Chapter 4

Seismic Horizon Linking

4.1 Introduction

In this chapter, we solve seismic horizon linking problem using line linking method. Figure 4.1 shows the system of seismic horizon linking. In the first stage, the seismic data would pass through a preprocessing process to find peaks. Then, we fed the seismic data into the network to link patterns. The linked patterns are regarded as seismic horizons. We must to know which peaks compose a horizon. So, we find all peaks from every linking pattern. In the following sections, we will explain preprocessing and pattern search stage. Finally, the experiment results will be shown.

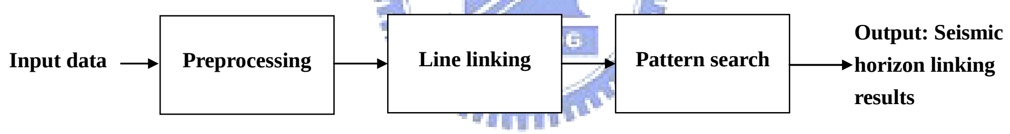


Figure 4.1.System of seismic horizon linking.

4.2 Preprocessing

A seismogram is composed by many 1D seismic traces. Figure 4.2 shows the bright spot seismogram with 64 traces, 512 samples per trace and the sampling interval is 0.004 seconds. Now, we will present every step of preprocessing and demonstrate preprocessing results using Figure 4.2.

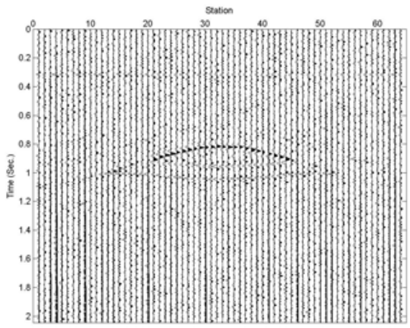


Figure 4.2. Simulated seismogram.

Before we input the seismogram to the network, the seismogram must pass through preprocessing, which includes envelope 、thresholding 、peaking of seismogram and compression in the vertical time-axis direction [8]. Figure 4.3 shows the block diagram of preprocessing step.

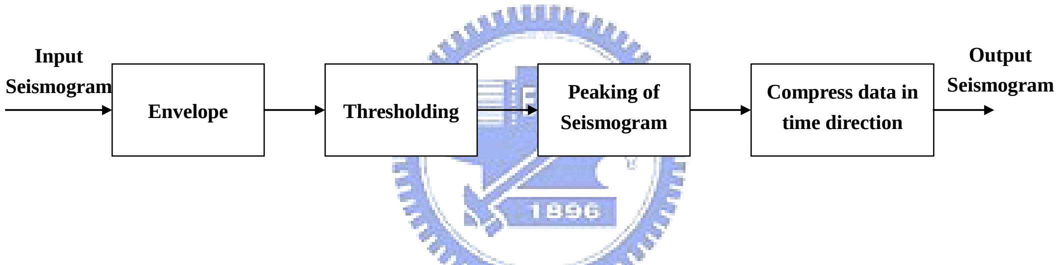


Figure 4.3. Preprocessing steps of Seismic data.

A. Envelope

The envelope describes the outer shape of the wavelet. Defined as [9]

Envelope: $A(t) = \sqrt{s^2(t) + \bar{s}^2(t)}$

where $s(t)$ is the signal function and $\bar{s}(t)$ is the Hilbert transform of $s(t)$. Take every trace to do envelope, we can get the outer shape of the wavelet shown in Figure 4.4.

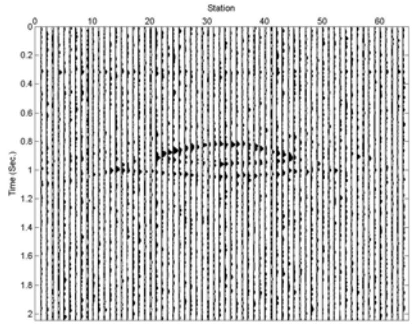


Figure 4.4. The envelope result of Figure 4.2.

B. Threasholding

For envelope result, Figure 4.4, $S(x,t)\,(1 \le x \le 64\,, 1 \le t \le 512)$, we set a threshold T such that $S(x_i\,, t_i) \ge T$, i=1, 2, …, n, where n is the number of the preprocessed data. Figure 4.5 illustrate concept of thresholding.

Figure 4.5. Concept of thresholding

Figure 4.6 shows the threasholding result, here we set $T = 0.5$.

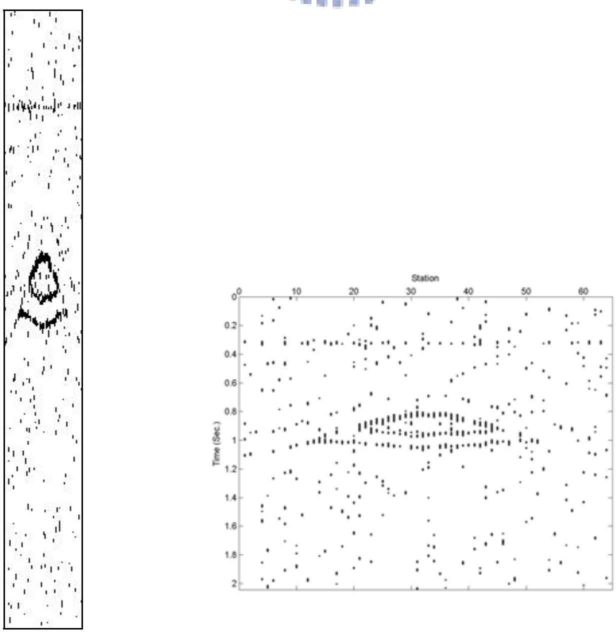


Figure 4.6.Threasholding result.

C. Peaking the seismogram

We can see that the threasholding result is a vertical line segment for a peak. Next, we choose peaks in a vertical line segment. The result is shown in Figure 4.7.

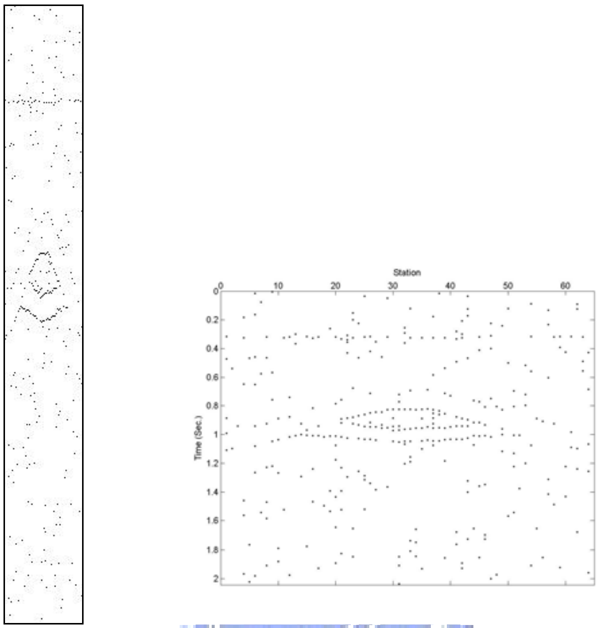


Figure 4.7. Result of peaking the seismogram.

D. Compression in the vertical time-axis direction

Because the distance of one peak and neighboring peak may be large. It is difficult in line linking. We can find a number n. For every trace, n samples are grouped as one peak. If there is any peak in the group, the point is set to 1 else set to 0. If there are over two peaks in a group, the peak can not recover at the final result. So we use the force algorithm to find the best n. Initially, n set to 1, then we increase n and choice the maximum n that makes every group only has one peak. Figure 4.8 shows the compression result, we choose $n = 4$.

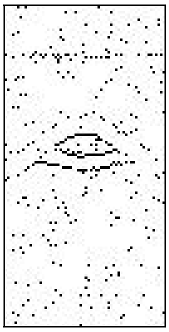


Figure 4.8. Compression result.

4.3 **Pattern Search**

We explain line linking process in chapter 2 and 3. In this section, we explain how to find peaks in a pattern. We consider a linked pattern as a tree, then trace all points in a pattern and keep point if it is a peak [10]. Suppose that each node has eight children, namely its eight neighbors. The order of children is shown in Figure 4.9.

1	2	3
8	Node	4
7	6	5

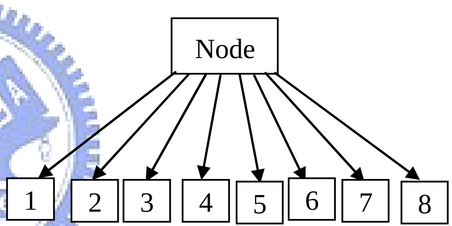


Figure 4.9.A 3×3 image transfer to a tree structure.

First, we must find a node as root. We search an image from top to bottom and left to right. We set the first node as root and start to trace linked points. The trace algorithm is shown below.

Trace algorithm：

1. Find first node (root) by searching an image from top to bottom and left to right. Stop trace algorithm if without finding any node from image.
2. Keep node if it is a peak.
3. Find node from eight neighbors which is not checked by searching order.
4. If find node, set the point as the next trace node and go to step 2, else go to step5.

5. If the parent node existence, trace back to parent node and go to step 2, else go to step 6.
6. Output all kept nodes
7. Delete all checked nodes from image and go to step 1.

For example, we design a pattern shows in Figure 4.10. The numbers that write in the nodes denote the node number. The circle points denote the peaks.

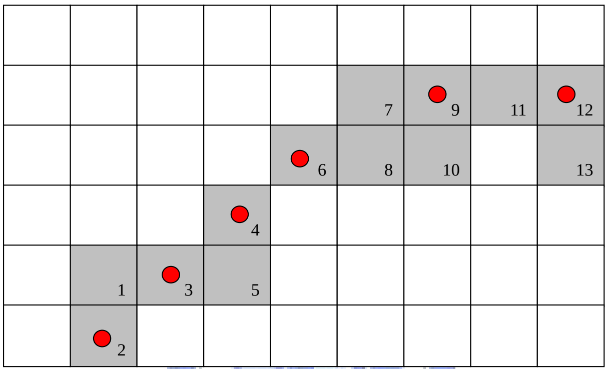
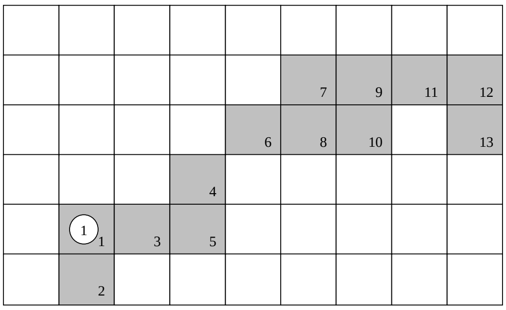


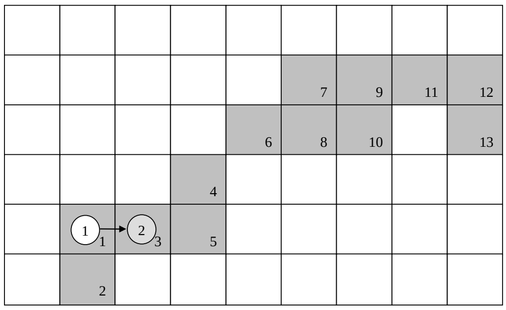
Figure 4.10.A pattern sample.

After searching, we set node 1 is root node. Then we check its eight children and find two nodes which are not checked, node 3 and node 2. Dependent on searching order defined in Figure 4.9, we choose node 3 as the second node and keep node 3 because it is a peak. Next, we consider the node 3 and find three points not checked, node 4, node 5 and node 2. The node 4 will be chosen as the third node. When the node can not finding any unchecked nodes in its eight neighbors. We trace back to its parent node and check eight neighbors of parent node whether it has any child not checked. By this step, we can trace all nodes. Figure 4.11 shows trace process step by step.



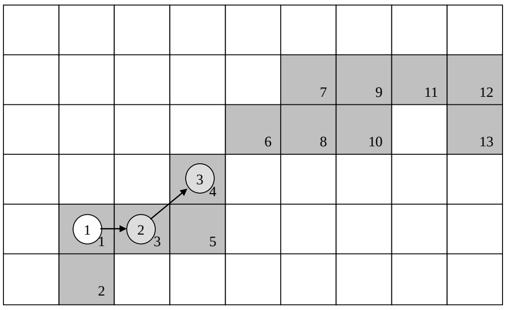
7 9 11 12
6 8 10 13
4
1 1 3 5
2

(1)



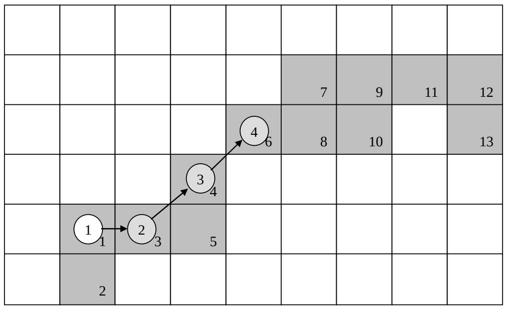
7 9 11 12
6 8 10 13
4
1 1 2 3 5
2

(2)



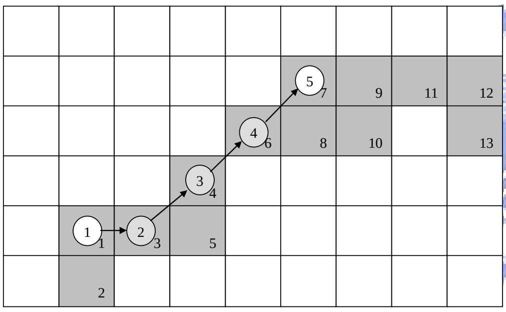
7 9 11 12
6 8 10 13
3 4
1 1 2 3 5
2

(3)



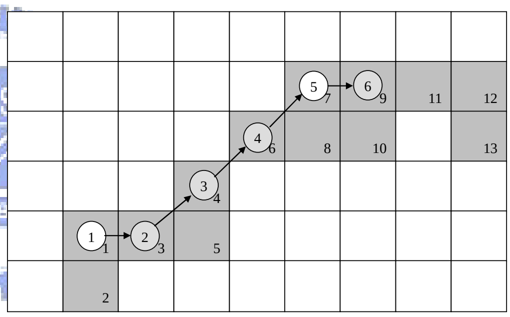
7 9 11 12
4 6 8 10 13
3 4
1 1 2 3 5
2

(4)



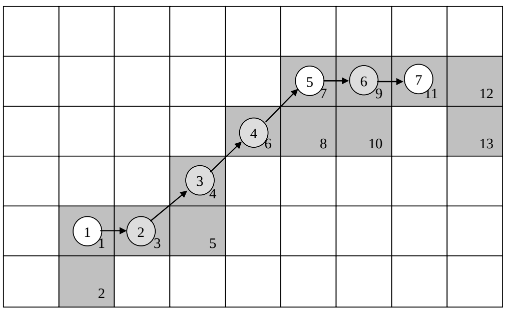
5 7 9 11 12
4 6 8 10 13
3 4
1 1 2 3 5
2

(5)



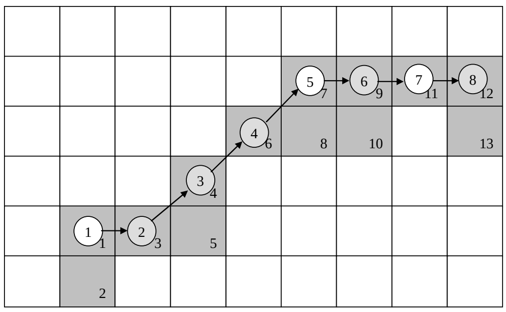
5 7 6 9 11 12
4 6 8 10 13
3 4
1 1 2 3 5
2

(6)



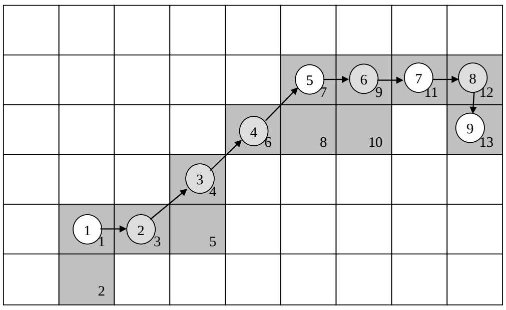
5 7 6 9 7 11 12
4 6 8 10 13
3 4
1 1 2 3 5
2

(7)

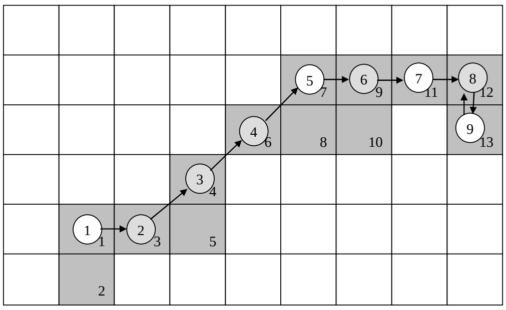


5 7 6 9 7 11 8 12
4 6 8 10 13
3 4
1 1 2 3 5
2

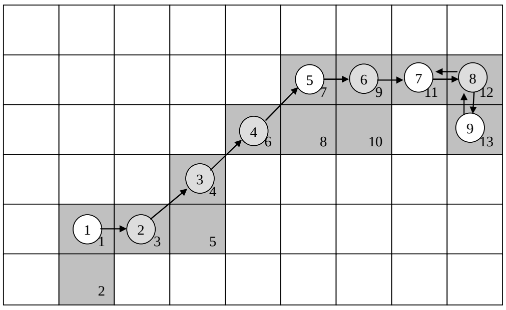
(8)



(9)



(10)



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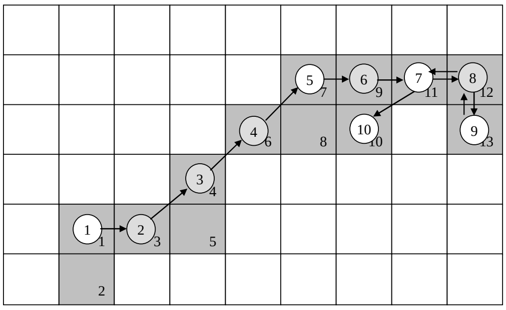

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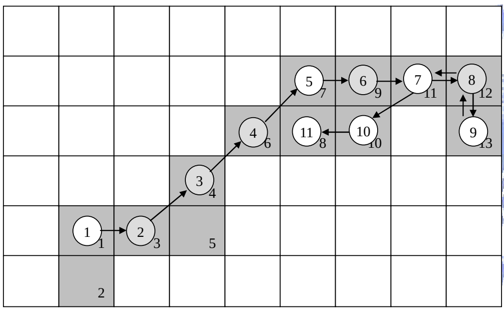

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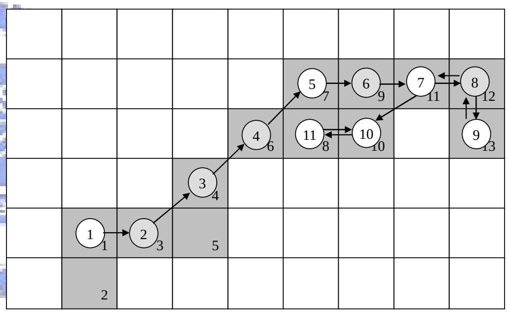

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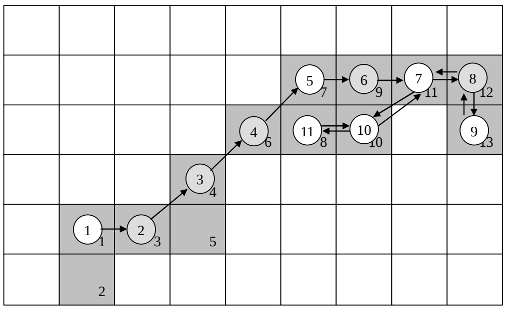

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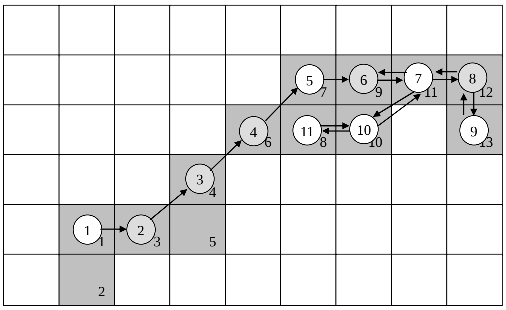

