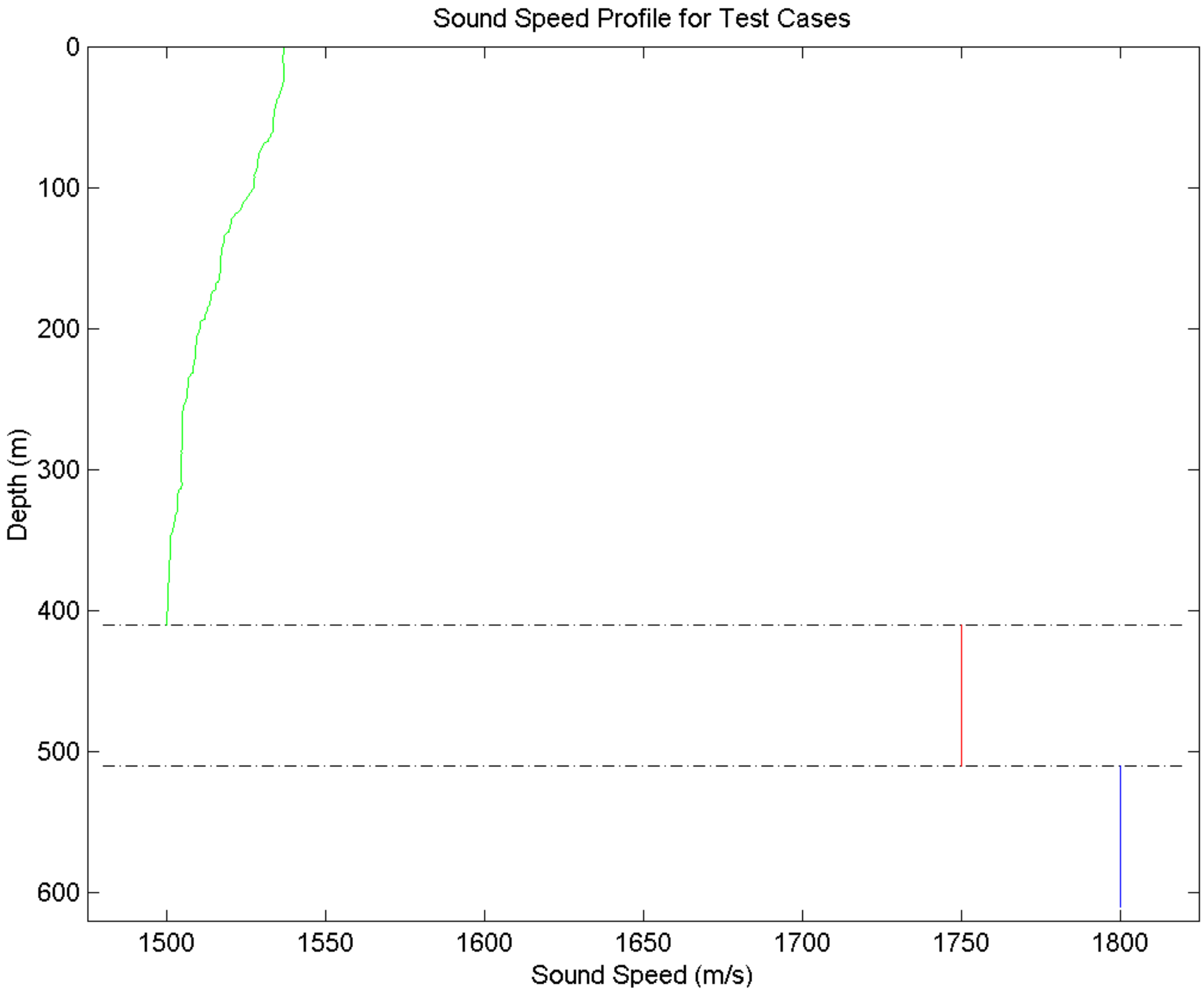

Figure 3. Sound speed profile for simulation set 1.

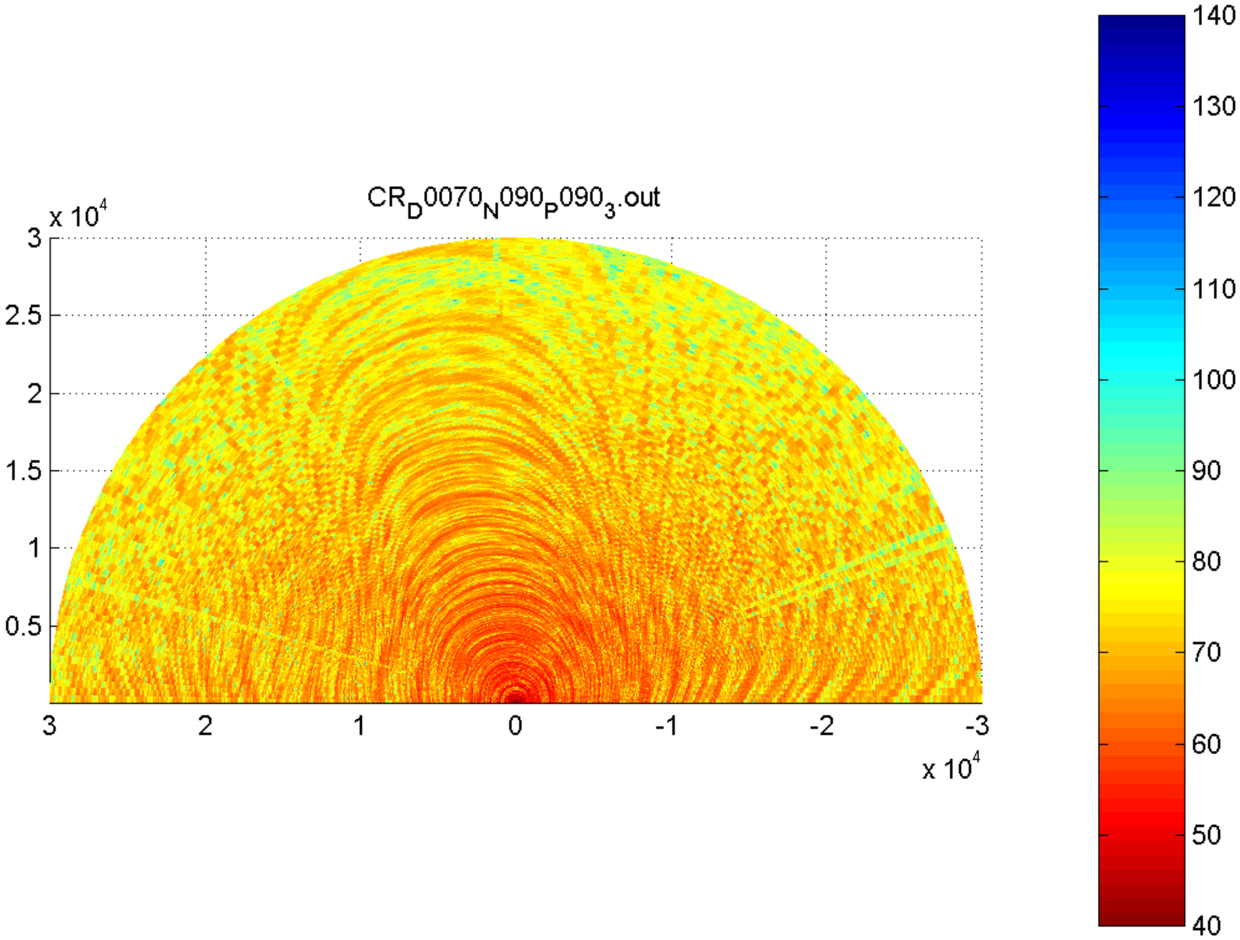

Fig 4 (a) Case A – TL contour of 3D solution at depth of 70 m.