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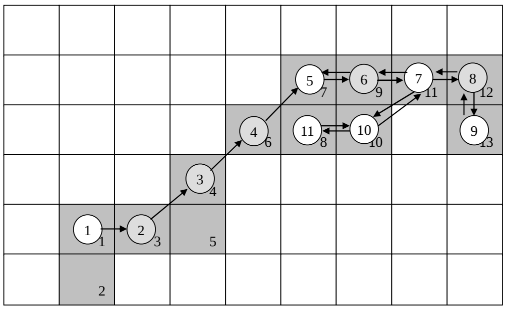	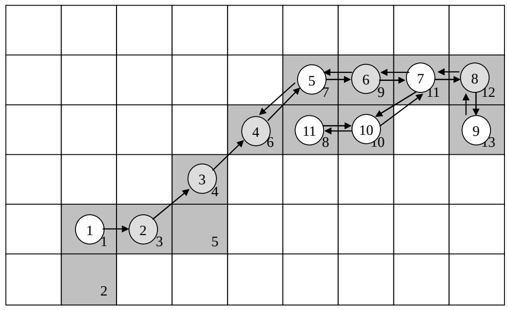
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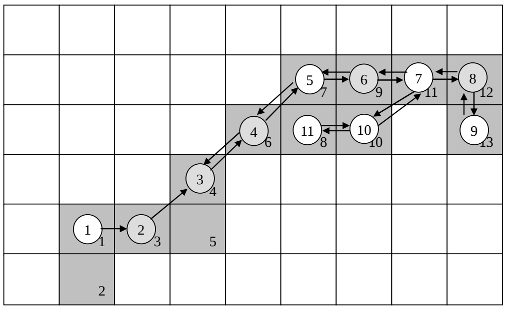
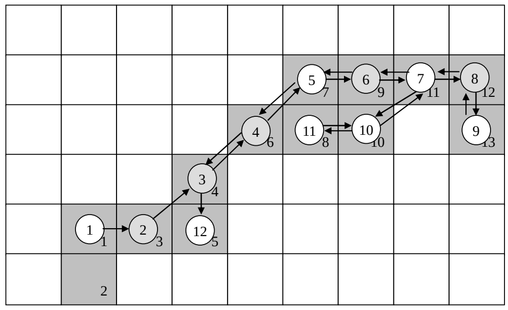
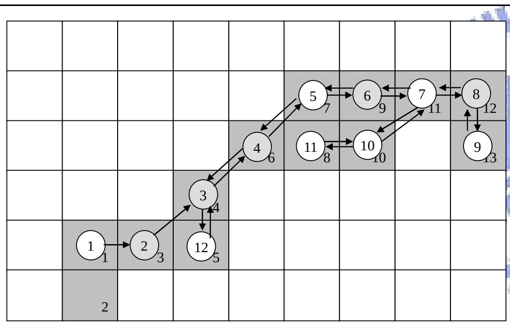
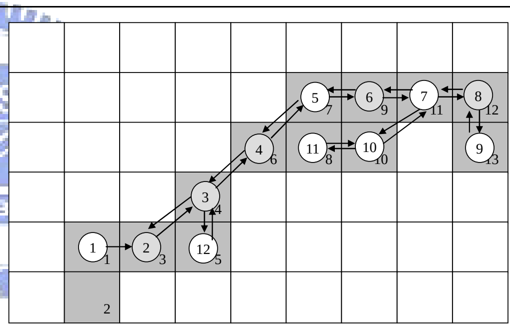
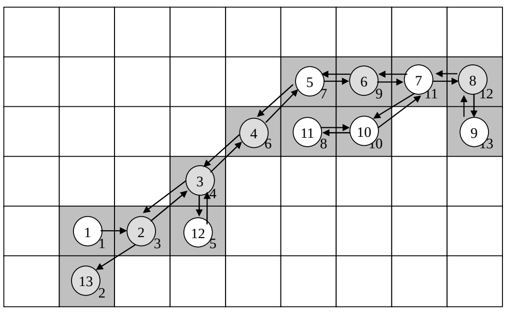
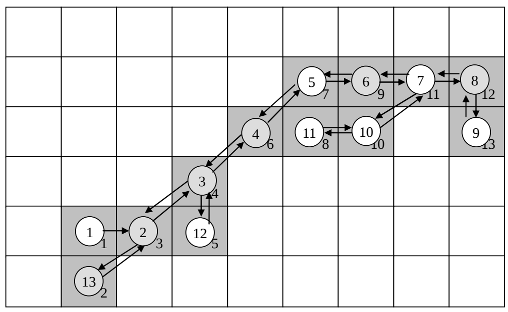
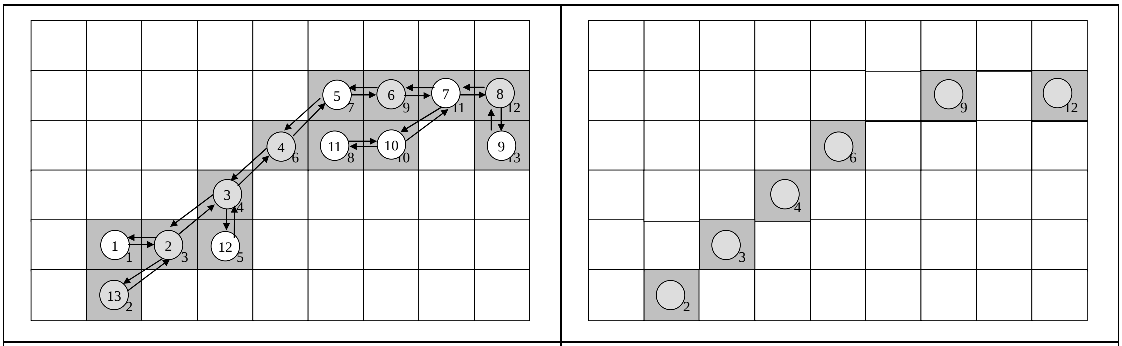
	
(19)	(20)
	
(21)	(22)
	
(23)	(24)



(25) (26)

Figure 4.11.Trace process.

When all points in a pattern had checked, we output all kept peaks. These peaks denote a horizon in a seismogram.

Remove noise from seismogram

After line linking process is finished, we find horizons by pattern search. Here we set a Min-Peaks to decide the minimum peaks that a horizon should contain. For example, we set Min-peaks is 3, this means if a linked pattern contains peaks less than 3, consider them as noise, and delete them.

4.4 Experiments

In this section, we show eight experiment results. Each experiment divide by three parts including preprocessing, line linking and pattern search. The first four experiments we use connectionist model with 1-neighborhood that explain in chapter 2 to do experiment and the last four experiments we use model with large neighborhood that explain in chapter 3.

Experiment I

The one-shot simulated seismogram shown in Figure 4.12 is 512×64 with 64 traces and has 512 points in one trace. The sampling rate is 0.004 seconds.

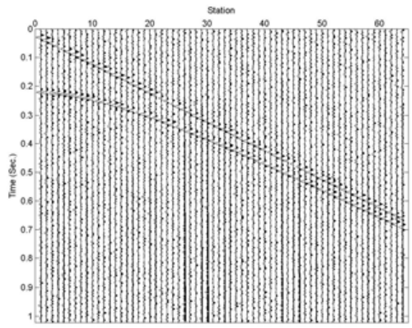


Figure 4.12. Simulated Seismogram.

Part I: Preprocessing

The Preprocessing result is shown in Figure 4.13 which includes envelope, thresholding, peaking and compression result.

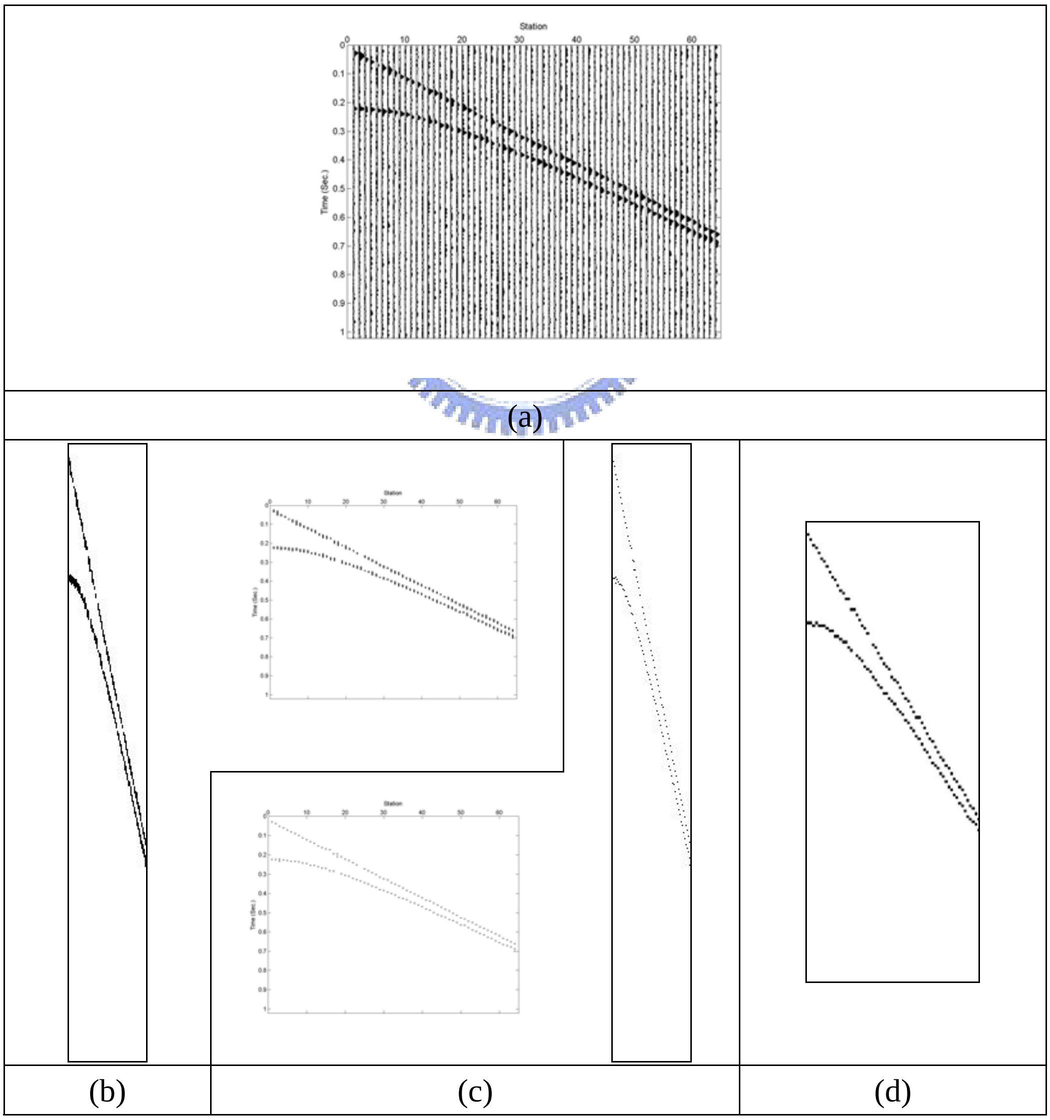


Figure 4.13.Preprocessing results (a) envelope, (b) thresholding, (c) peaking, (d) compression result, compression number $n = 3$.

Part II: Line linking

We set the parameters as $w_{ij} = 1 \ \forall i, j$, $w_s = 1.2$, state number of each PE $n = 16$ and stop constraint $\varepsilon = 1$ in this experiment. The update process is shown in Figure 4.14.

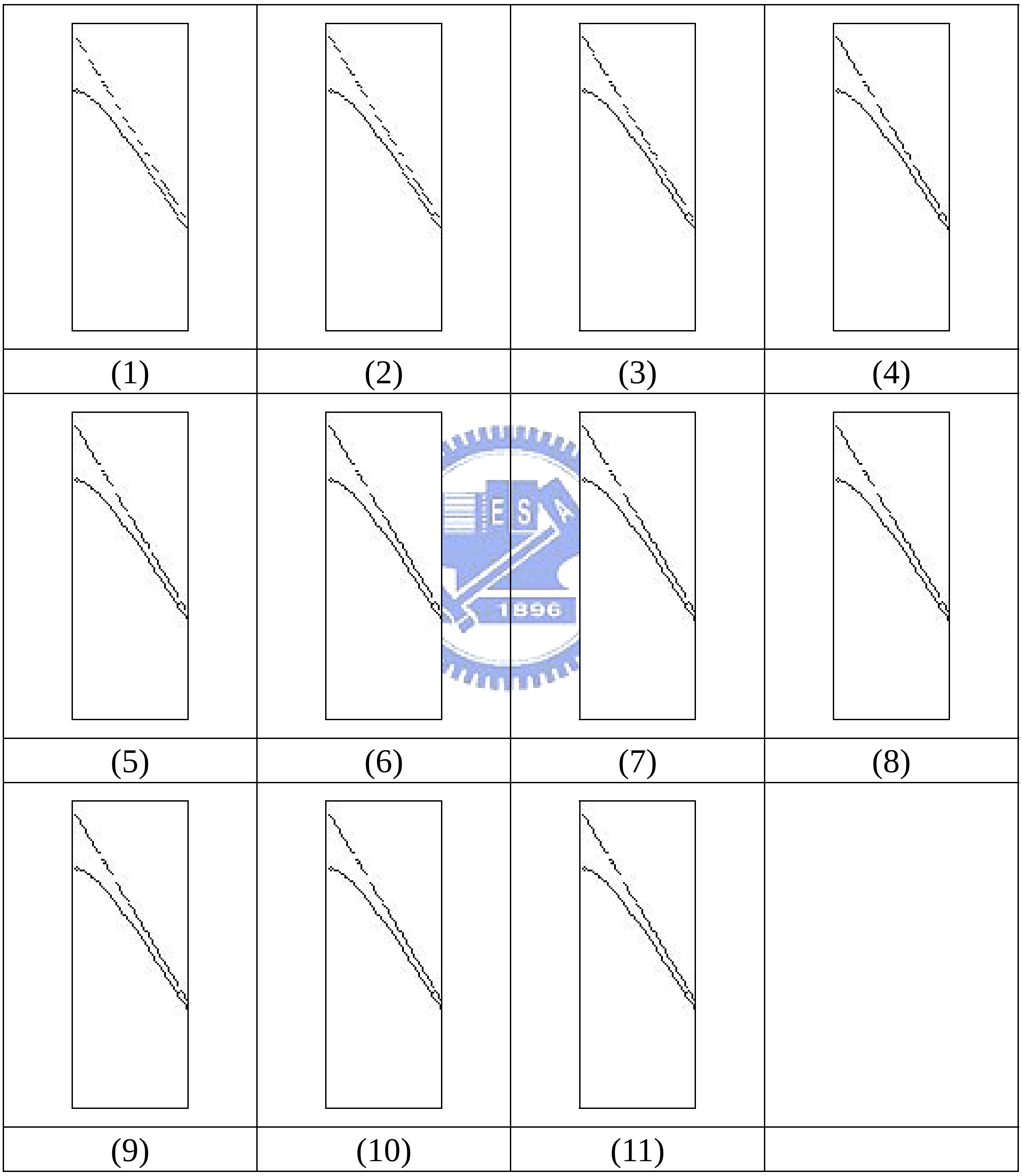
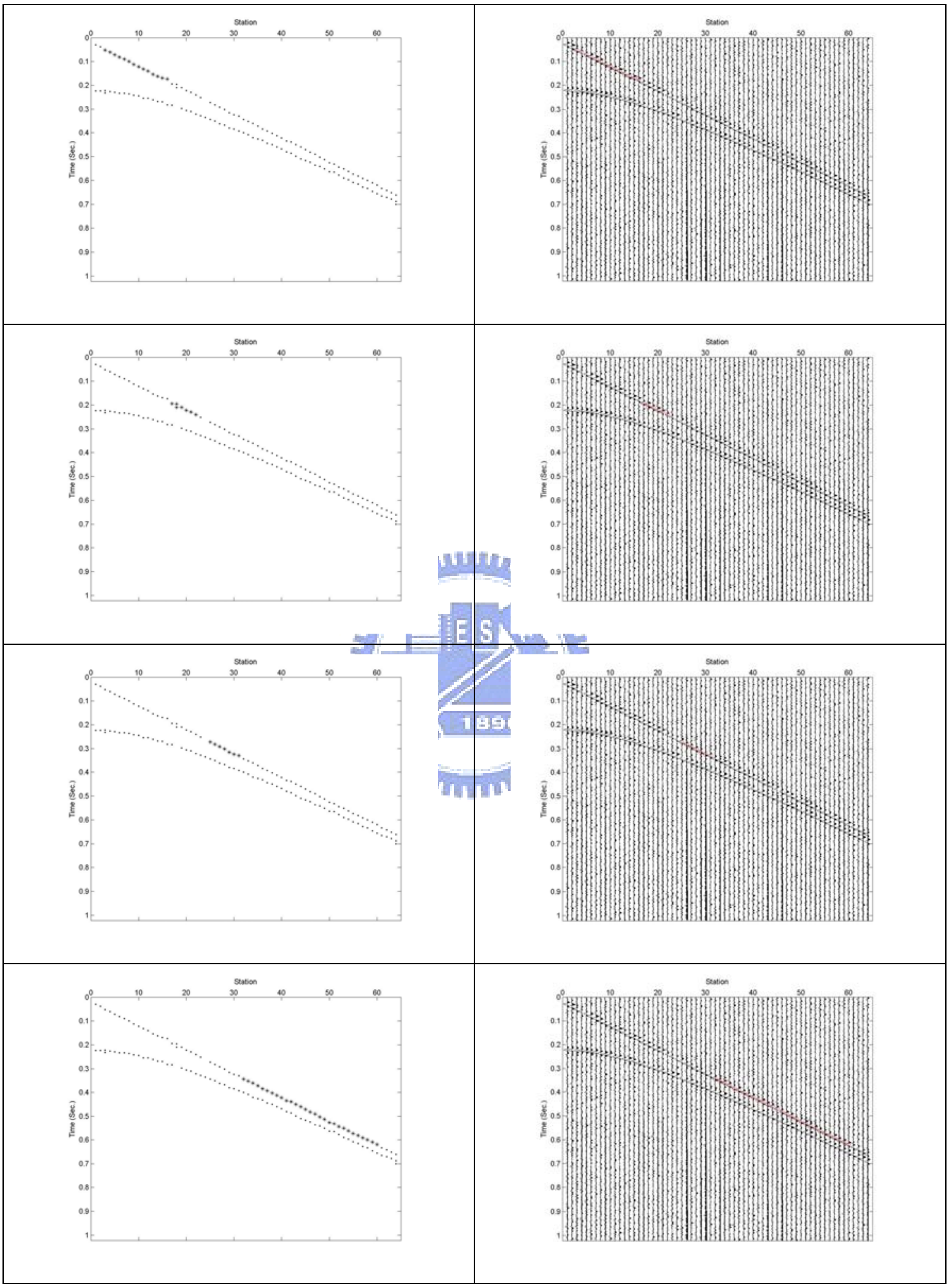


Figure 4.14. Update process from $t = 1$ to $t = 11$

Part III: Pattern search

In this part, all horizons that have been detected will be shown. Figure 4.15 shows the pattern search results. The left picture shows all peaks after preprocessing and the thick dots denote the detected horizon. We draw the detected horizon on the original seismogram.



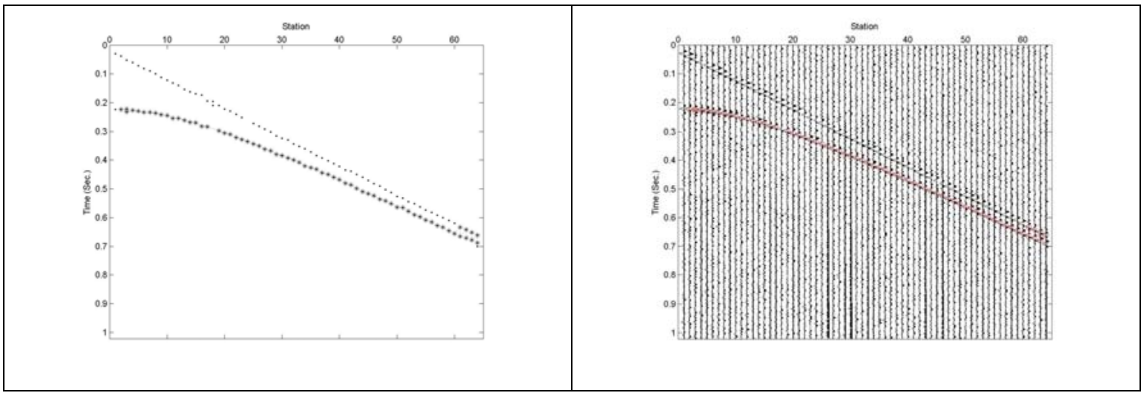


Figure 4.15.Pattern search results.

Experiment II

The real seismogram shown in Figure 4.16 is 3100×48 which is the Canadian Artic's seismic data with 48 traces and has 3100 points in one trace. The sampling rate is 0.002 seconds. We obtain the data from Seismic Unix System developed by Colorado School of Mine.

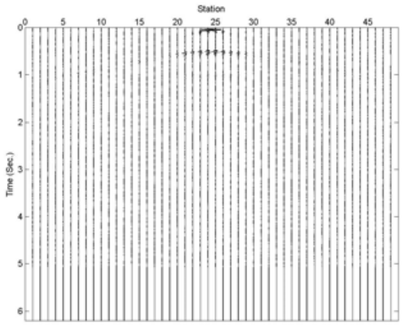


Figure 4.16. Real Seismogram.

Part I: Preprocessing

The Preprocessing result is shown in Figure 4.17 which includes envelope, thresholding, peaking and compression result.