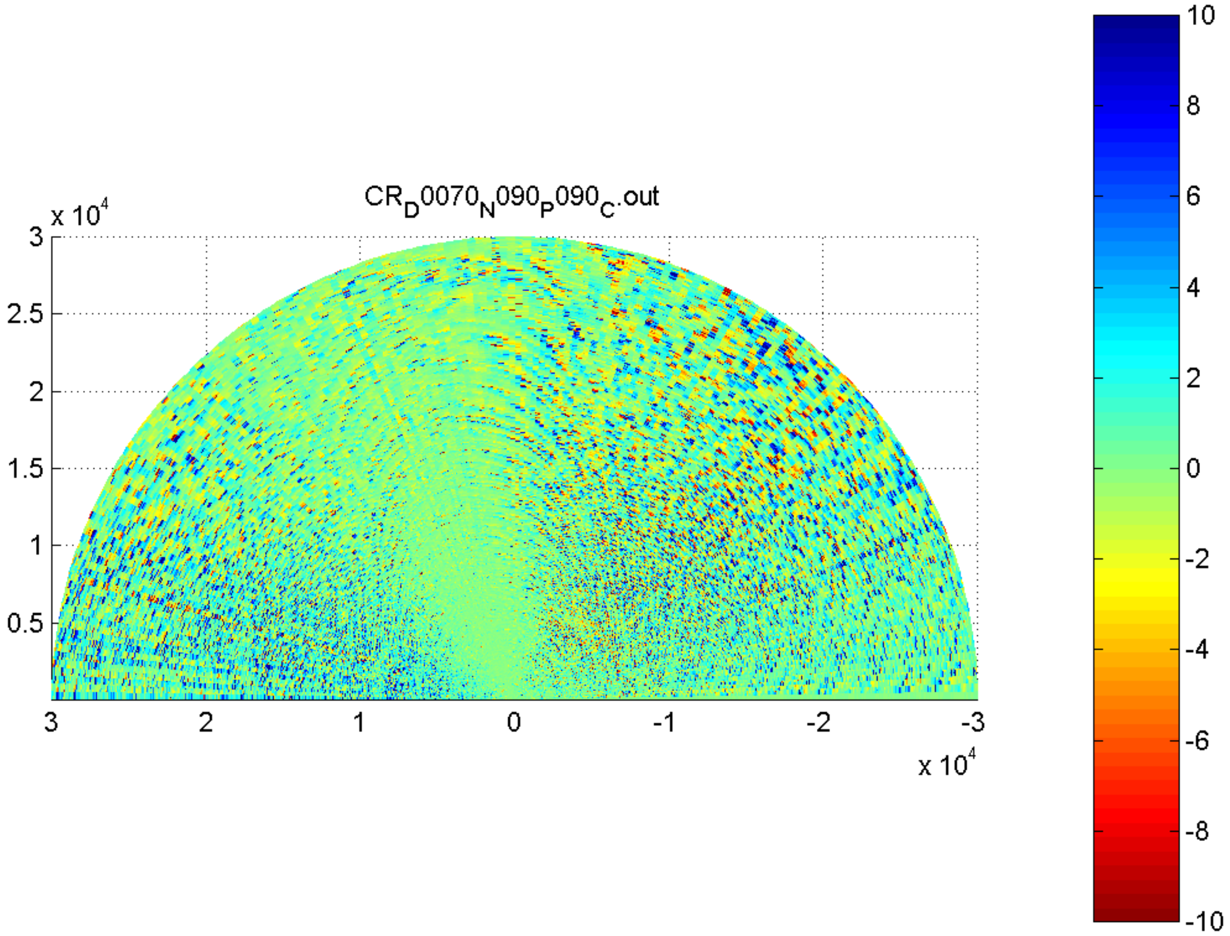

Fig 4 (b) Case A – Contour of TL difference between 3D and Nx2D solution at depth of 70 m.

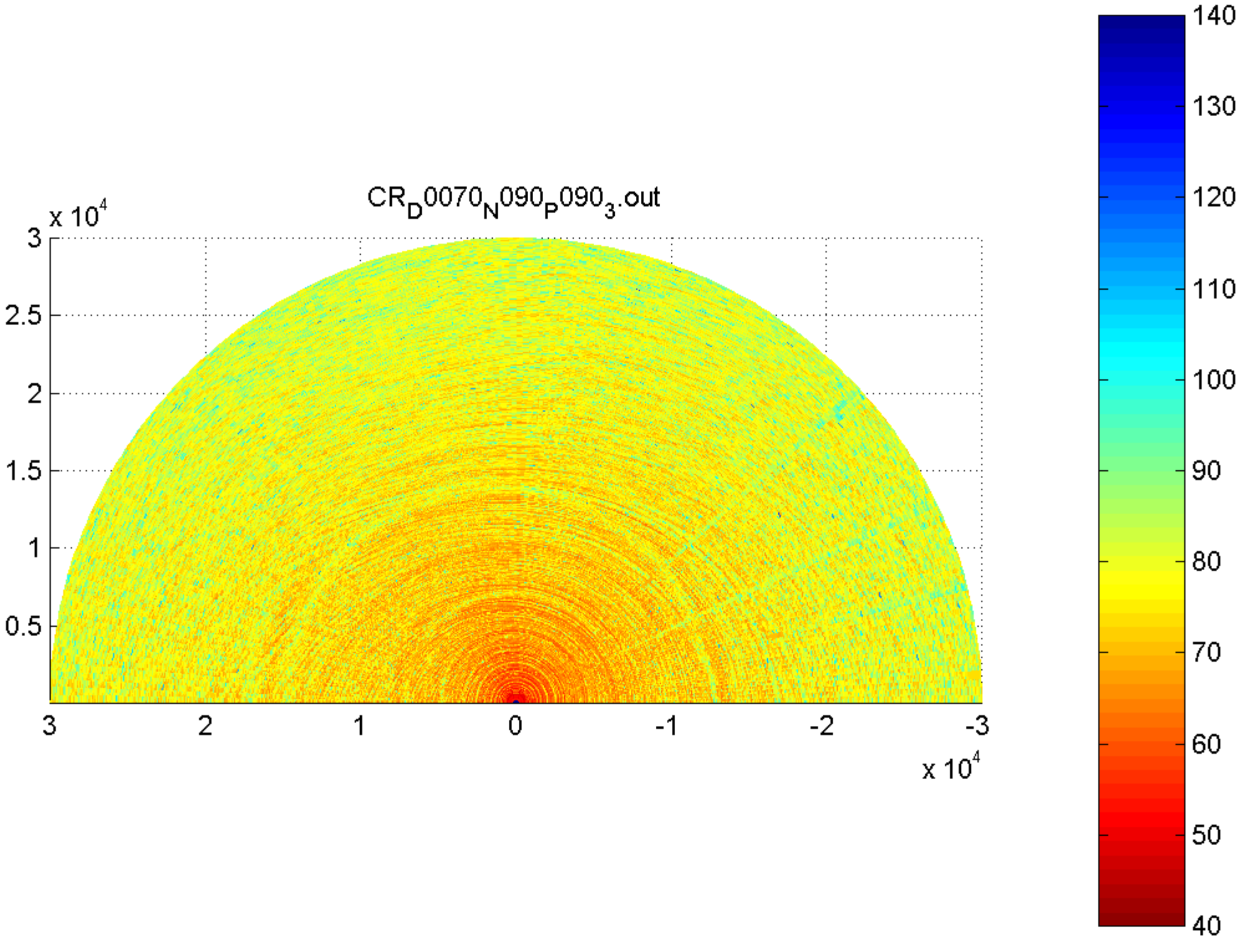

Fig 5 (a) Case B – TL contour of 3D solution at depth of 70 m.

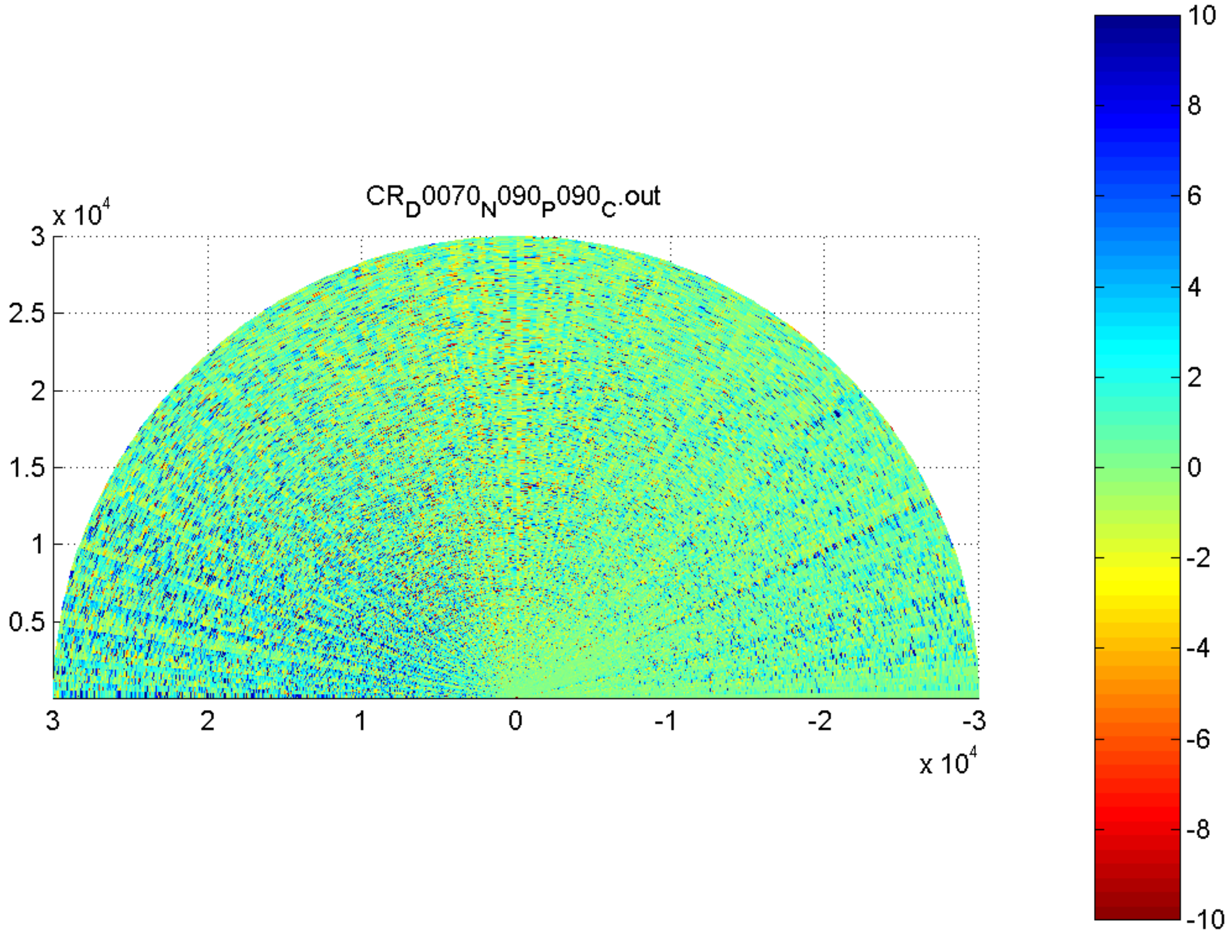

Fig 5 (b) Case B – Contour of TL difference between 3D and Nx2D solution at depth of 70 m.

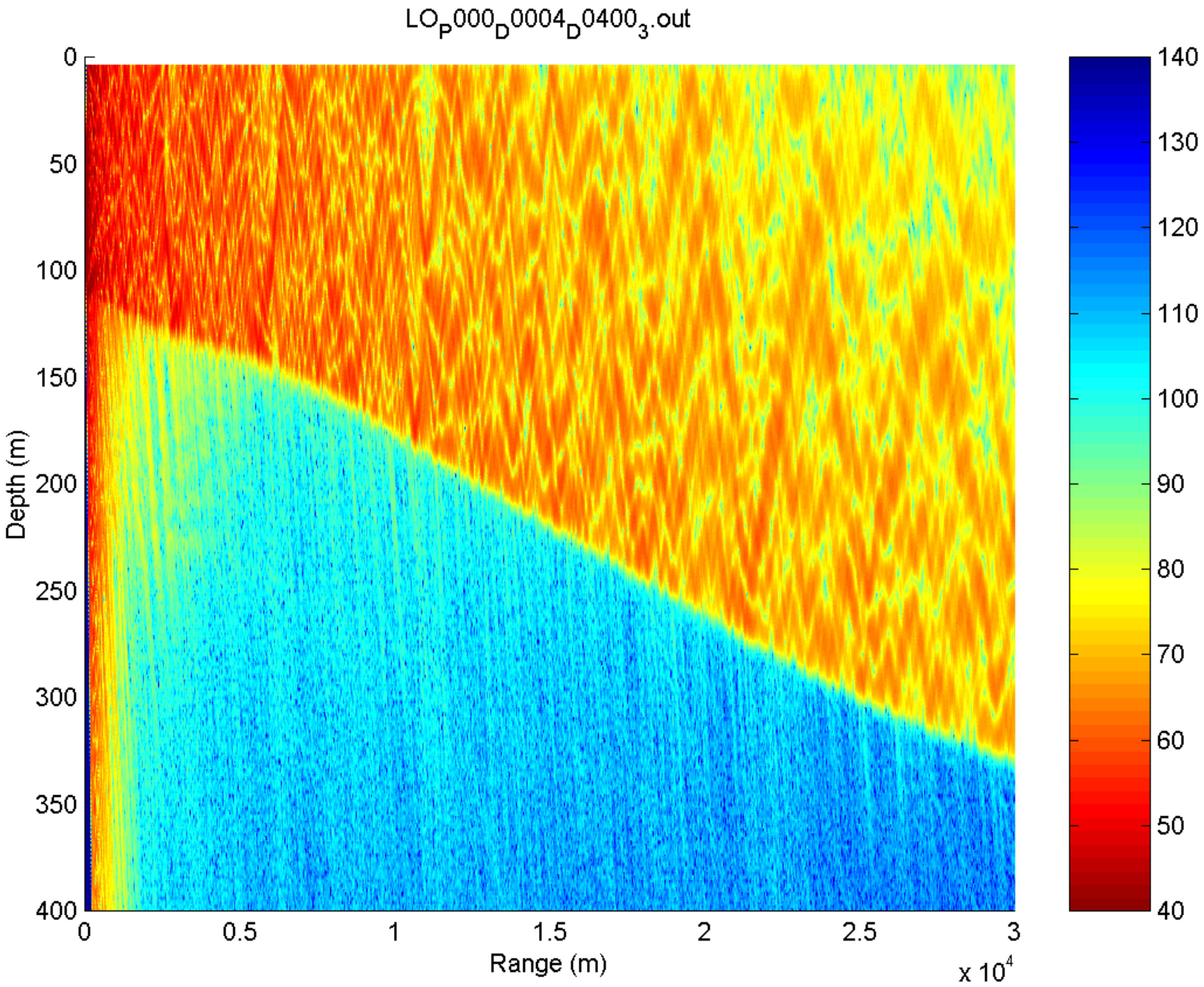

Fig 6 (a) Case A – TL contour of 3D solution at 0 deg.