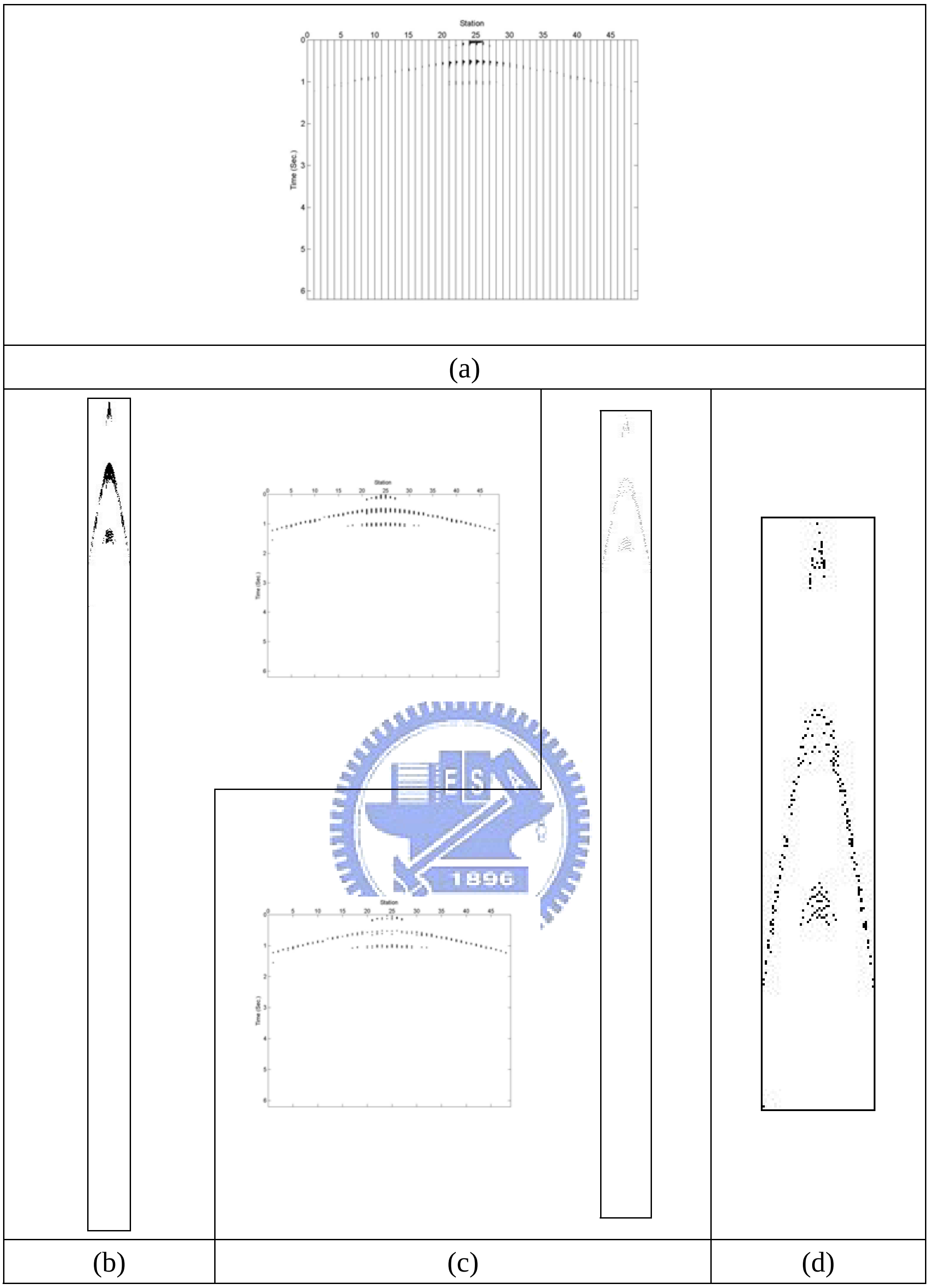


Figure 4.17.Preprocessing results (a) envelope, (b) thresholding, (c) peaking, (d) compression result, compression number $n = 3$.

Part II: Line linking

We set the parameters as $w_{ij} = 1 \ \forall i, j$, $w_s = 1$, state number of each PE $n = 16$ and stop constraint $\varepsilon = 1$ in this experiment. The update process is shown in Figure 4.18.

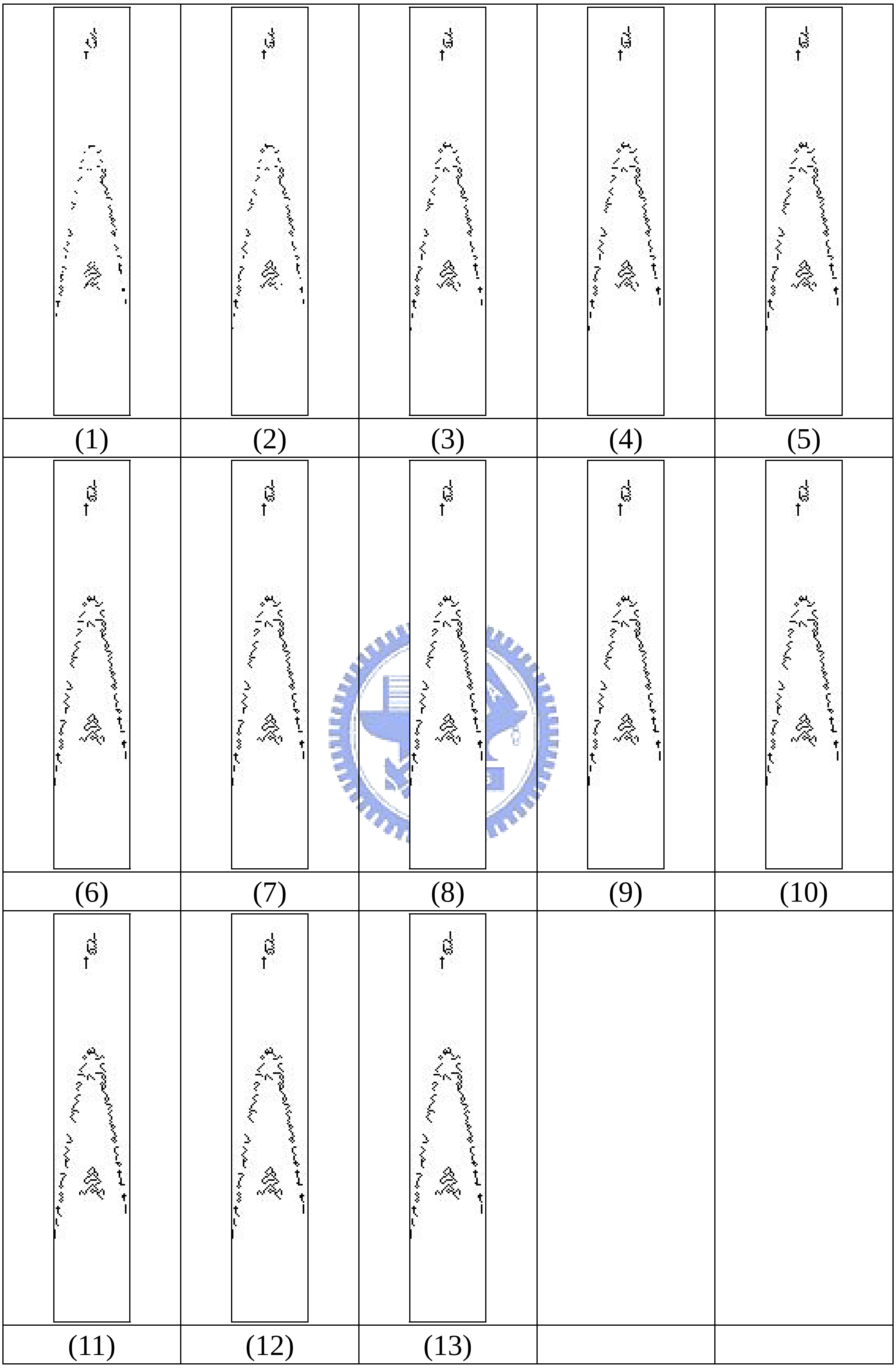
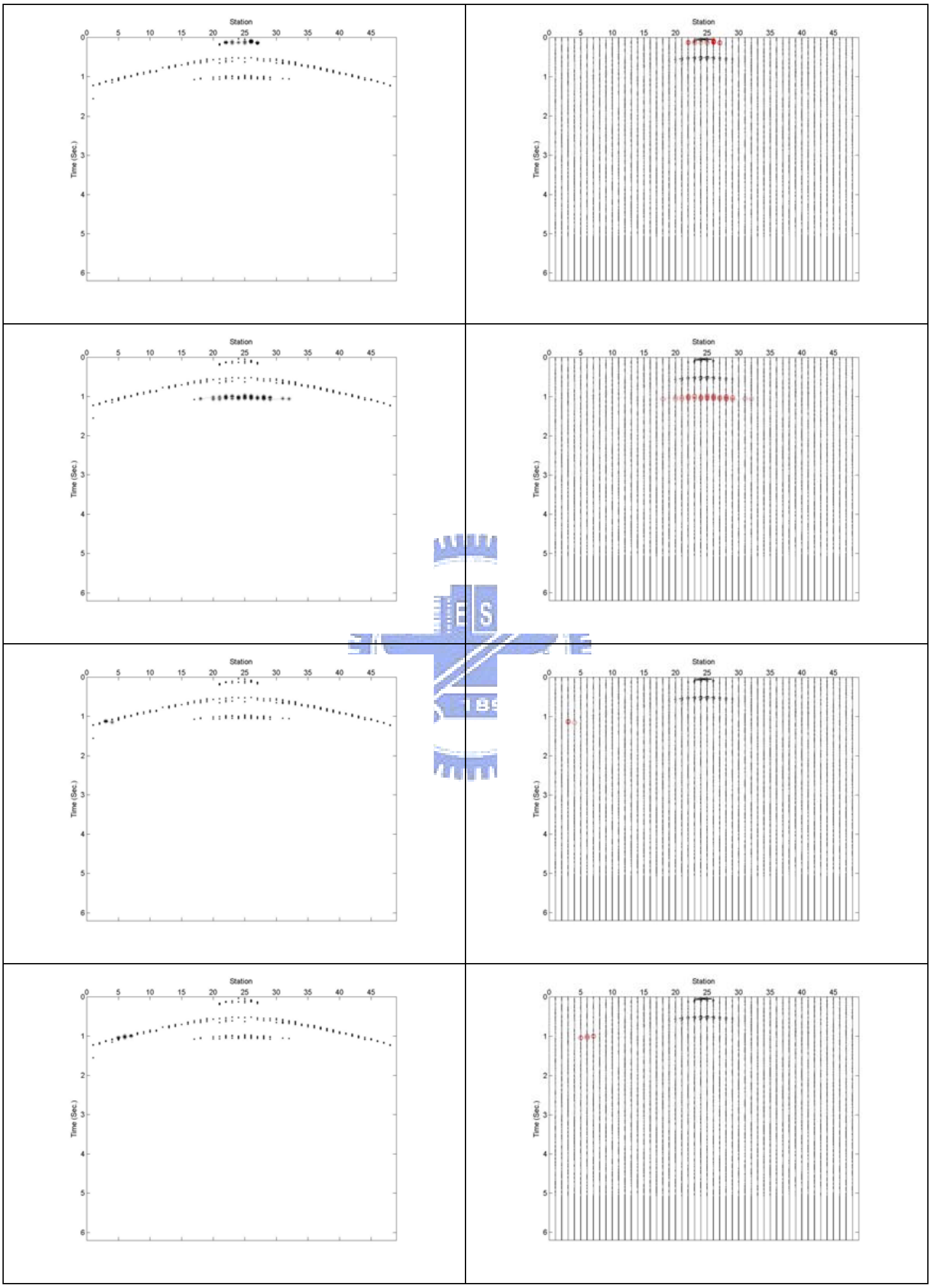
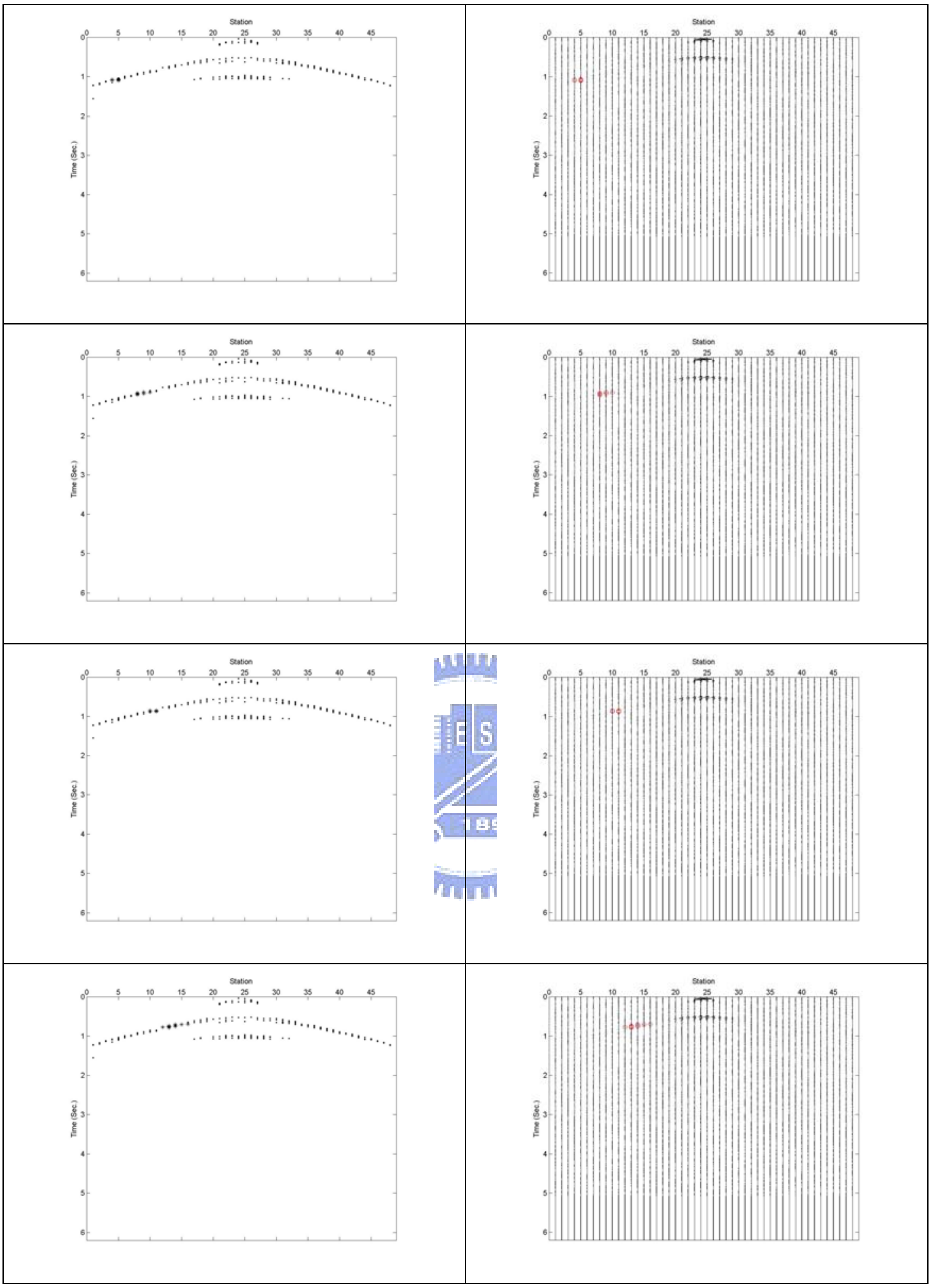


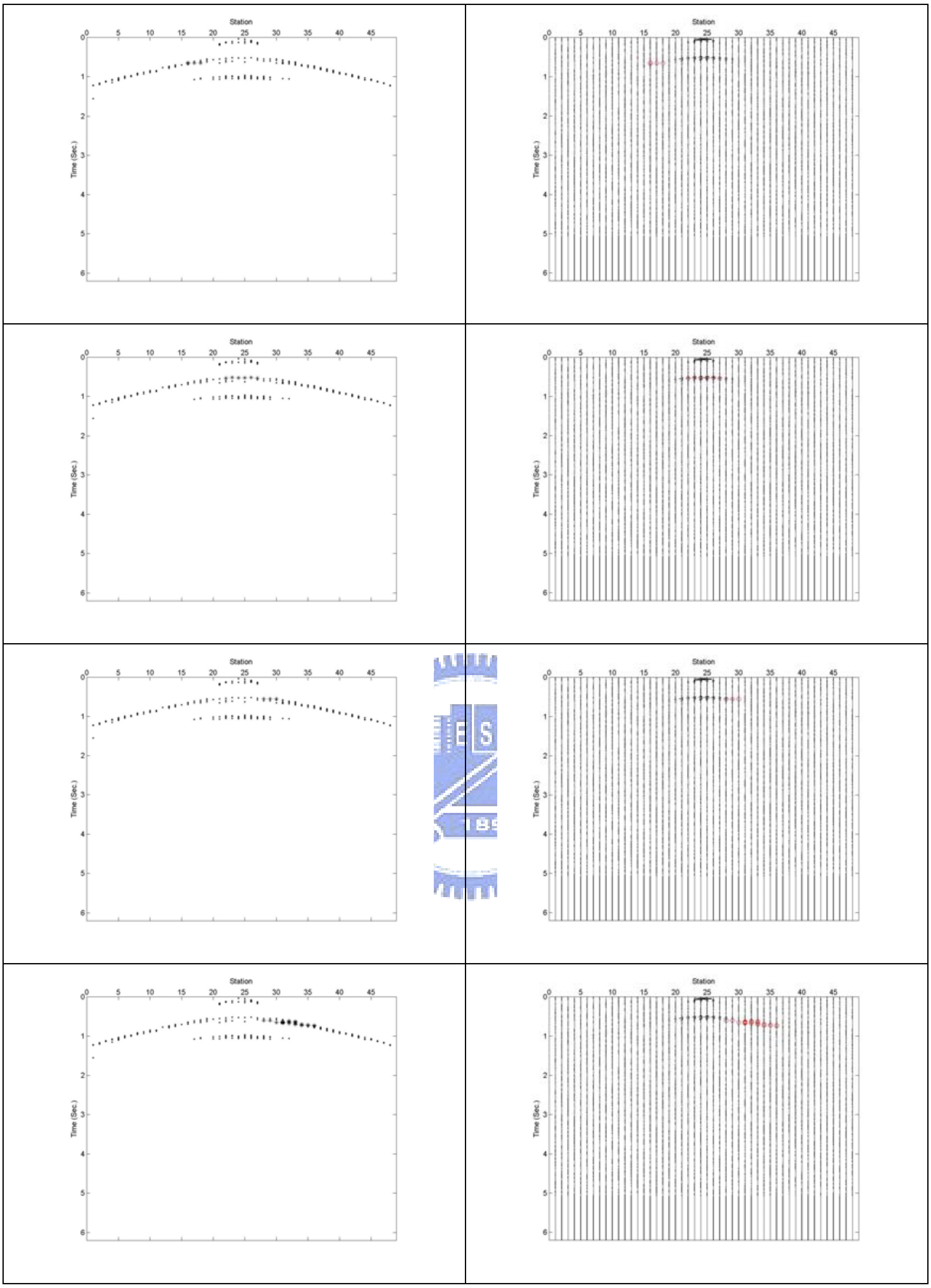
Figure 4.18. Update process from $t = 1$ to $t = 13$

Part III: Pattern search

All horizons that have detected are shown in Figure 4.19.