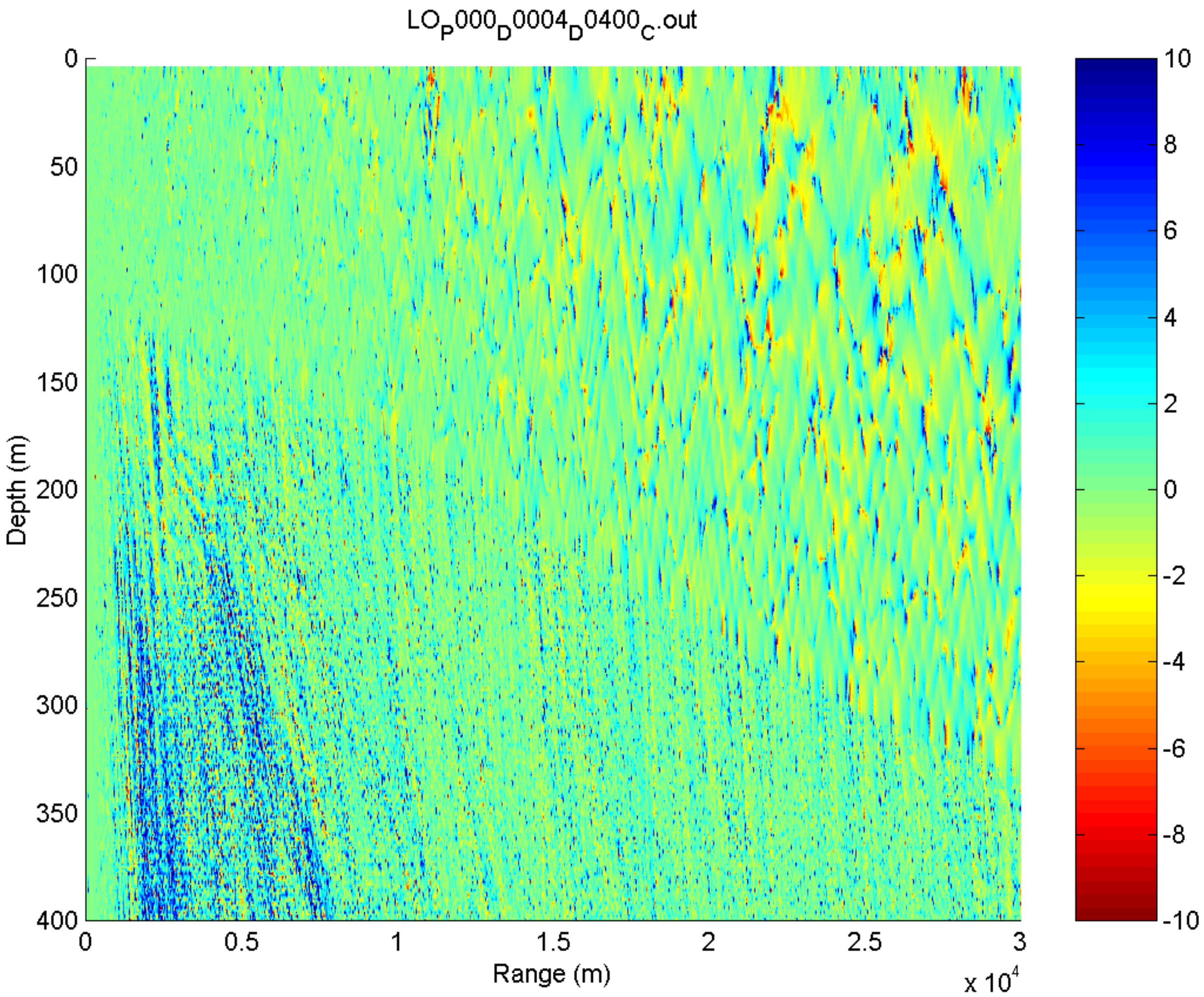

Fig 6 (b) Case A – Contour of TL difference between 3D and Nx2D solution at 0 deg.

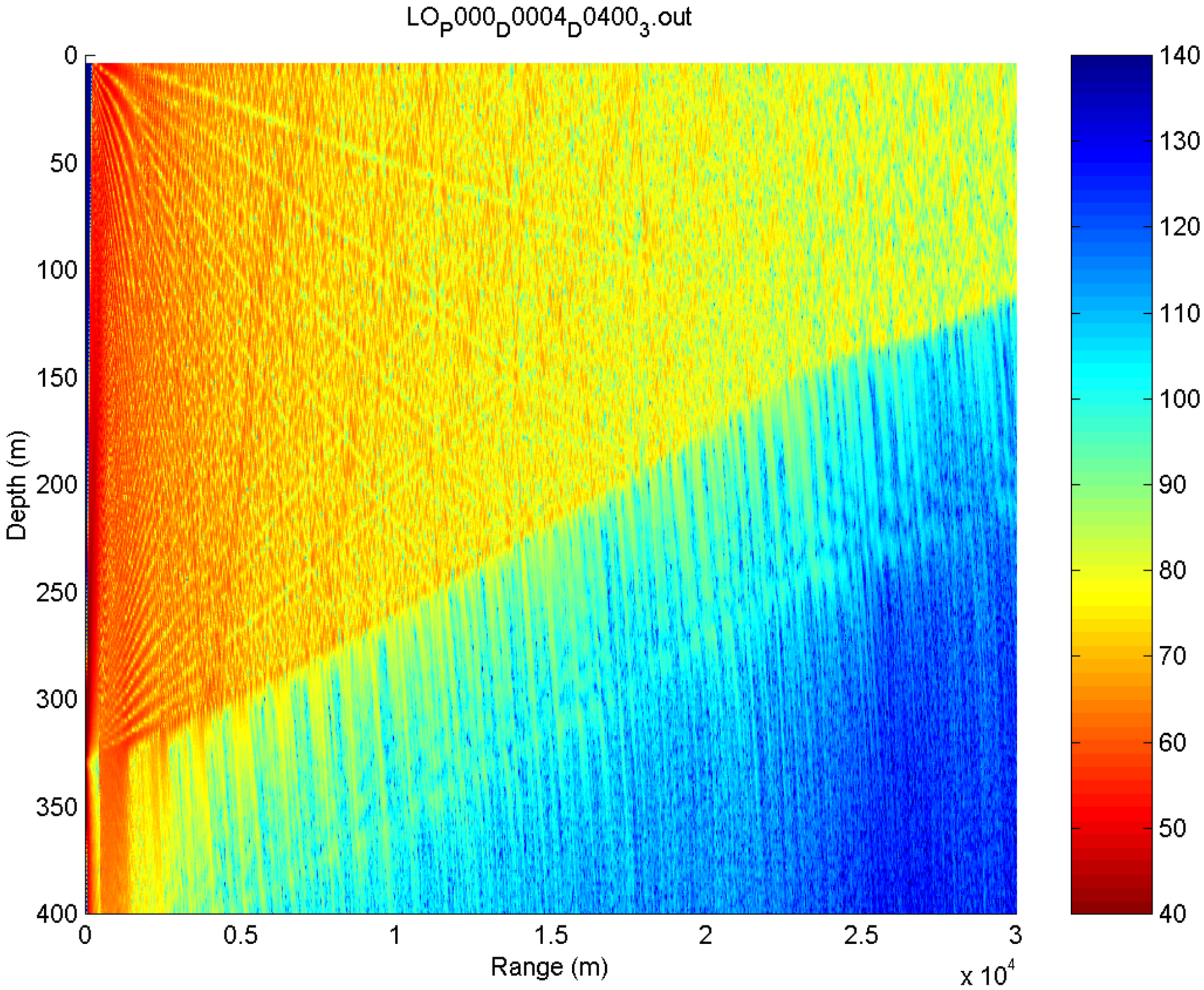

Fig 7 (a) Case B – TL contour of 3D solution at 0 deg.

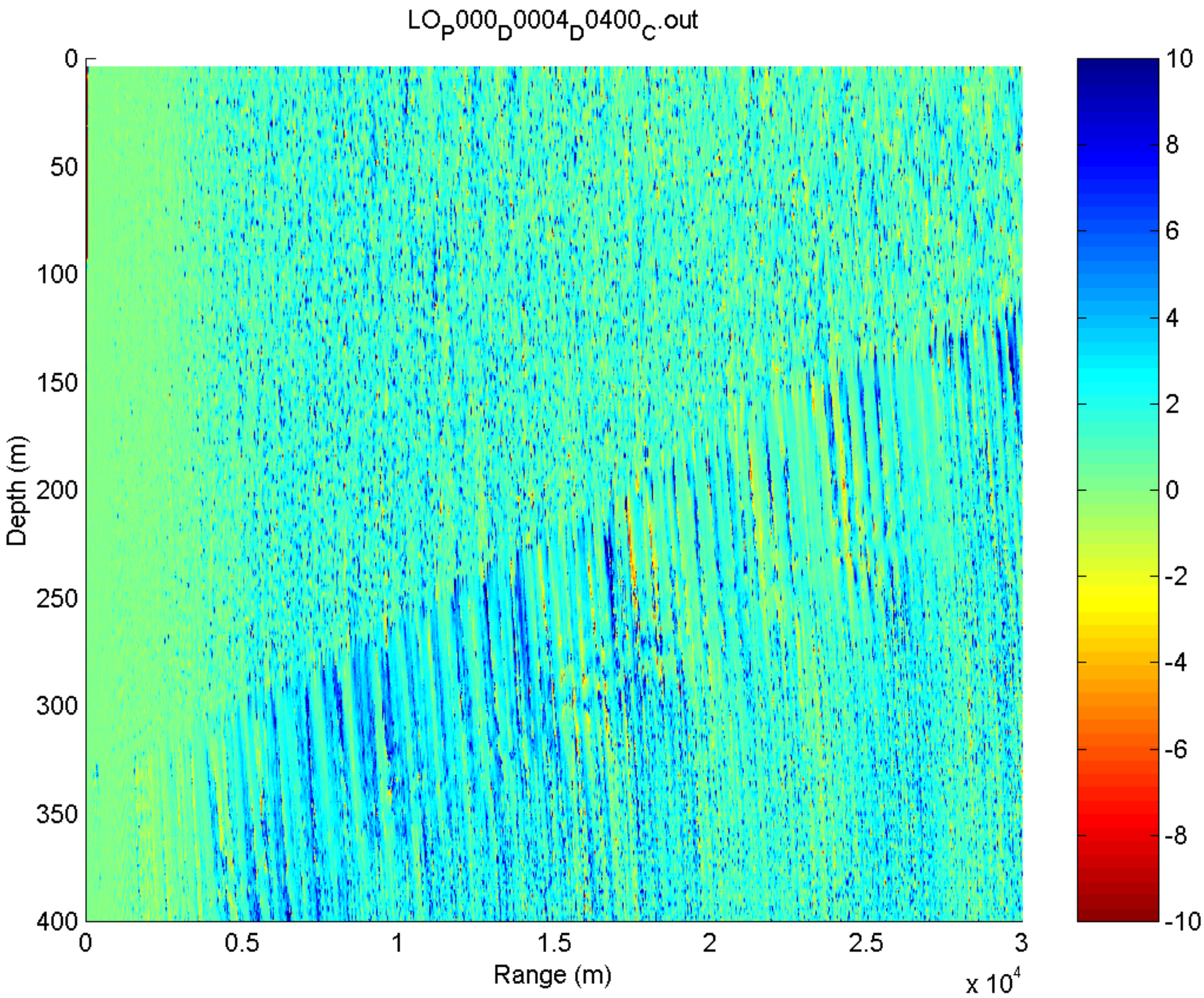

Fig 7 (b) Case B – Contour of TL difference between 3D and Nx2D solution at 0 deg.

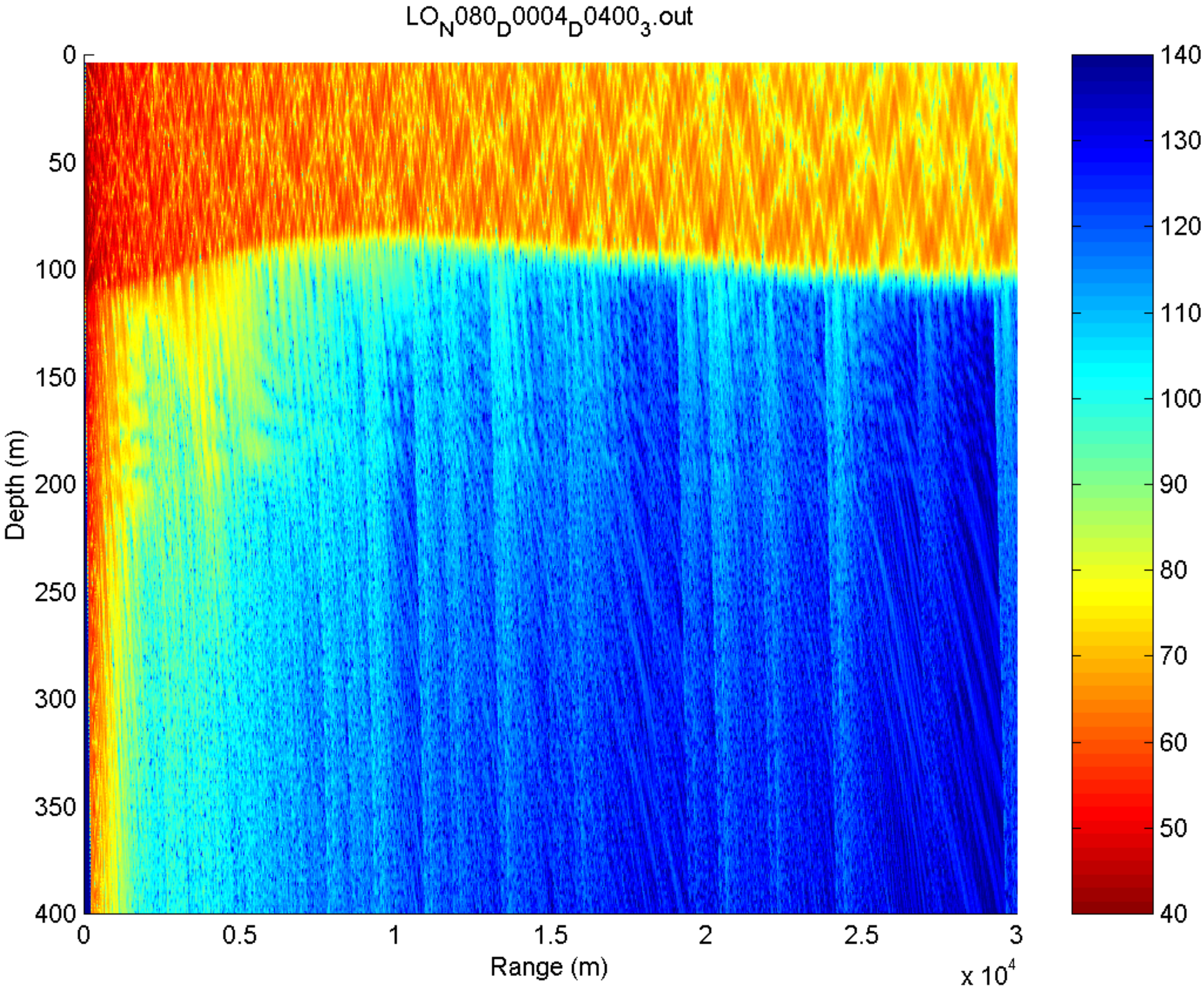

Fig 8 (a) Case A – TL contour of 3D solution at -80 deg.