Station
Time (Sec.)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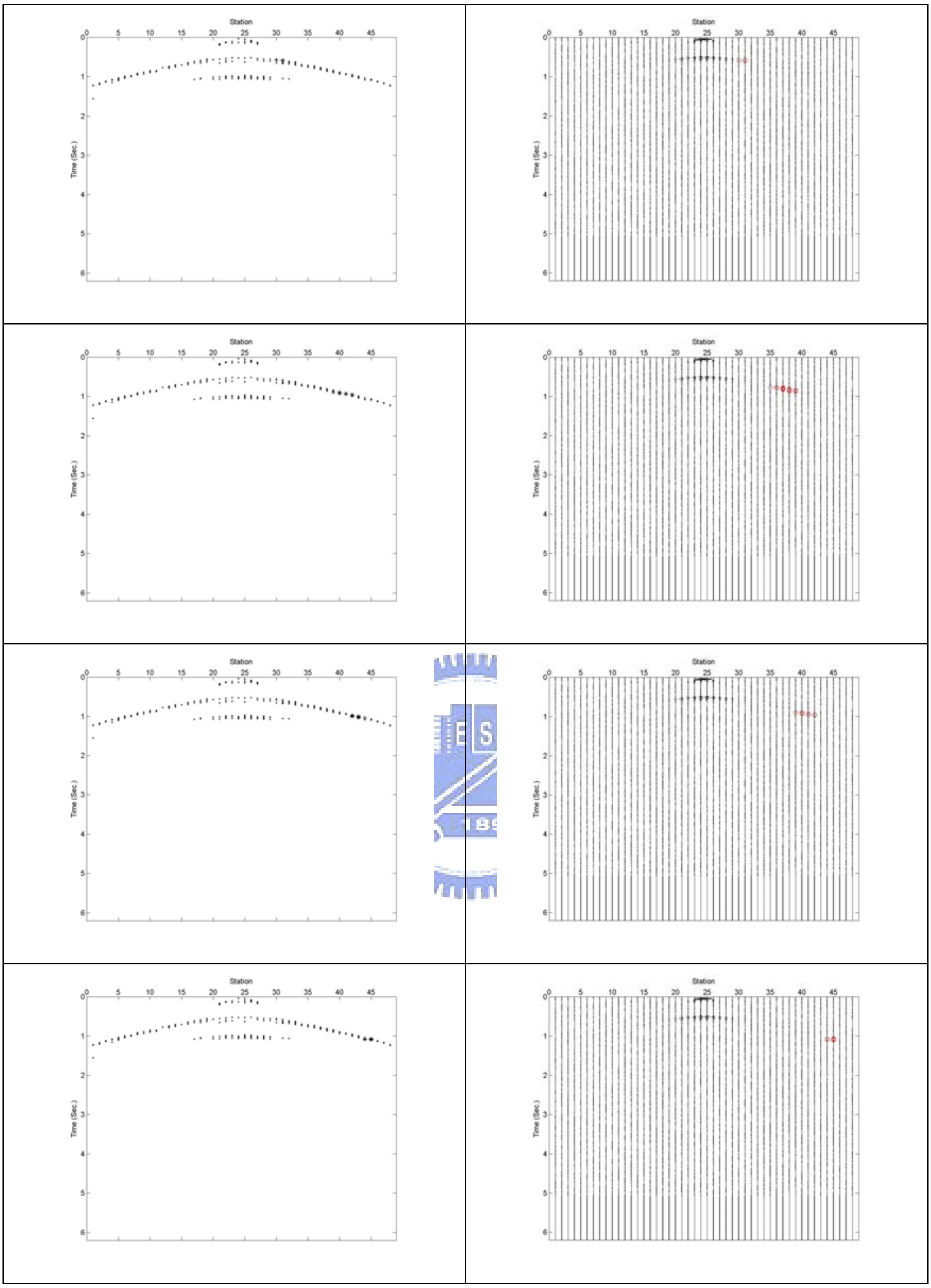
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Time (Sec.)

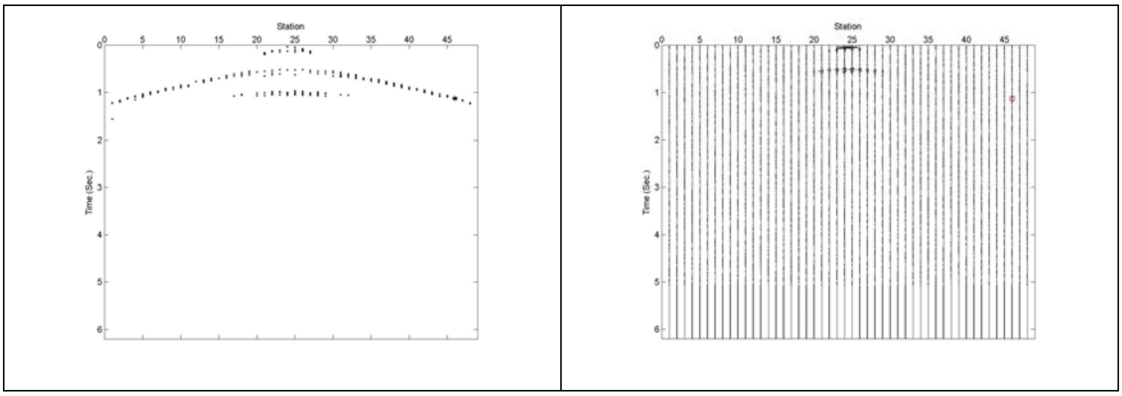


Figure 4.19.Pattern search results.

Experiment III

The real seismogram shown in Figure 4.20 iswith 64 traces and has 512 points in one trace. The sampling rate is 0.004 seconds.

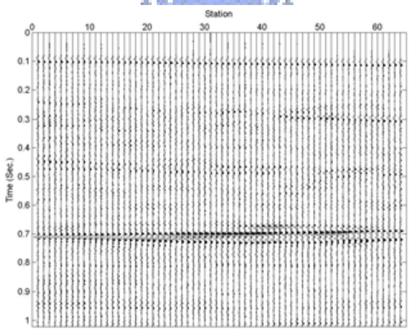


Figure 4.20. Real Seismogram.

Part I: Preprocessing

The Preprocessing result is shown in Figure 4.21 which includes envelope, thresholding, peaking and compression result.

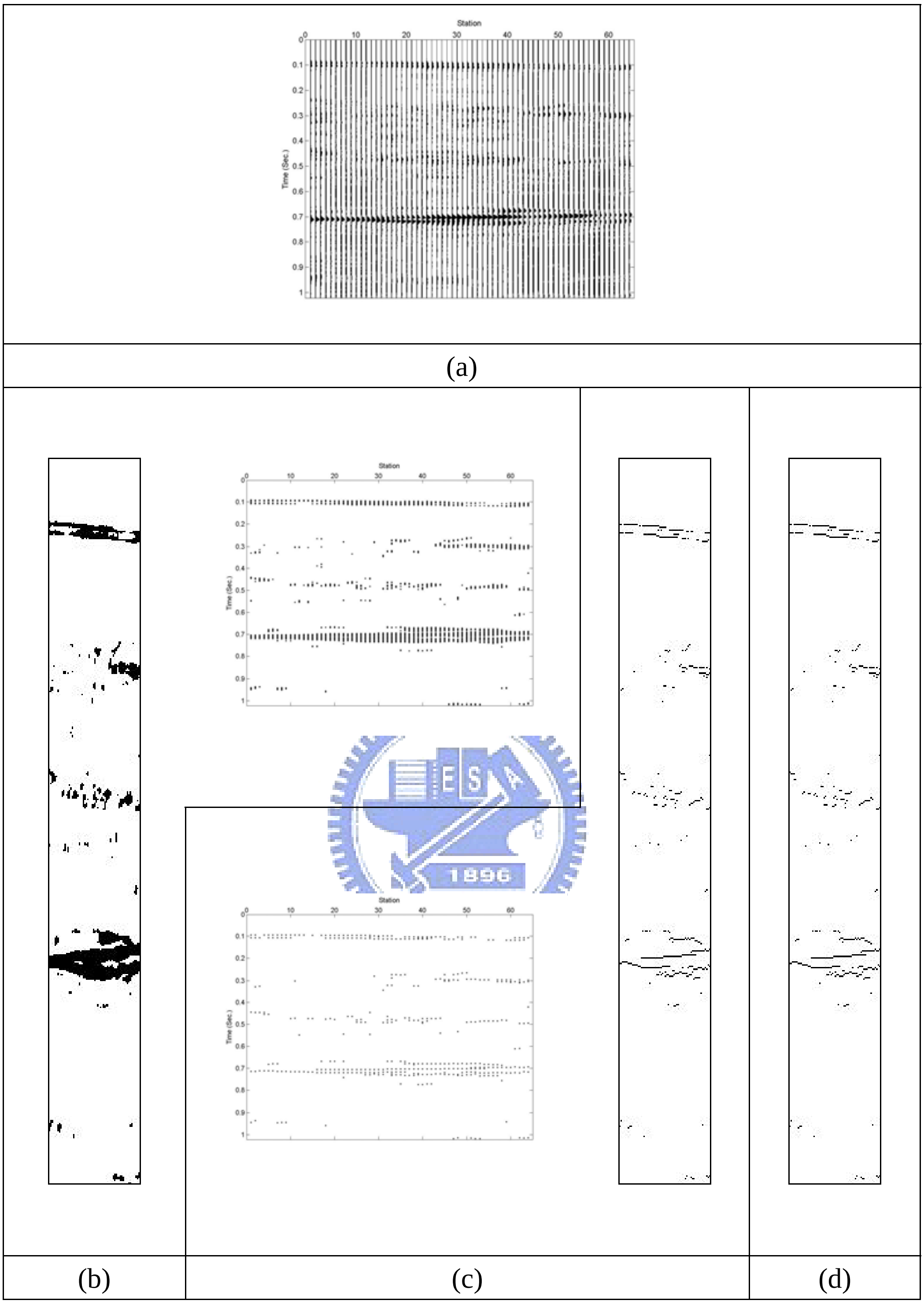
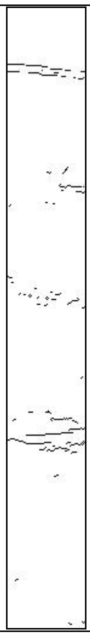
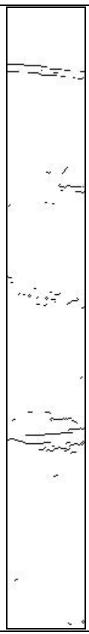
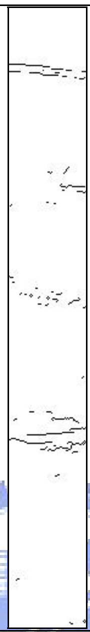
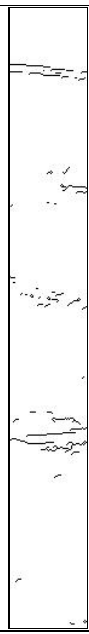
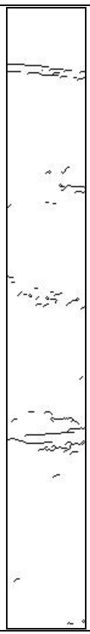
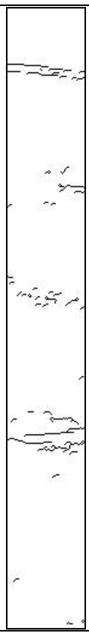
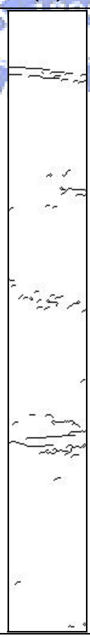
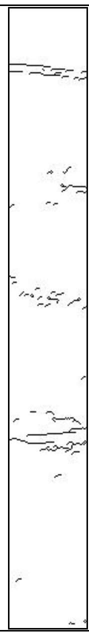
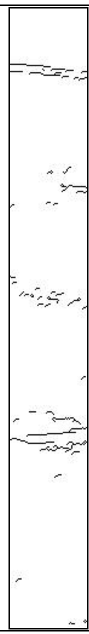
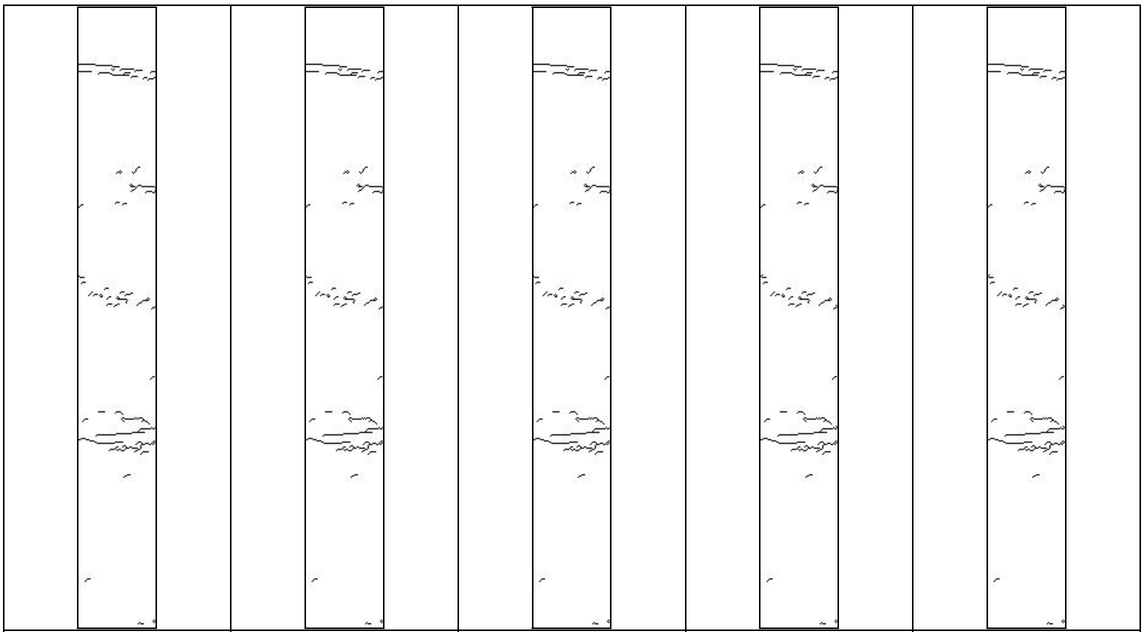


Figure 4.21.Preprocessing results (a) envelope, (b) thresholding, (c) peaking, (d) compression result, compression number $n = 1$.

Part II: Line linking

We set the parameters as $w_{ij} = 1 \ \forall i, j$, $w_s = 1$, state number of each PE $n = 16$ and stop constraint $\varepsilon = 1$ in this experiment. The update process is shown in Figure 4.22.

				
(1)	(2)	(3)	(4)	(5)
				
(6)	(7)	(8)	(9)	(10)

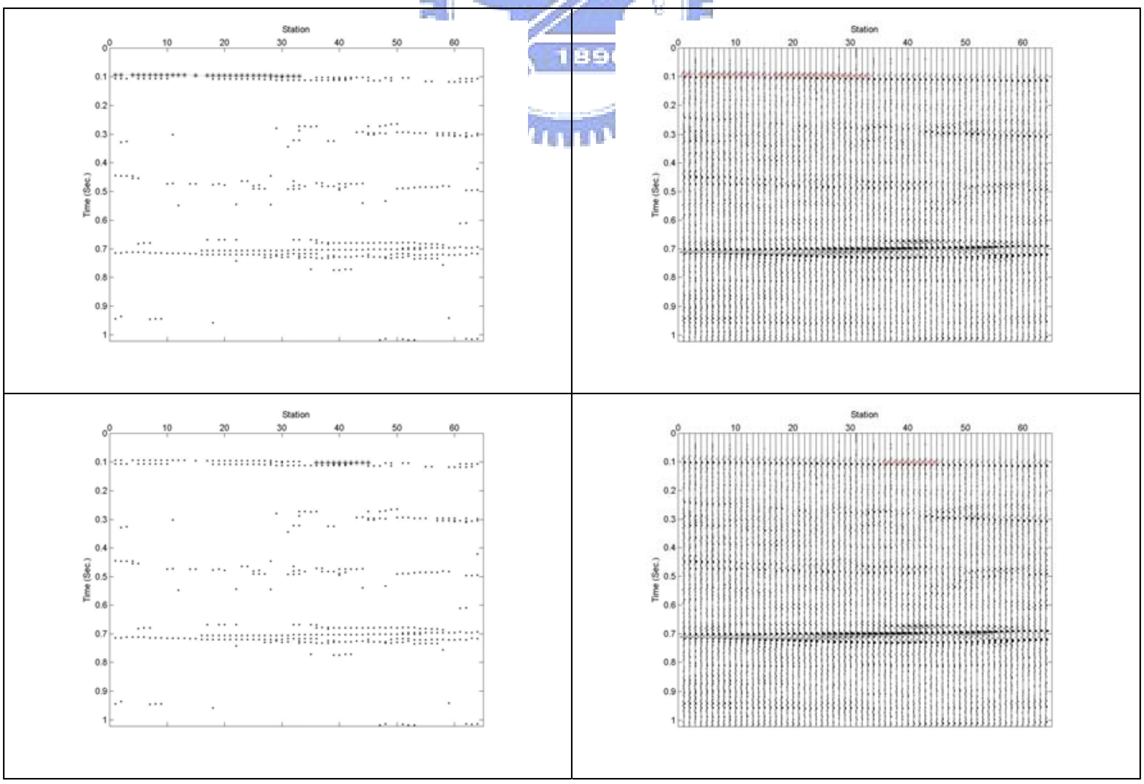


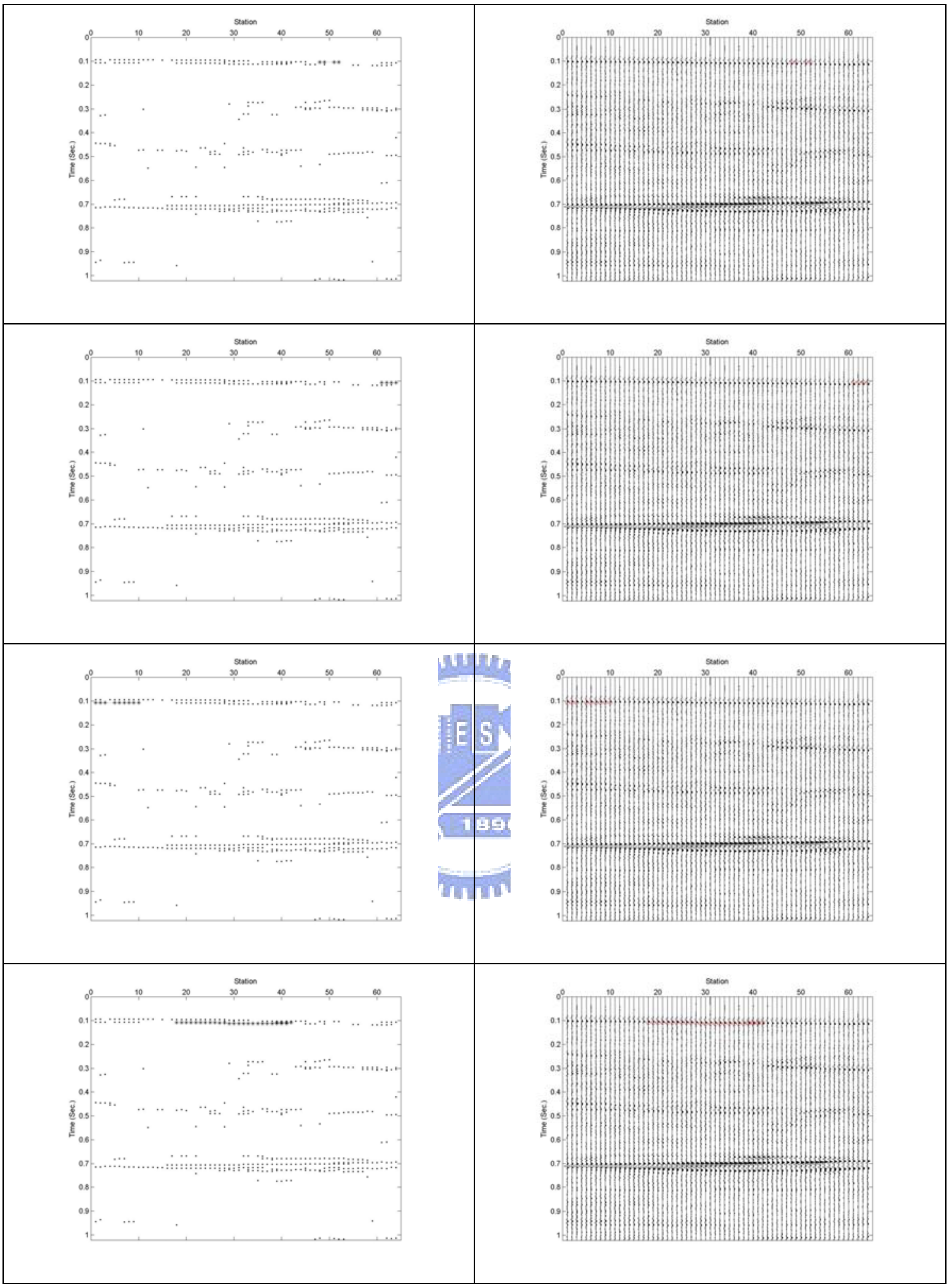
(11)	(12)	(13)	(14)	(15)