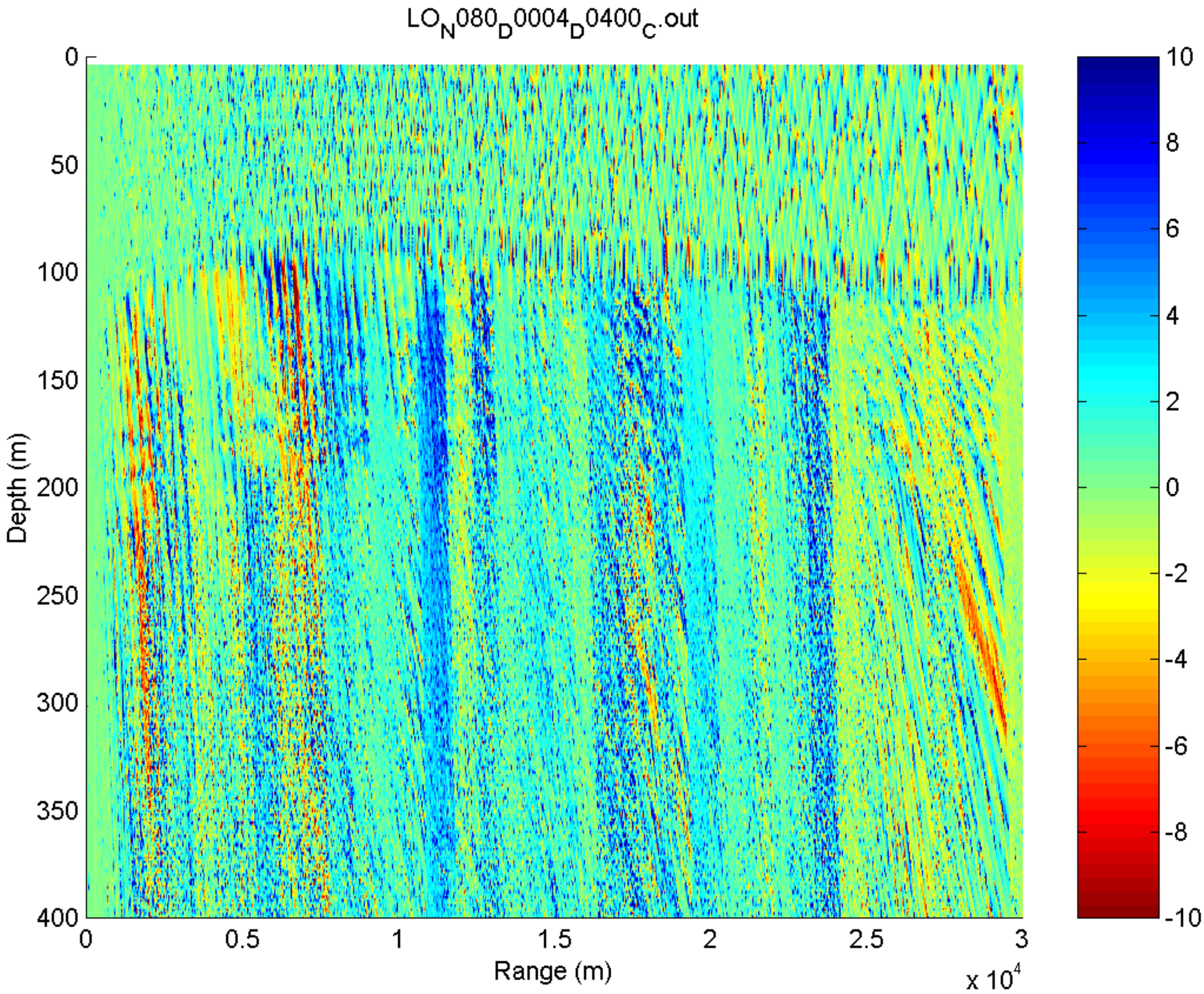

Fig 8 (b) Case A – Contour of TL difference between 3D and Nx2D solution at -80 deg.

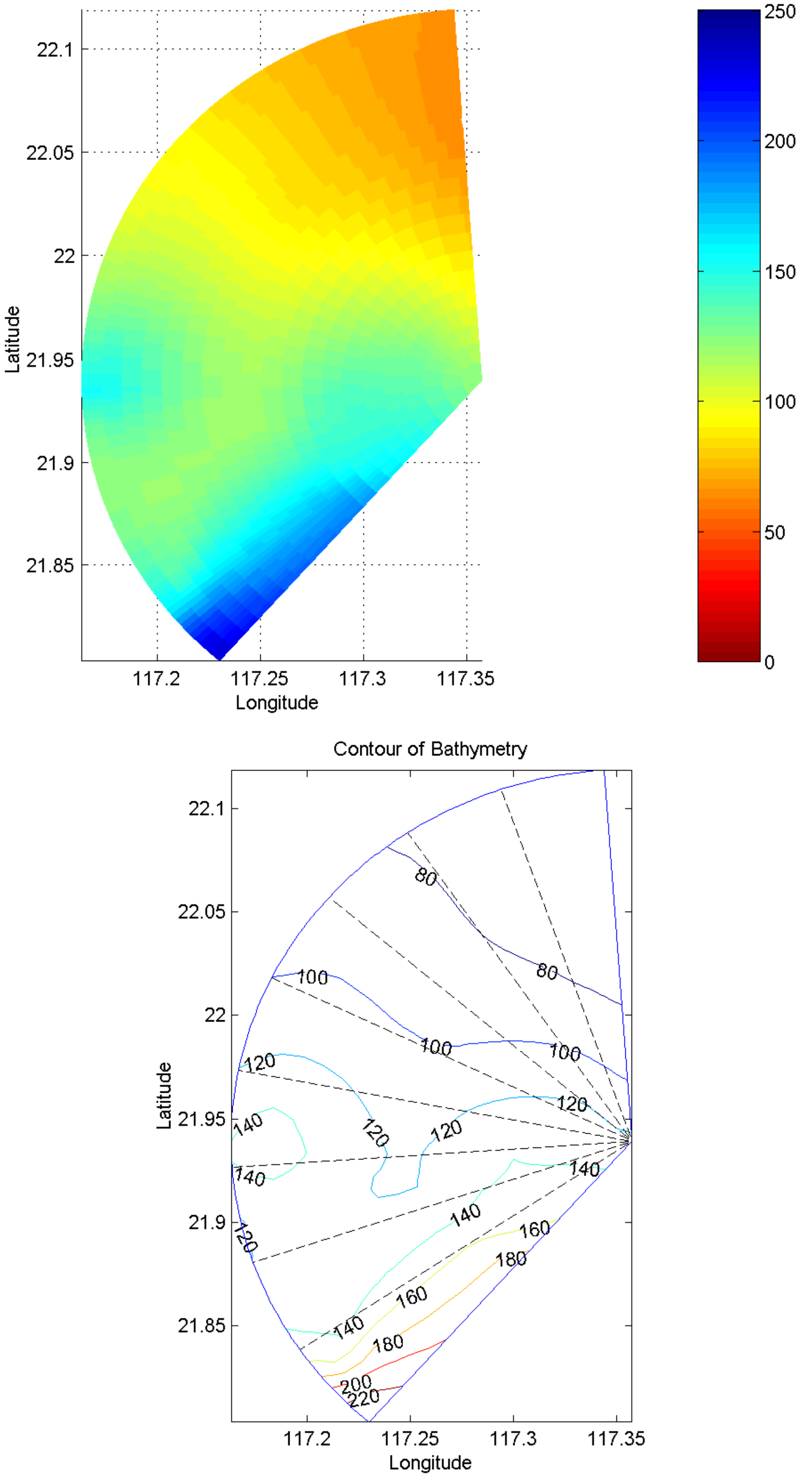

Figure 9. Topography of calculation area for simulation set 2.

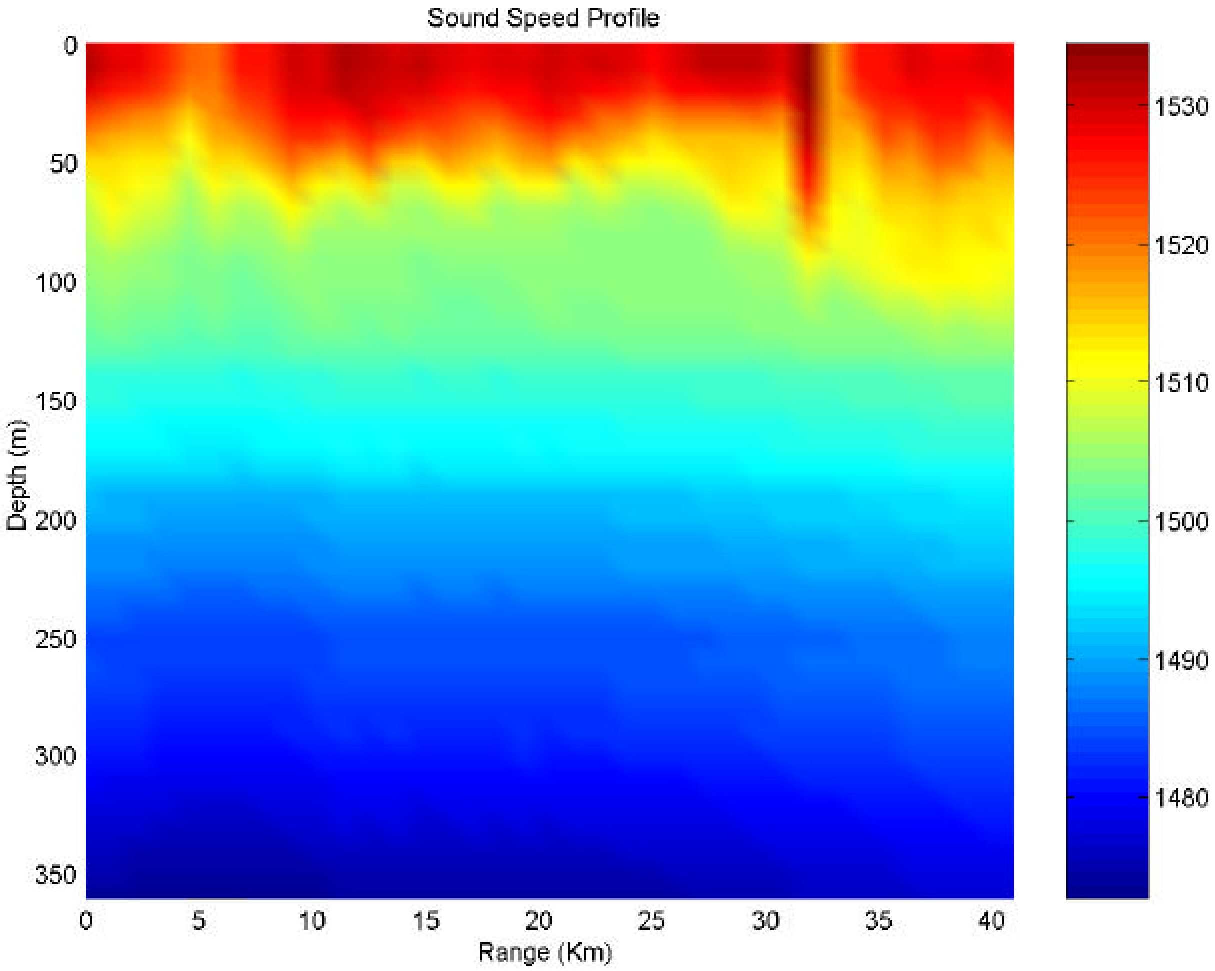

Figure 10. Sound speed profile with internal waves

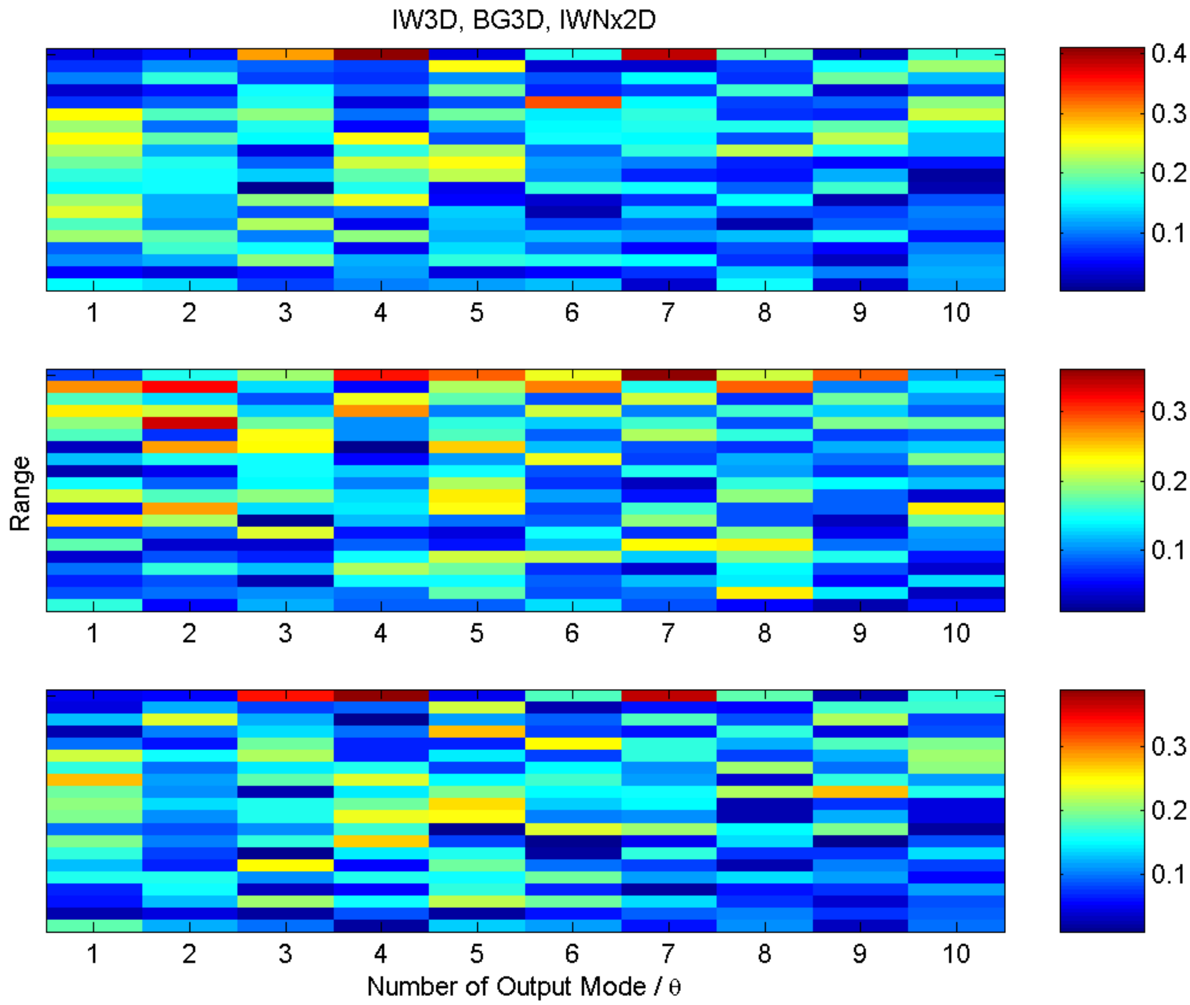

Figure 11. Comparison of the mode coupling matrices between calculation cases.