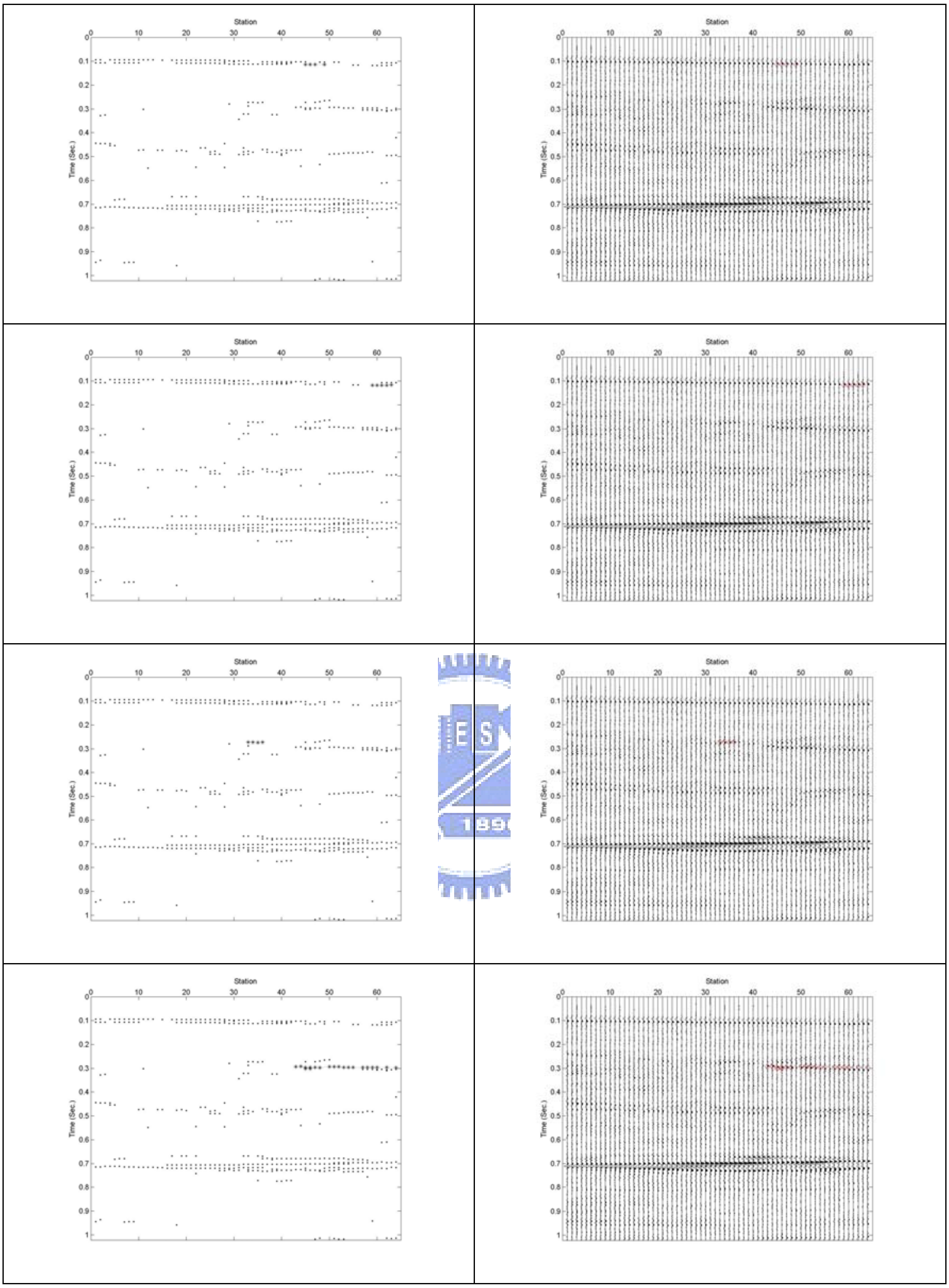
Figure 4.22. Update process from $t=1$ to $t=15$

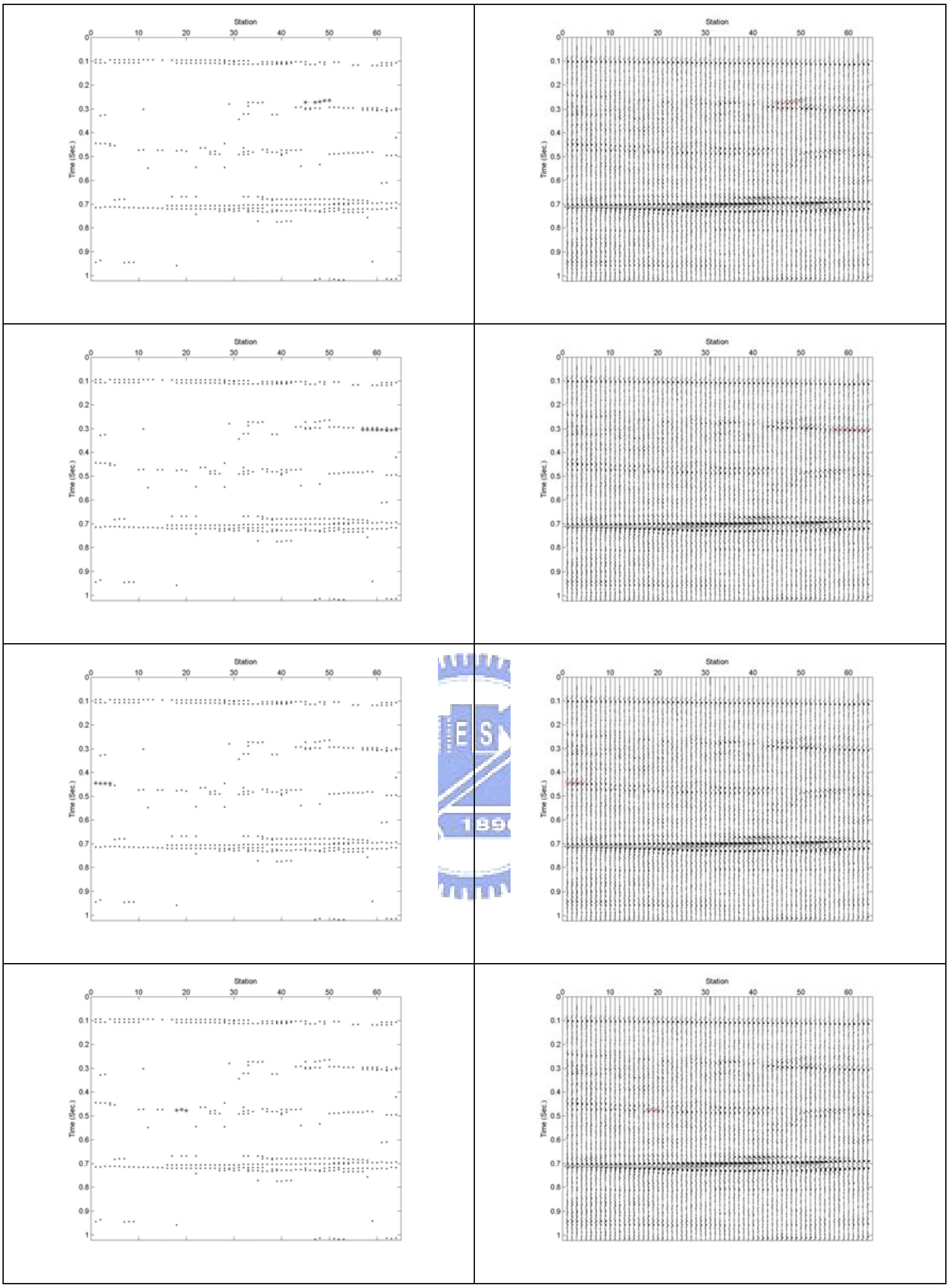
Part III: Pattern search

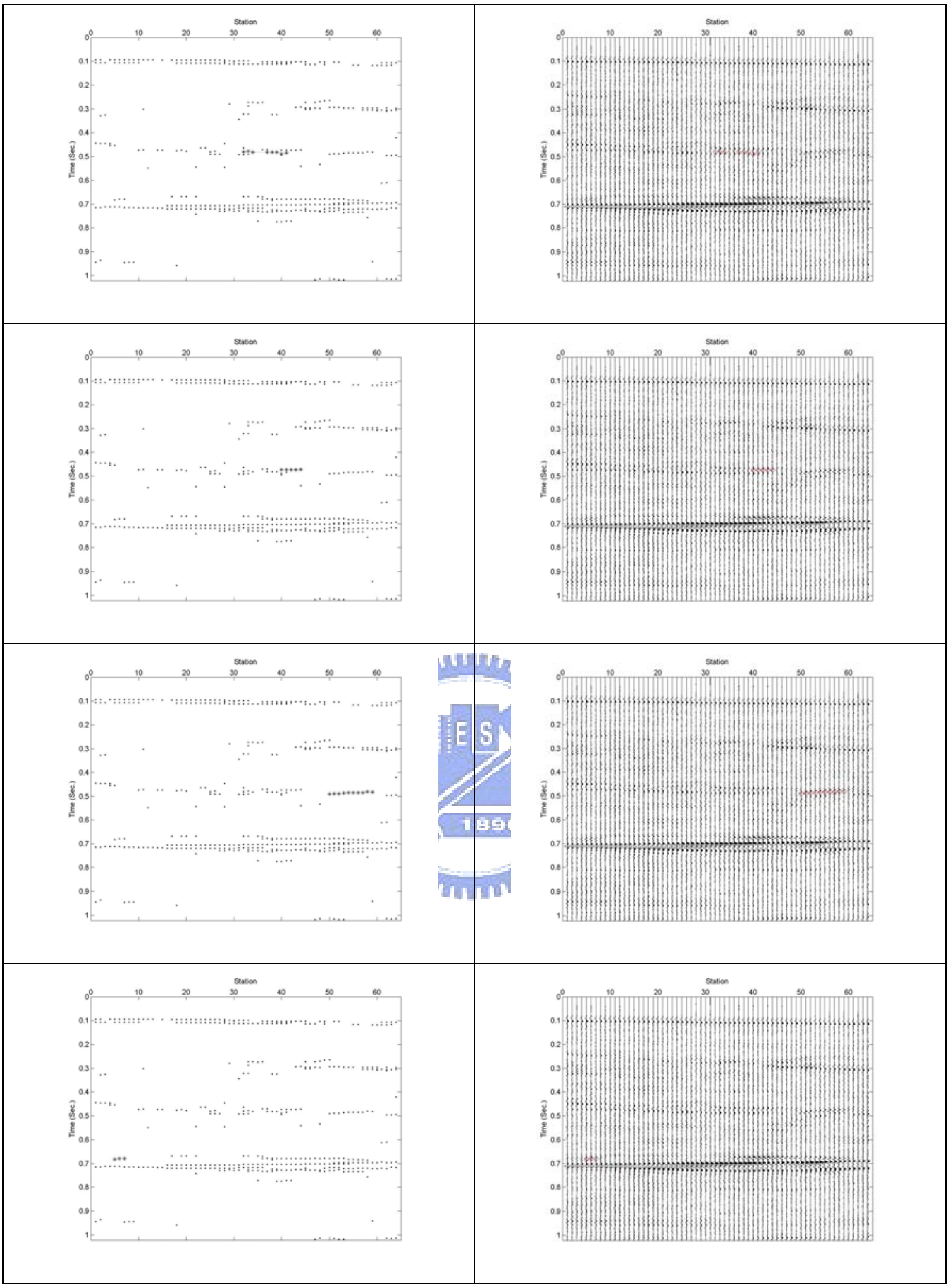
All horizons that have detected are shown in Figure 4.23.

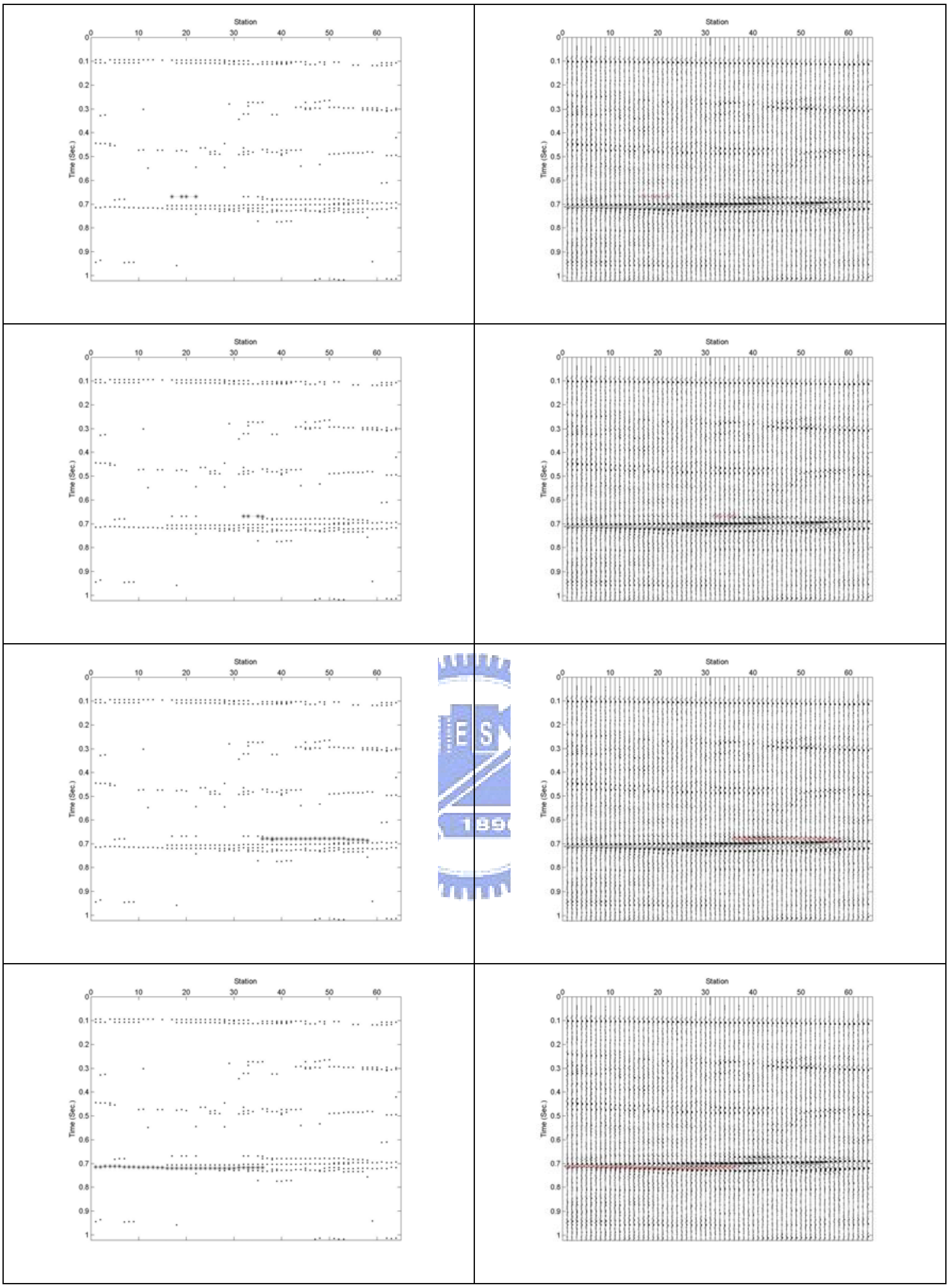


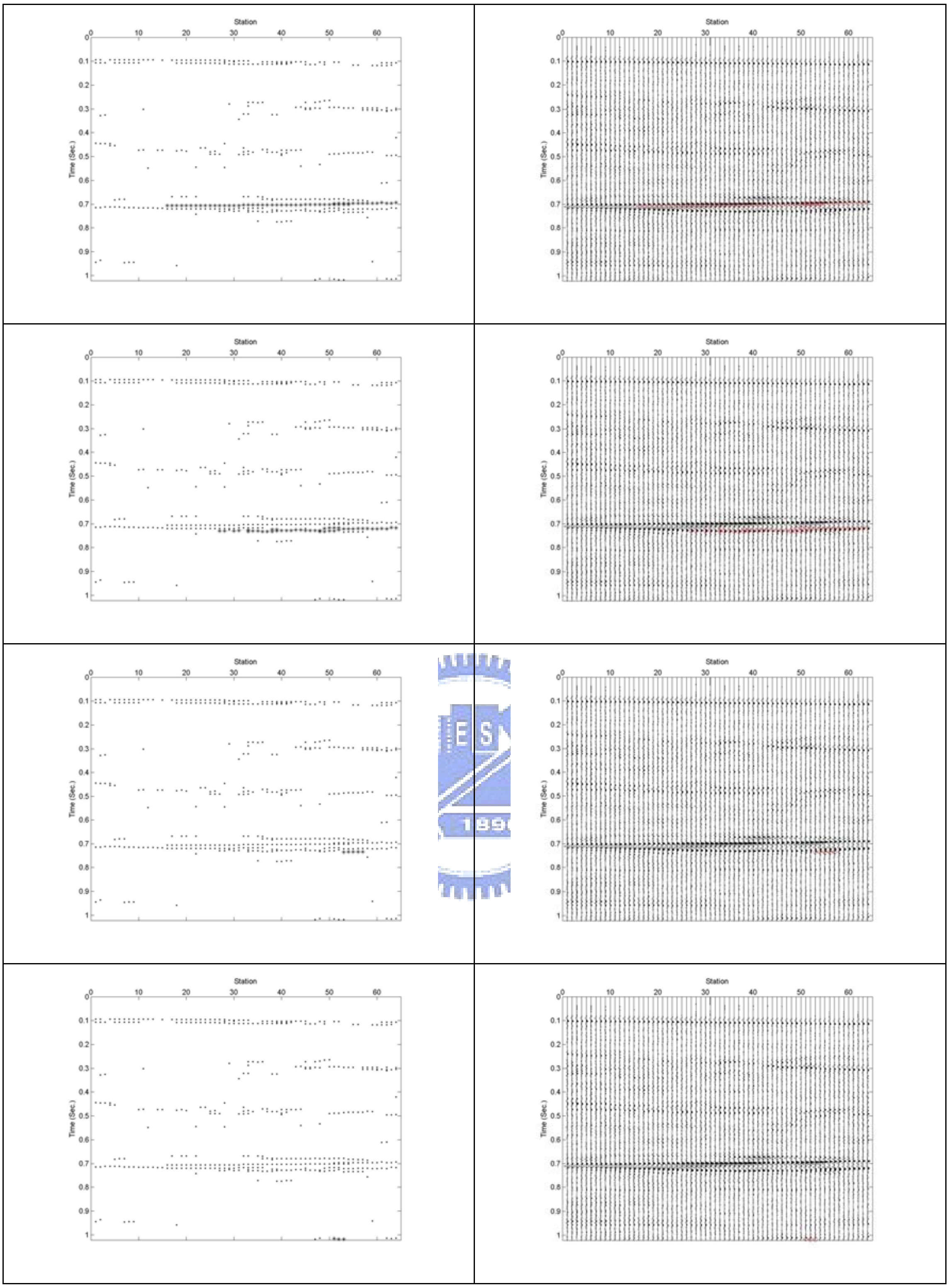

Station
Time (Sec.)


Station
Time (Sec.)


Station
Time (Sec.)


Station
Time (Sec.)


Station
Time (Sec.)


Station
Time (Sec.)

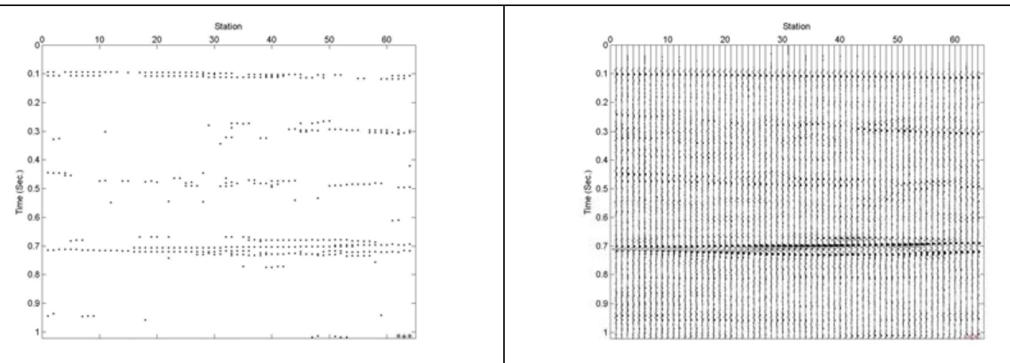


Figure 4.23.Pattern search results.

Experiment IV

The real seismogram shown in Figure 4.24 is 512×64 with 64 traces and has 512 points in one trace. The sampling rate is 0.004 seconds.