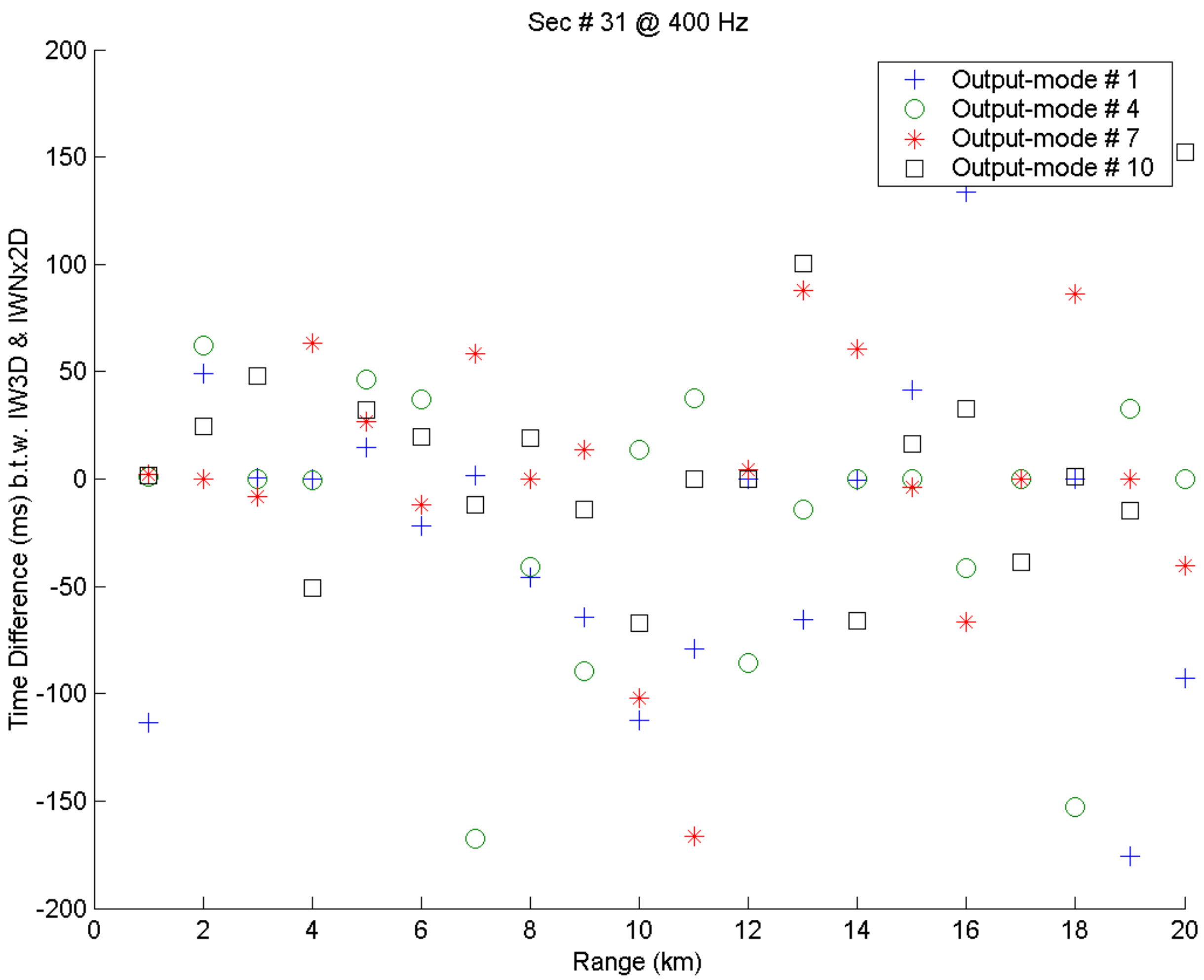

Figure 12. Modal travel time difference between case IW3D and IWNx2D.

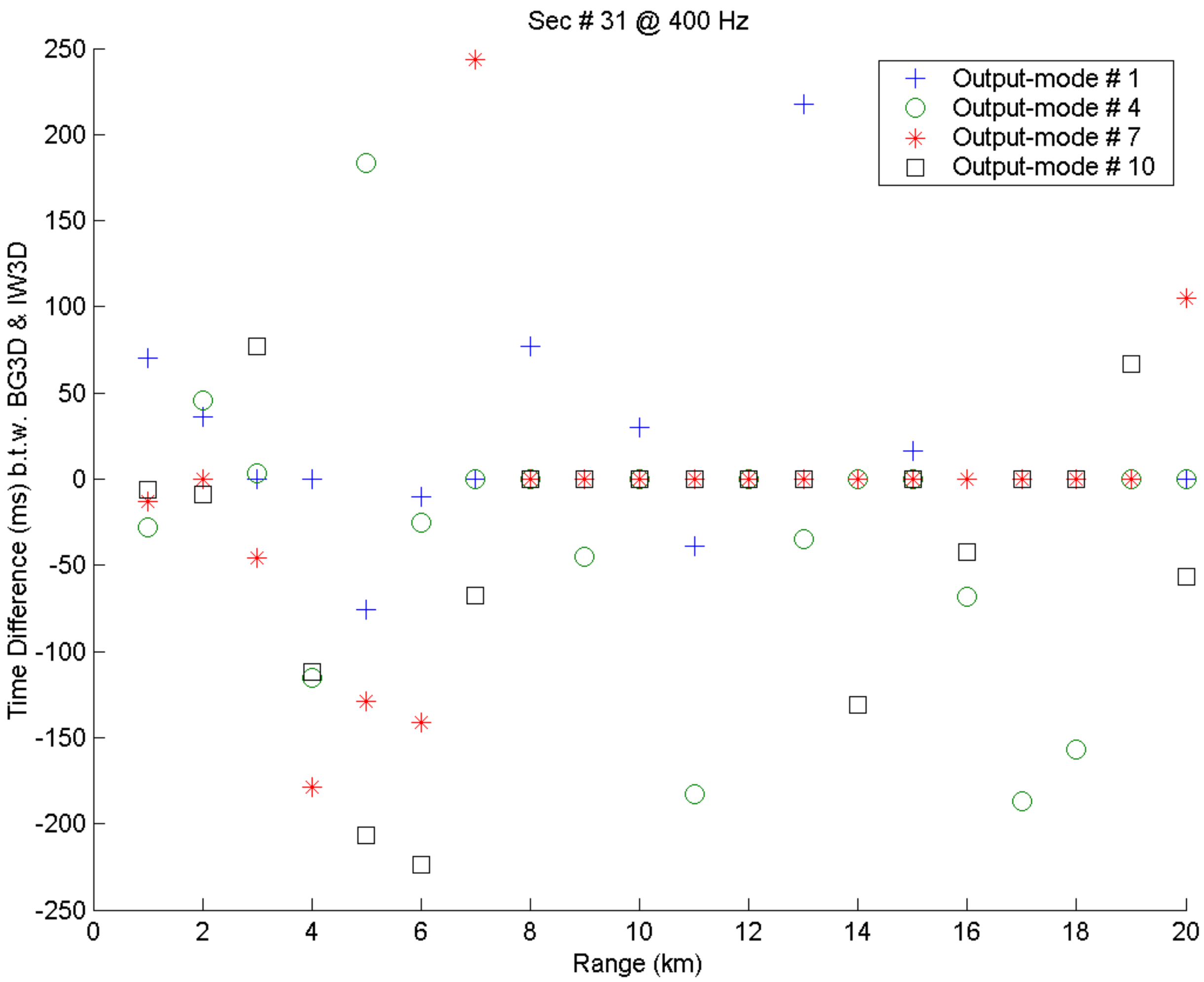

Figure 13. Modal travel time difference between case BG3D and IW3D.