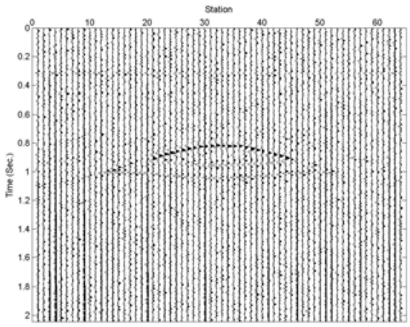
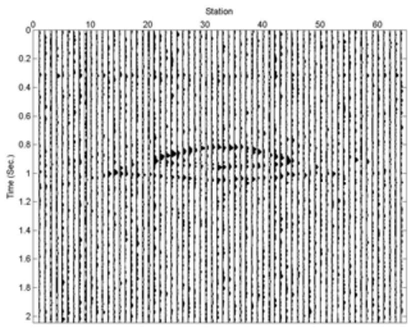


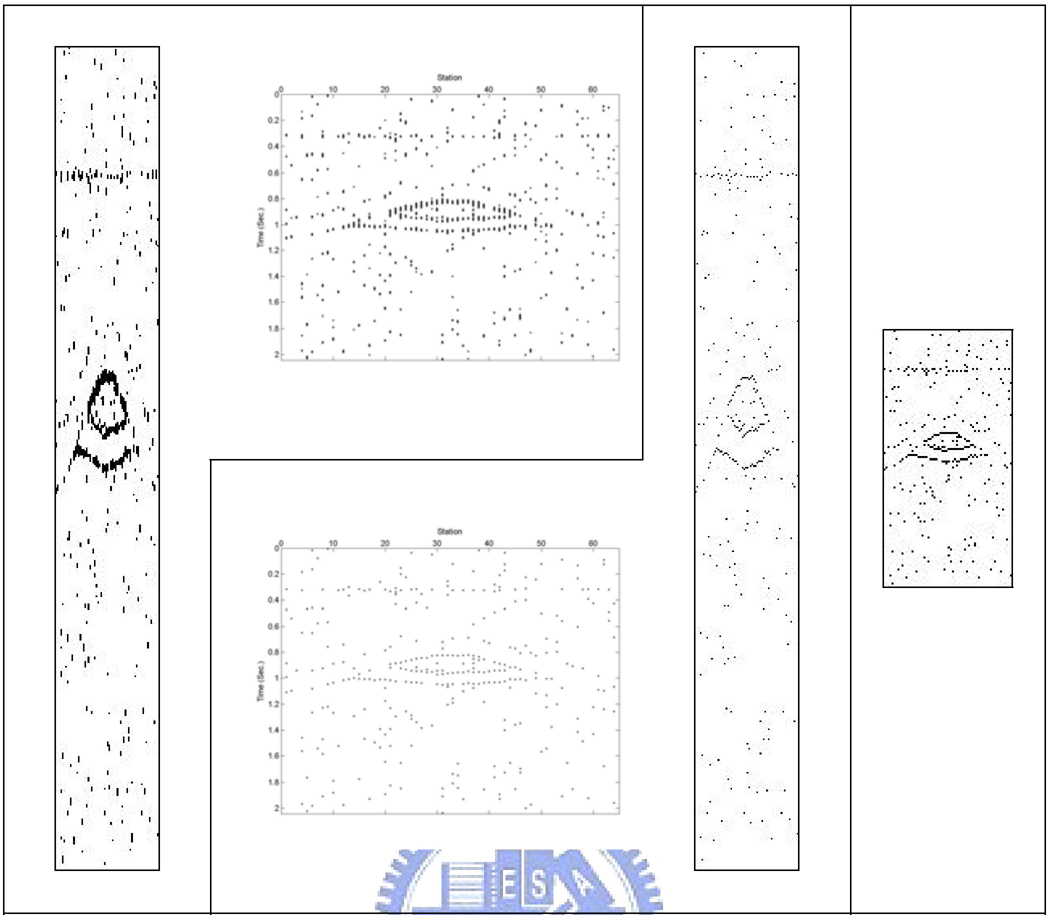
Figure 4.24. Real Seismogram.

Part I: Preprocessing

The Preprocessing result is shown in Figure 4.25 which includes envelope, thresholding, peaking and compression result.



(a)



(b)	(c)	(d)

Figure 4.25.Preprocessing results (a) envelope, (b) thresholding, (c) peaking, (d) compression result, compression number $n = 4$.

Part II: Line linking

We set the parameters as $w_{ij} = 1 \ \forall i, j$, $w_s = 1$, state number of each PE $n = 16$ and stop constraint $\varepsilon = 1$ in this experiment. The update process is shown in Figure 4.26.

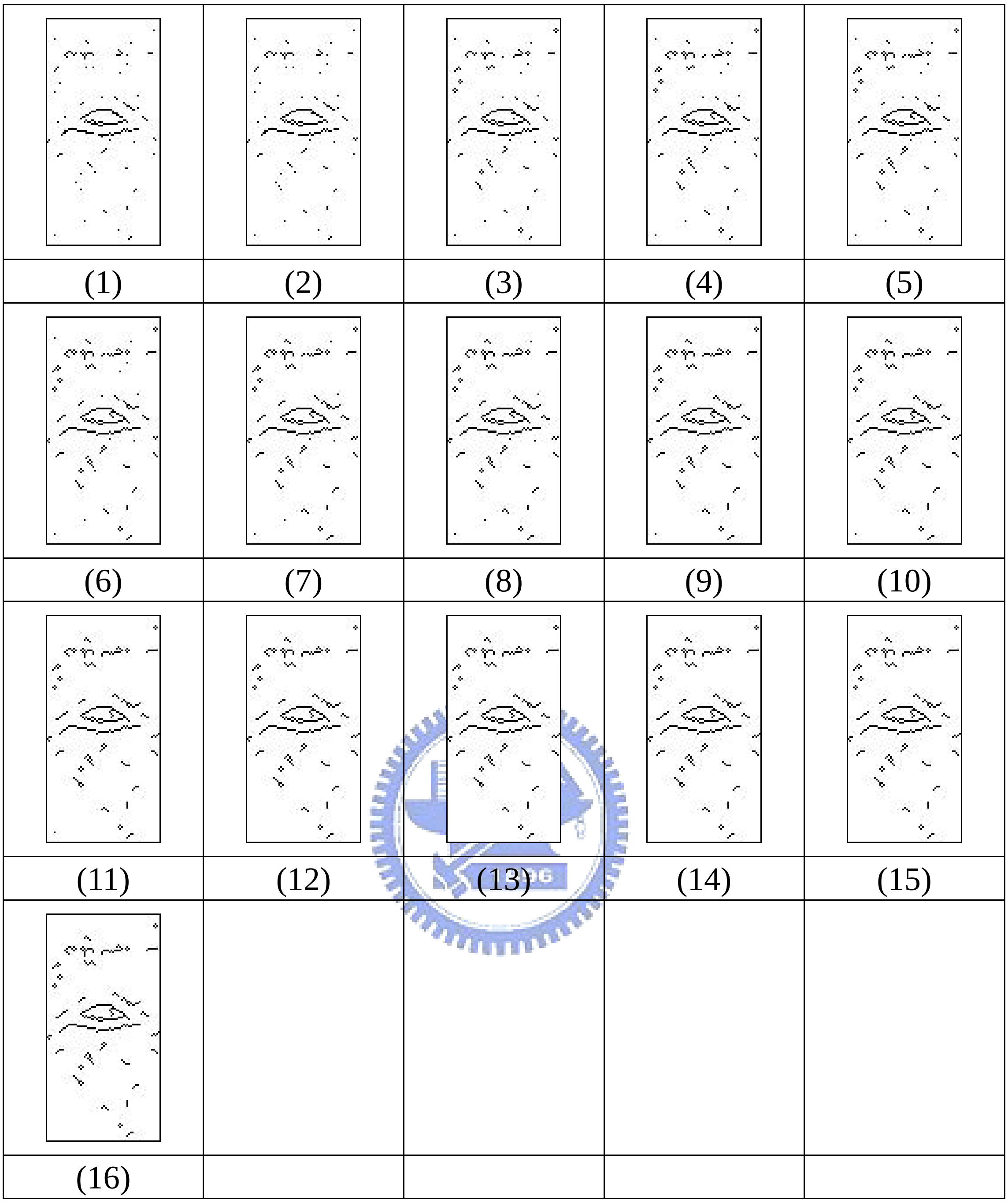
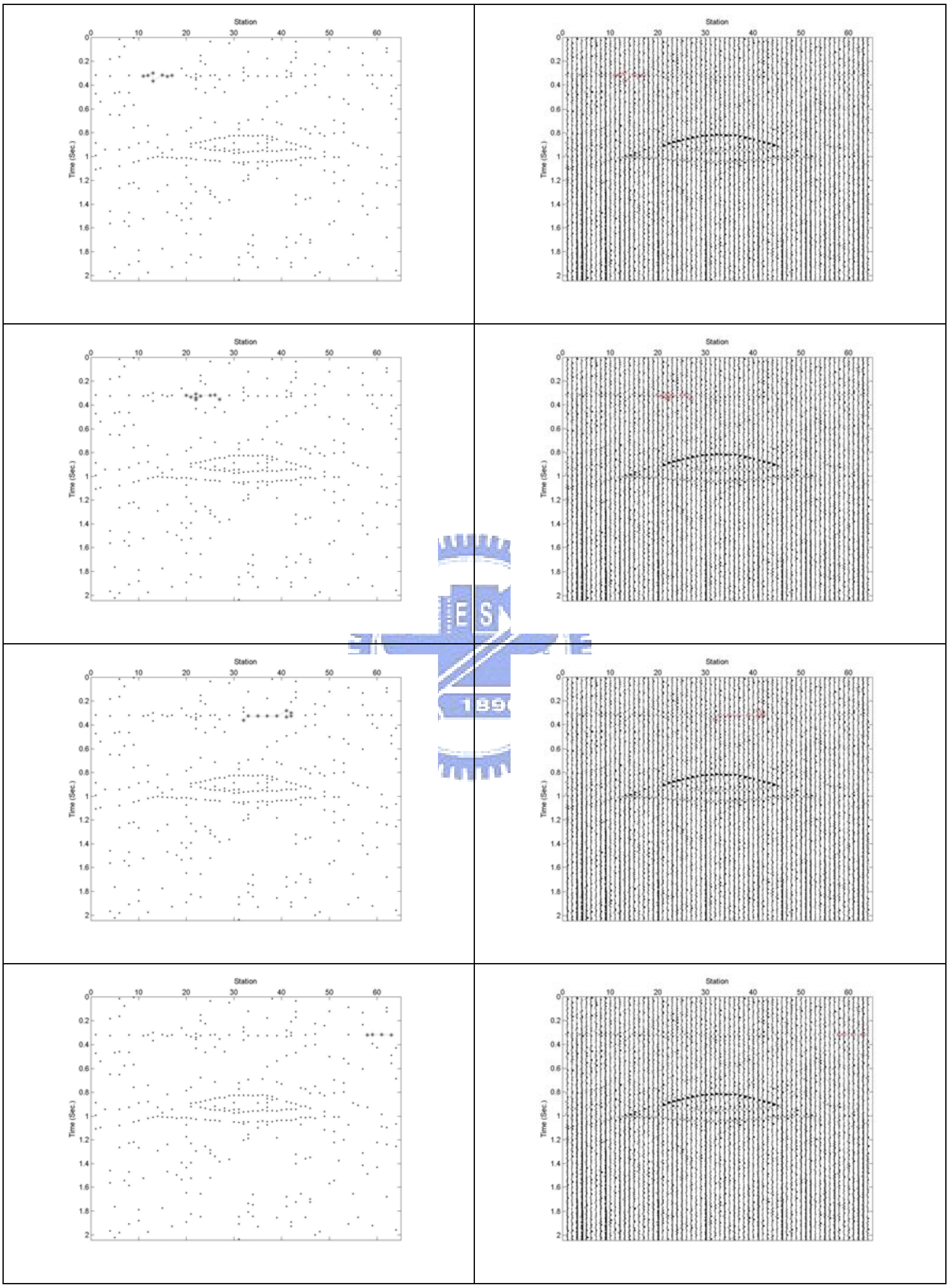
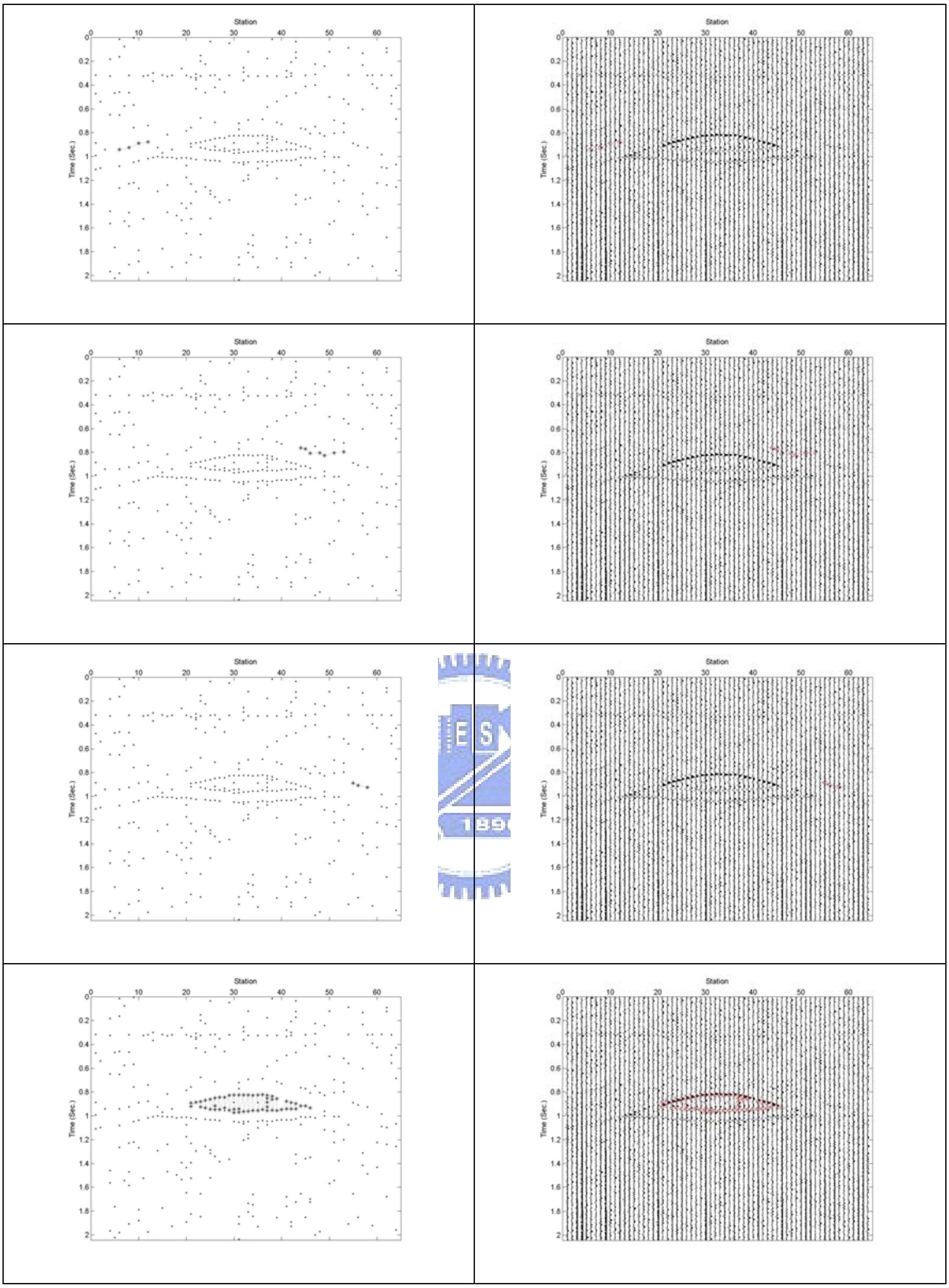


Figure 4.26. Update process from $t=1$ to $t=16$

Part III: Pattern search

All horizons that have detected are shown in Figure 4.27.




Station
Time (Sec.)

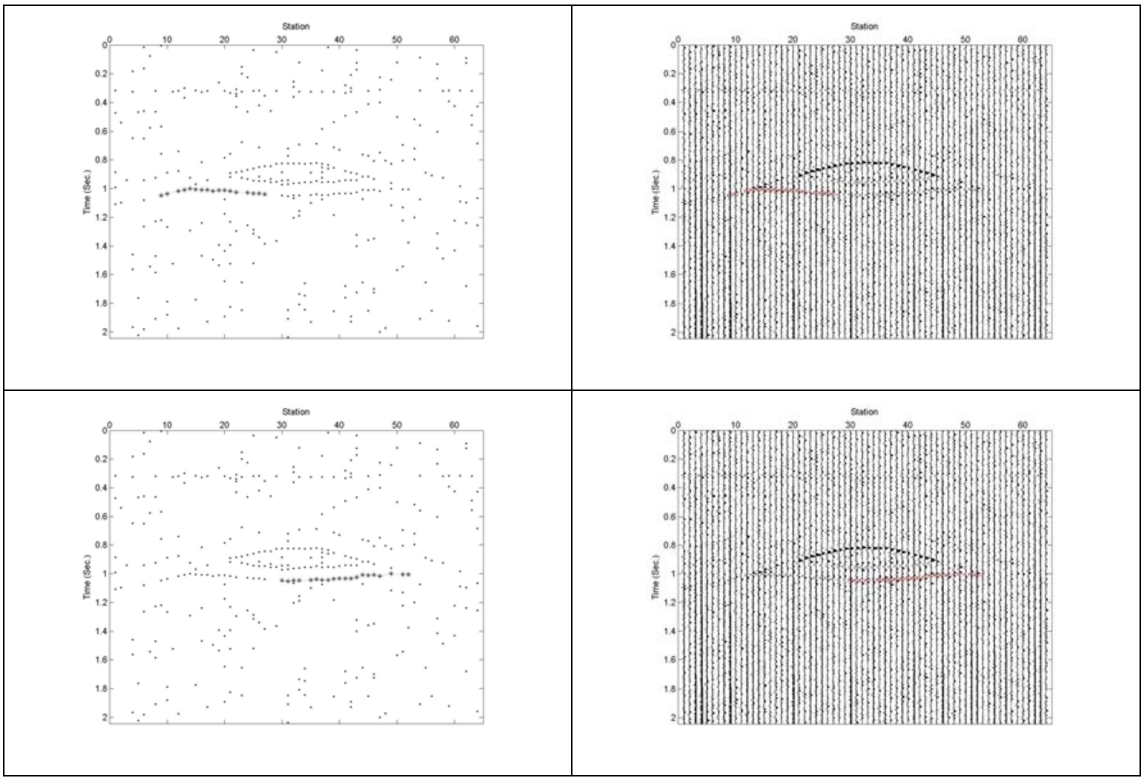


Figure 4.27.Pattern search results.

Experiment V

Part I: Preprocessing

This part is the same with the experiment I.

Part II: Line linking: model II

In this experiment, the parameters of the line linking we set the window size of linear regression is 3×7, $R(0)=3$, connection weight $w_{ji}=0.5*(1/R(0))\ \forall$i, j, self-feedback weight $w_s=0$, tolerance limit $p=30$, radius decreasing ratio $\gamma=0.4$. Figure 4.28 shows the update process from $t=1$ to $t=7$.

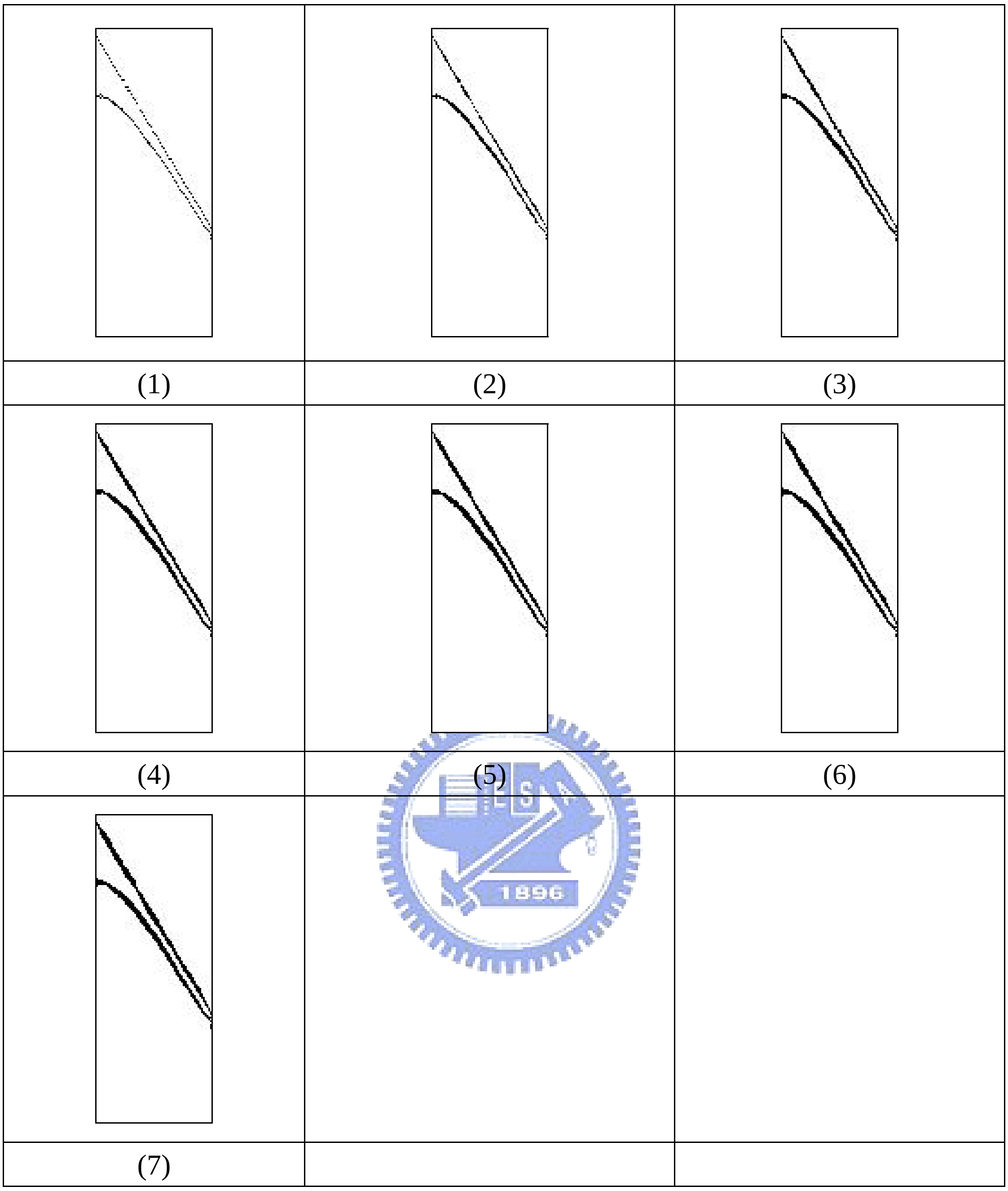


Figure 4.28. Update process from $t = 1$ to $t = 7$

Part III: Pattern search: model II

All horizons that have detected are shown in Figure 4.29.

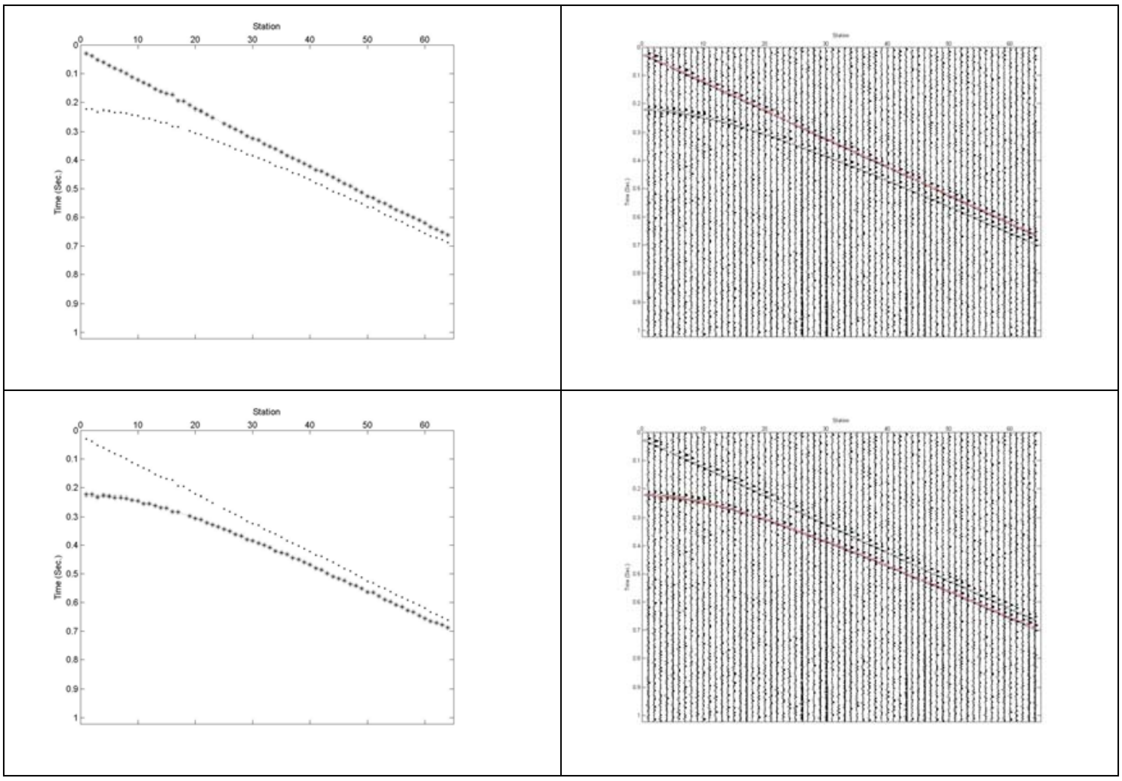


Figure 4.29.Pattern search results.

Experiment VI

Part I: Preprocessing

This part is the same with the experiment II.

Part II: Line linking

In this experiment, the parameters of the line linking we set the window size of linear regression is 19×5, $R(0) = 4$, connection weight $w_{ji} = 0.5 * (1/R(0))\ \forall \text{i, j}$, self-feedback weight $w_s = 0$, tolerance limit $p = 30$, radius decreasing ratio $\gamma = 0.4$. Figure 4.30 shows the update process from $t = 1$ to $t = 9$.

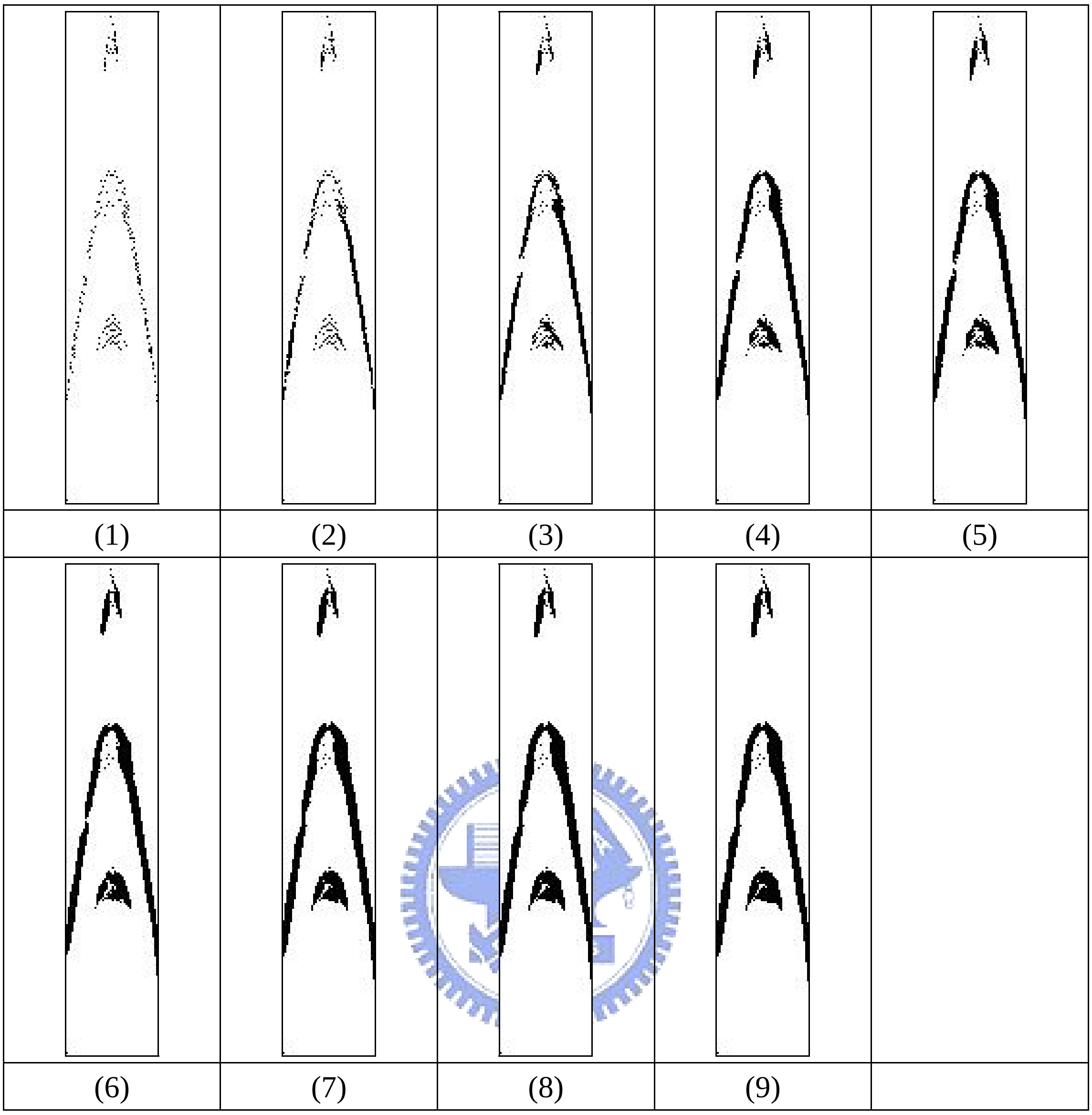
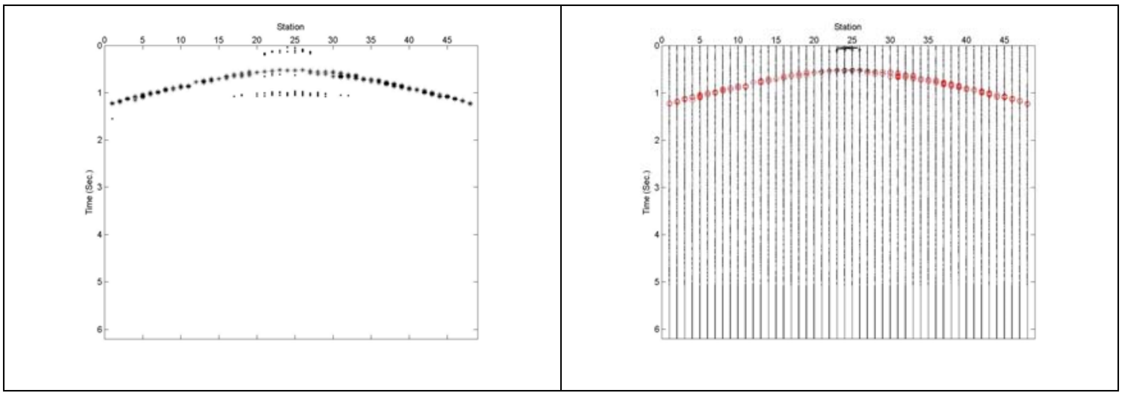


Figure 4.30. Update process from $t = 1$ to $t = 9$.

Part III: Pattern search

All horizons that have detected are shown in Figure 4.31.



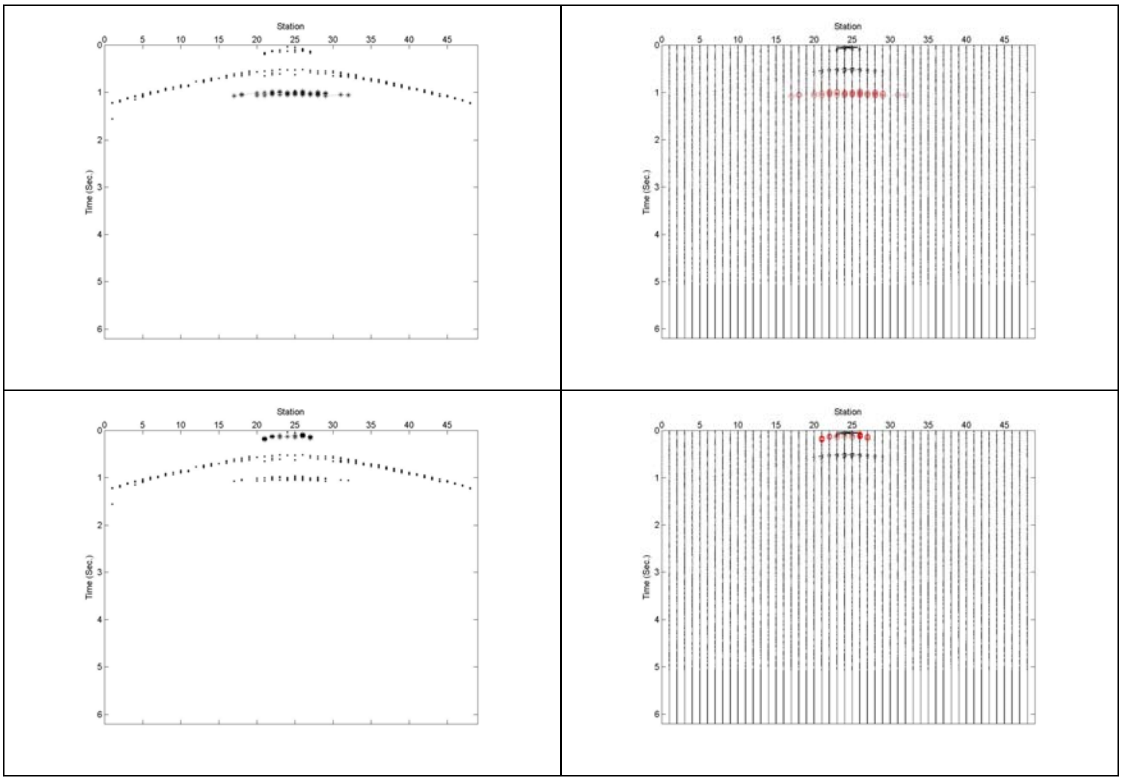


Figure 4.31.Pattern search results.

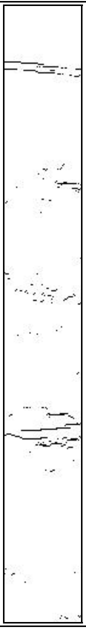
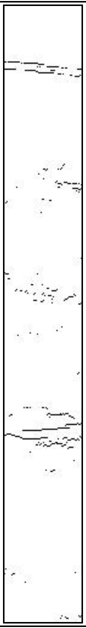
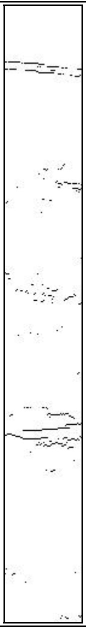
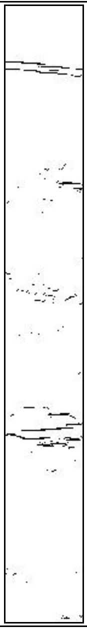
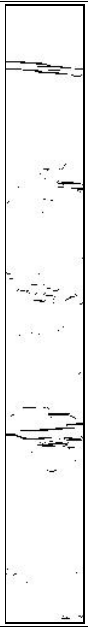
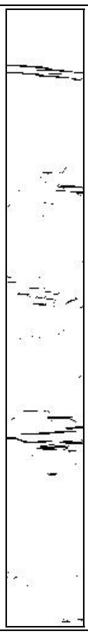
Experiment VII

Part I: Preprocessing

This part is the same with the experiment III.

Part II: Line linking

In this experiment, the parameters of the line linking we set the window size of linear regression is 13×3, $R(0) = 5$, connection weight $w_{ji} = 0.17 * (1/R(0))\ \forall \mathrm{i, j}$, self-feedback weight $w_s = 0$, tolerance limit $p = 30$, radius decreasing ratio $\gamma = 0.4$. Figure 4.32 shows the update process from $t = 1$ to $t = 12$.

				
(1)	(2)	(3)	(4)	(5)
				
(6)	(7)	(8)	(9)	(10)

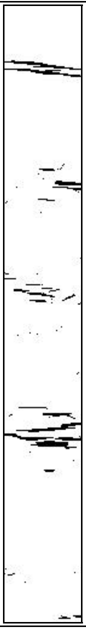
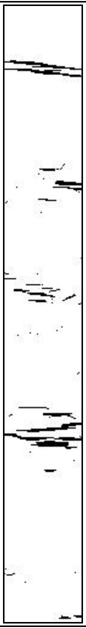
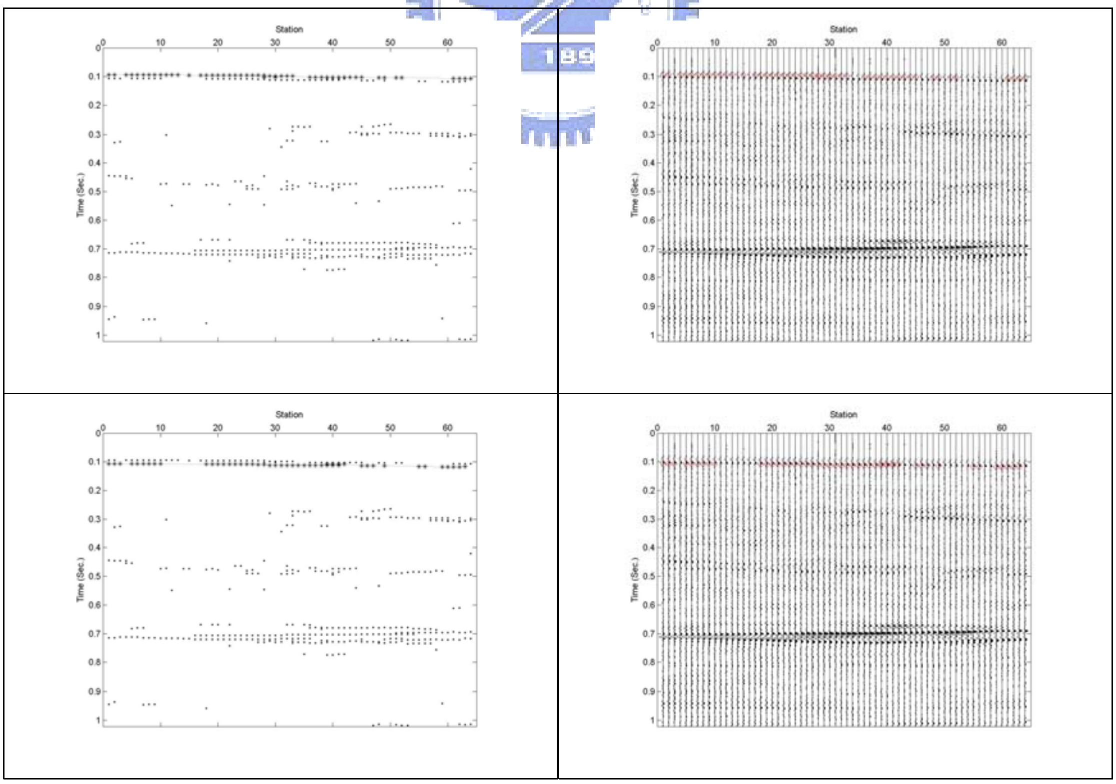
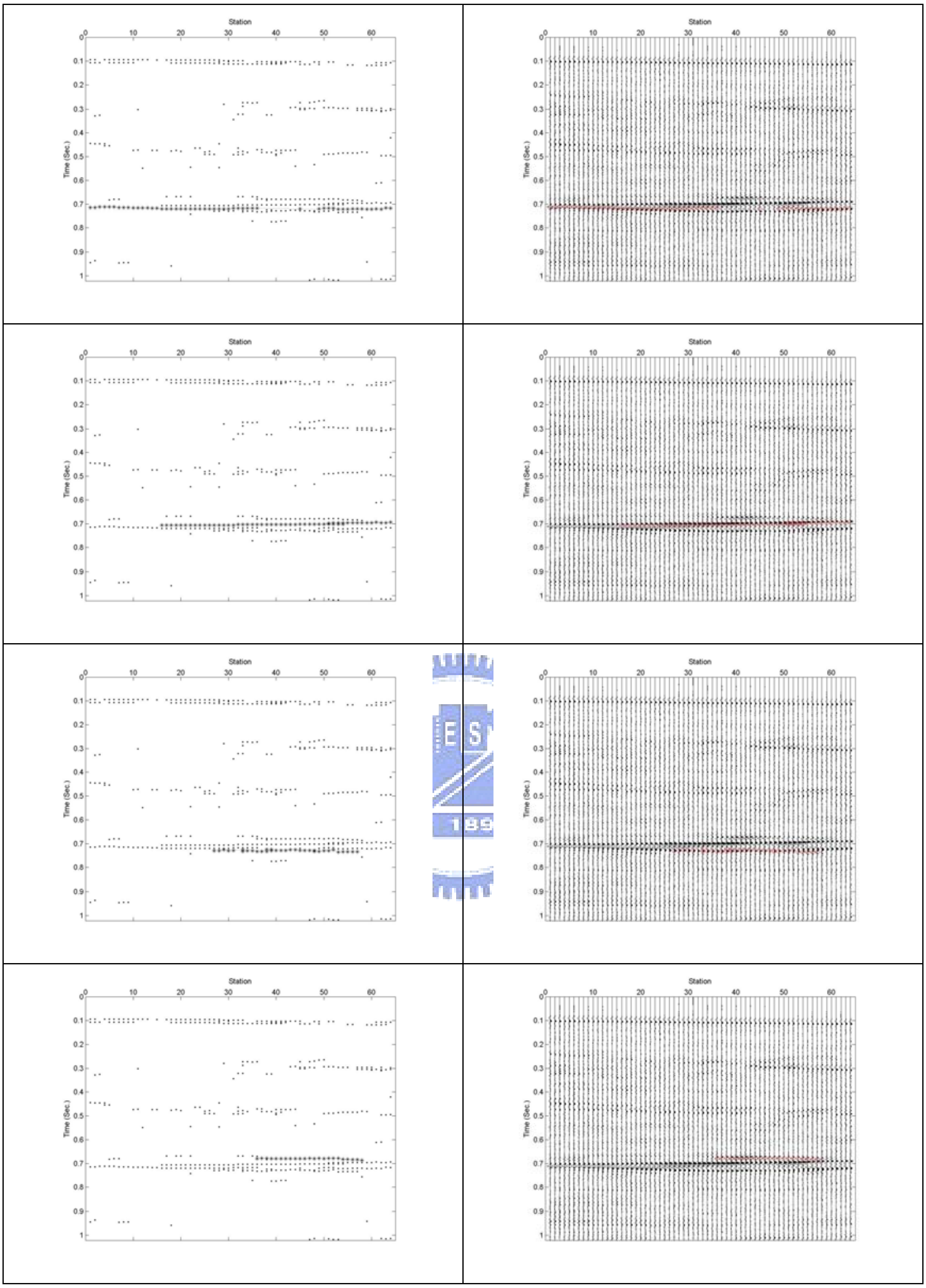
				
(11)	(12)			

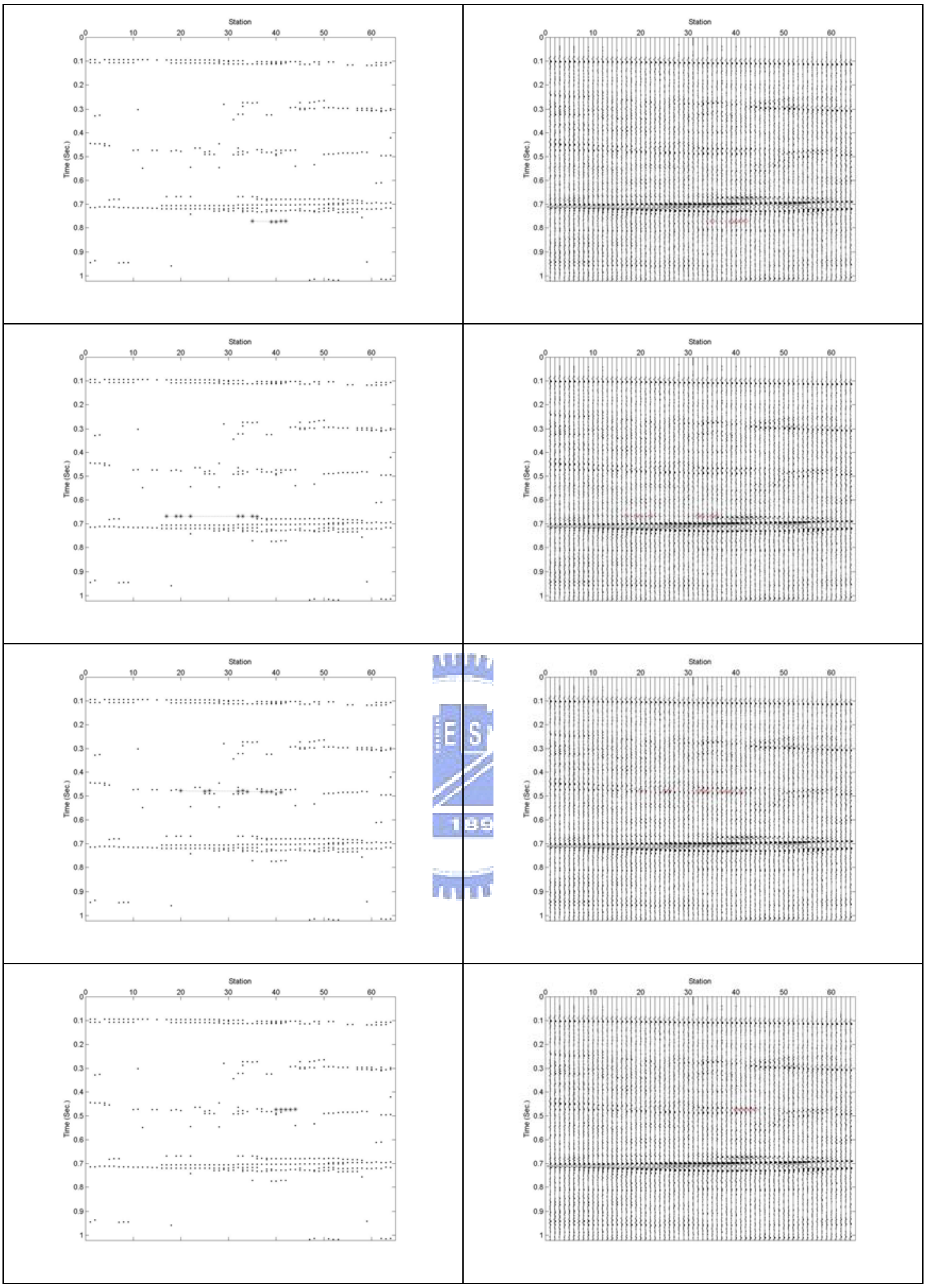
Figure 4.32. Update process from $t = 1$ to $t = 12$.

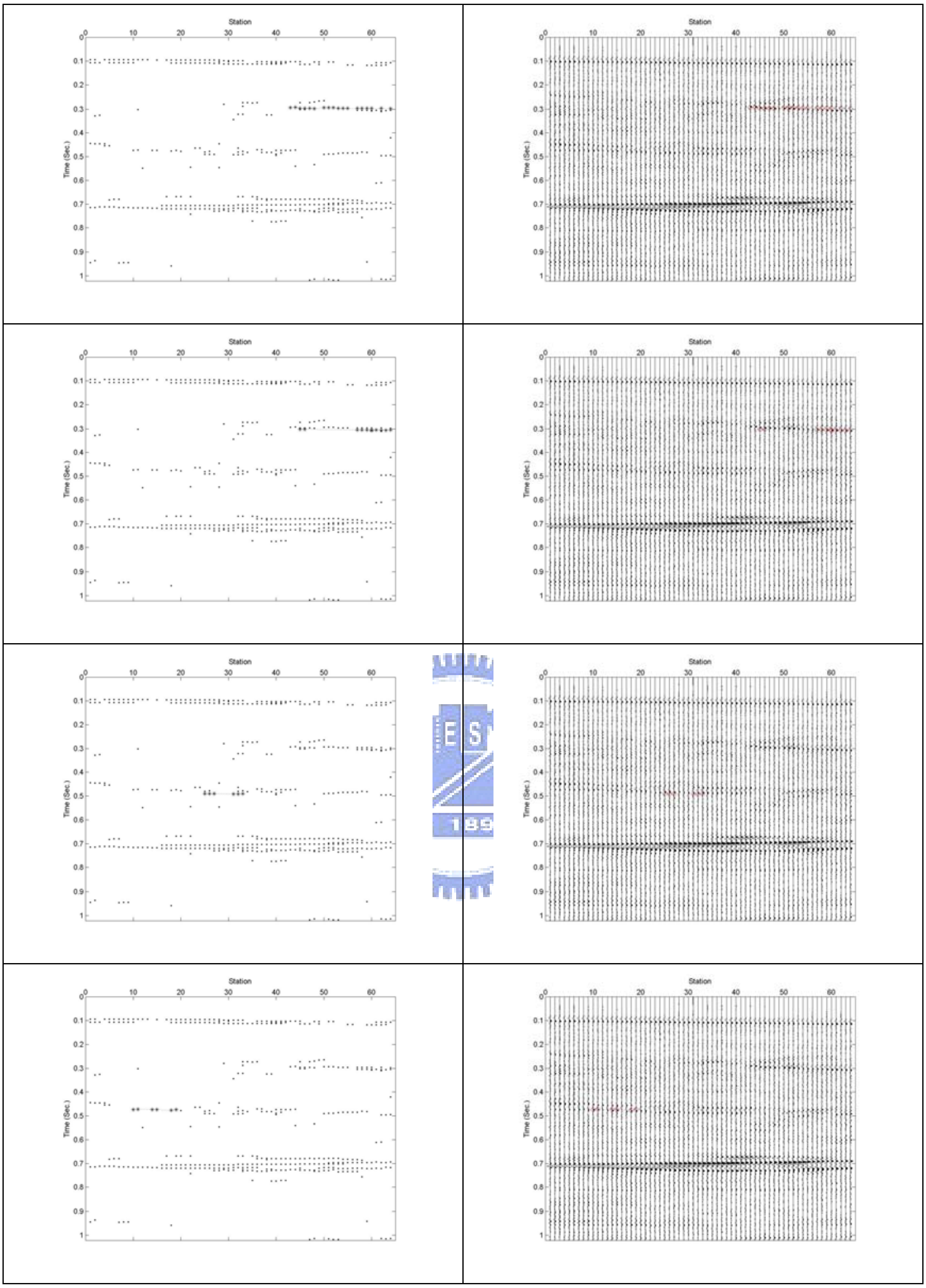
Part III: Pattern search

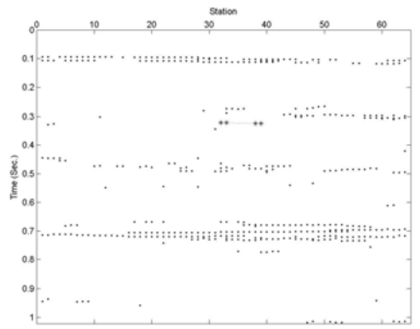
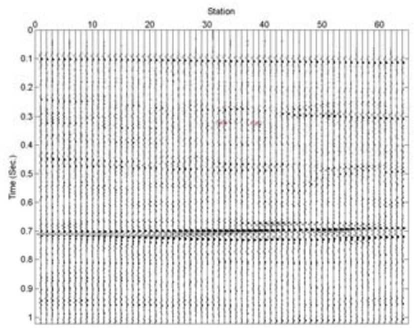
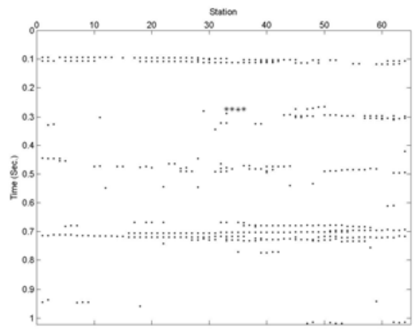
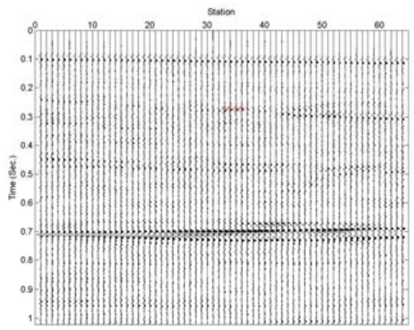
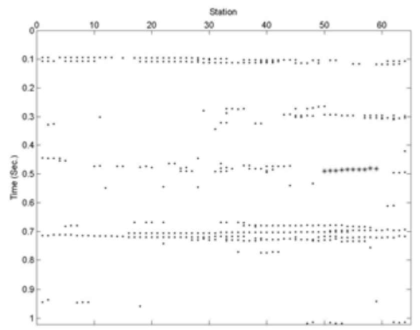
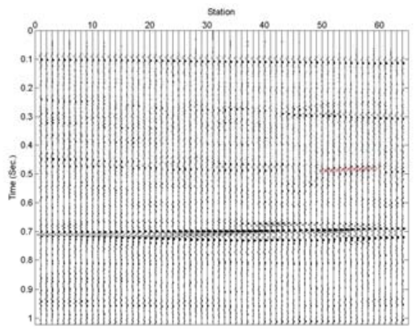
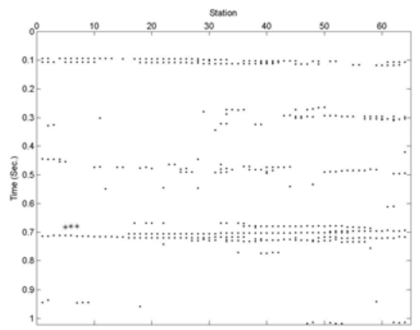
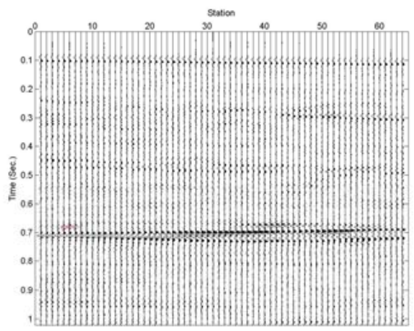
All horizons that have detected are shown in Figure 4.33.




Station
Time (Sec.)


Station
Time (Sec.)


Station
0
10
20
30
40
50
60
Time (Sec.)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


Station
Time (Sec.)

Station
Time (Sec.)

Station
Time (Sec.)

Station
Time (Sec.)

Station
Time (Sec.)

Station
Time (Sec.)

Station
Time (Sec.)

Station
Time (Sec.)

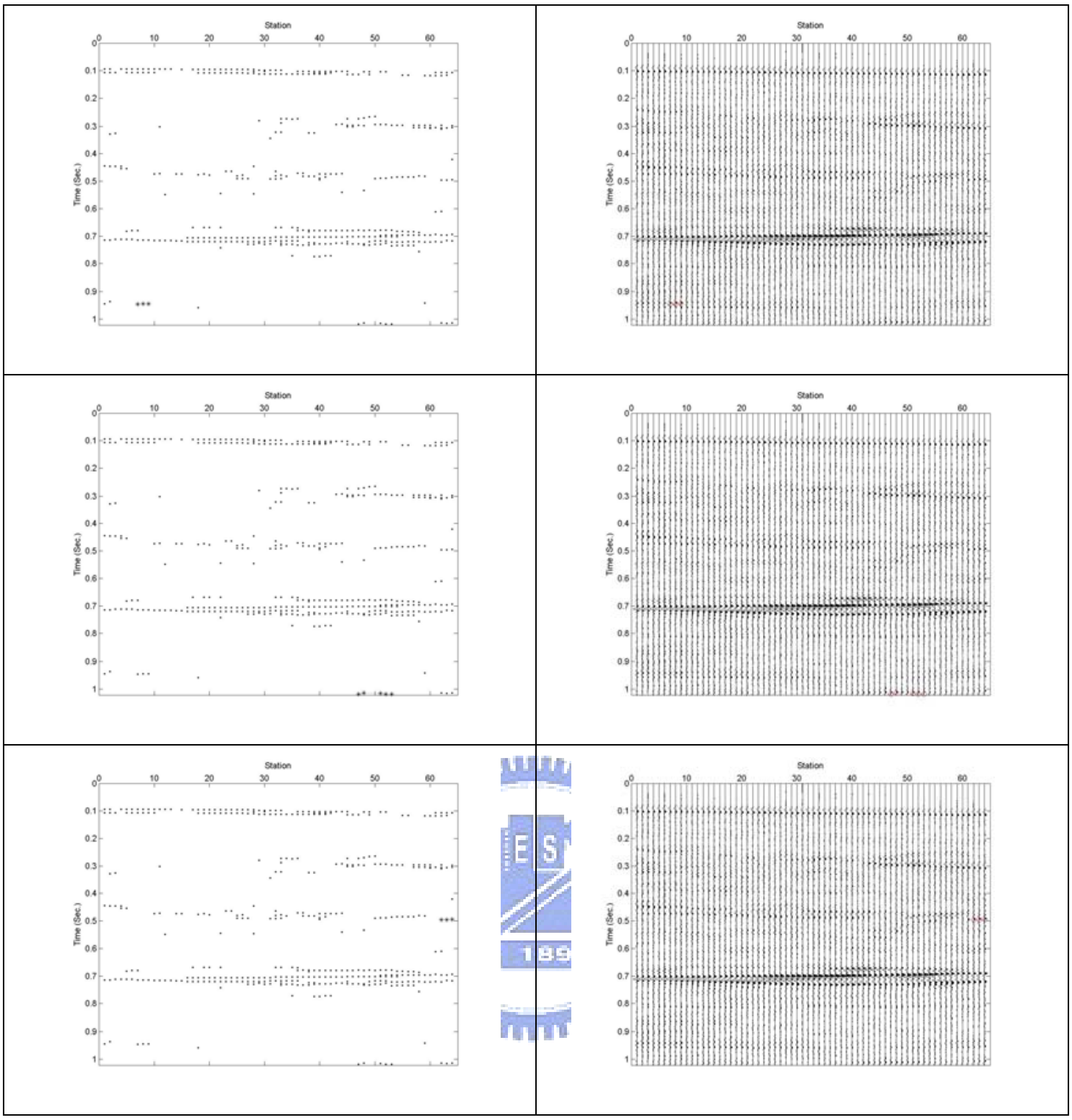


Figure 4.33.Pattern search results.

Experiment VIII

Part I: Preprocessing

This part is the same with the experiment IV.

Part II: Line linking

In this experiment, the parameters of the line linking we set the window size of linear regression is 7×5, $R(0) = 4$, connection weight $w_{ji} = 0.45 * (1/R(0))\ \forall \mathrm{i, j}$, self-feedback weight $w_s = 0$, tolerance limit $p = 30$, radius decreasing ratio

$\gamma = 0.4$. Figure 4.34 shows the update process from $t = 1$ to $t = 9$.

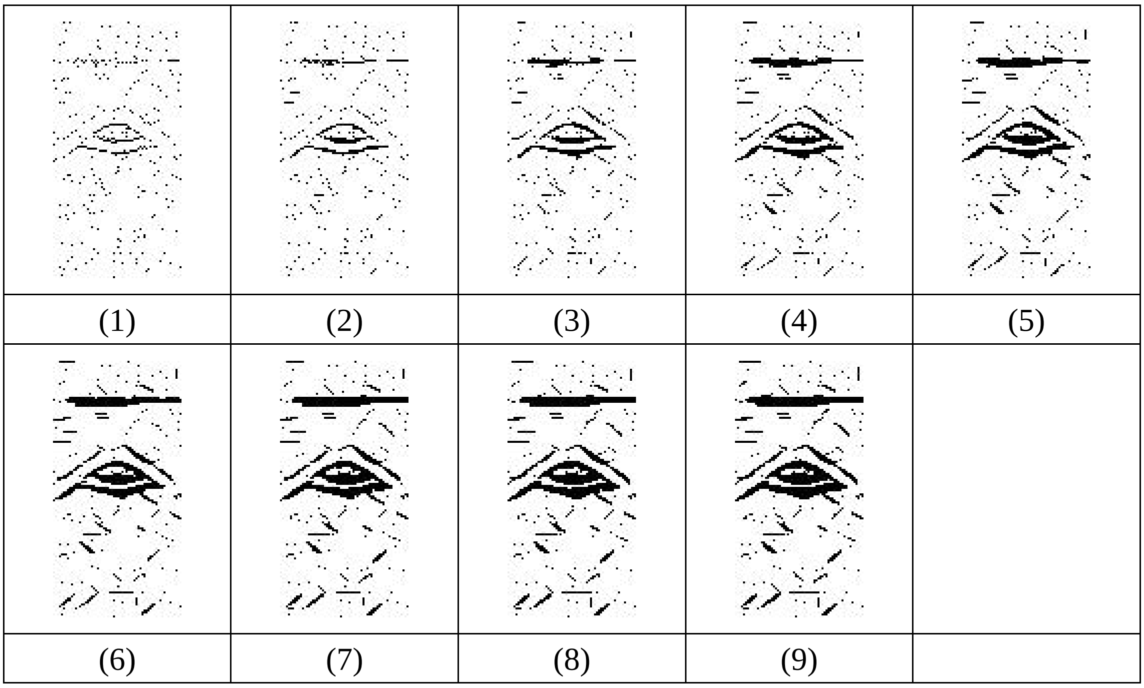
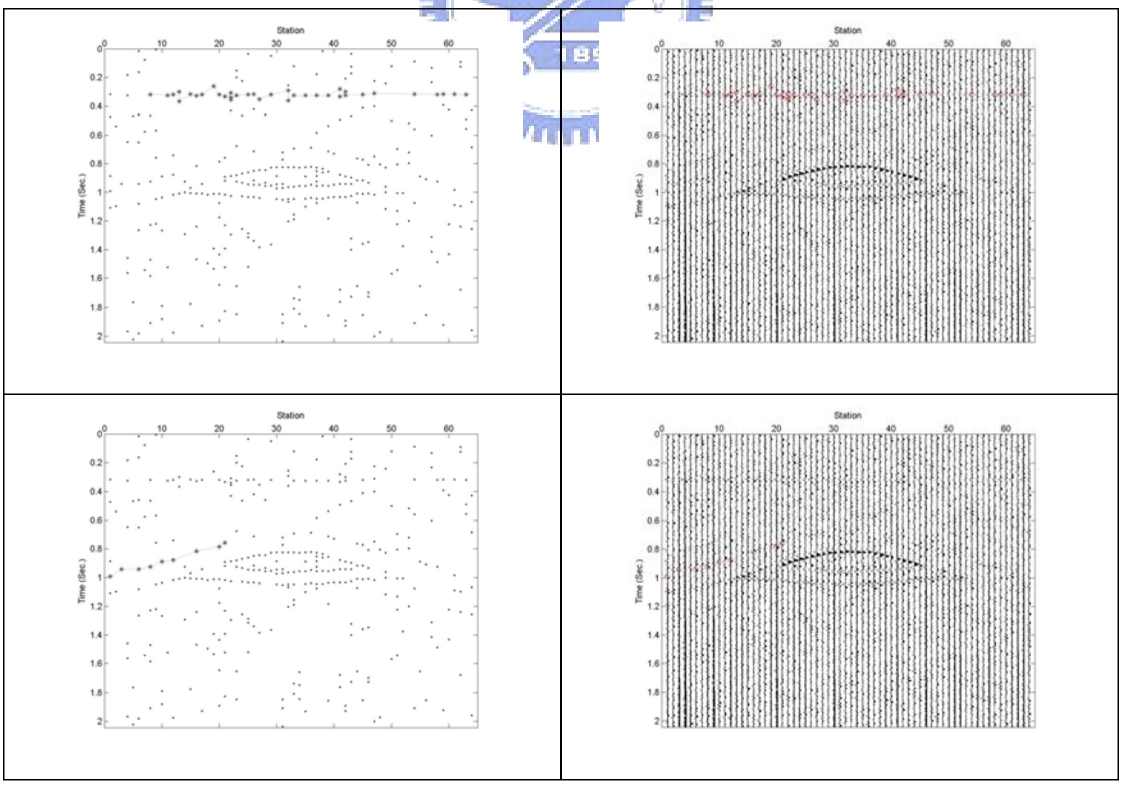
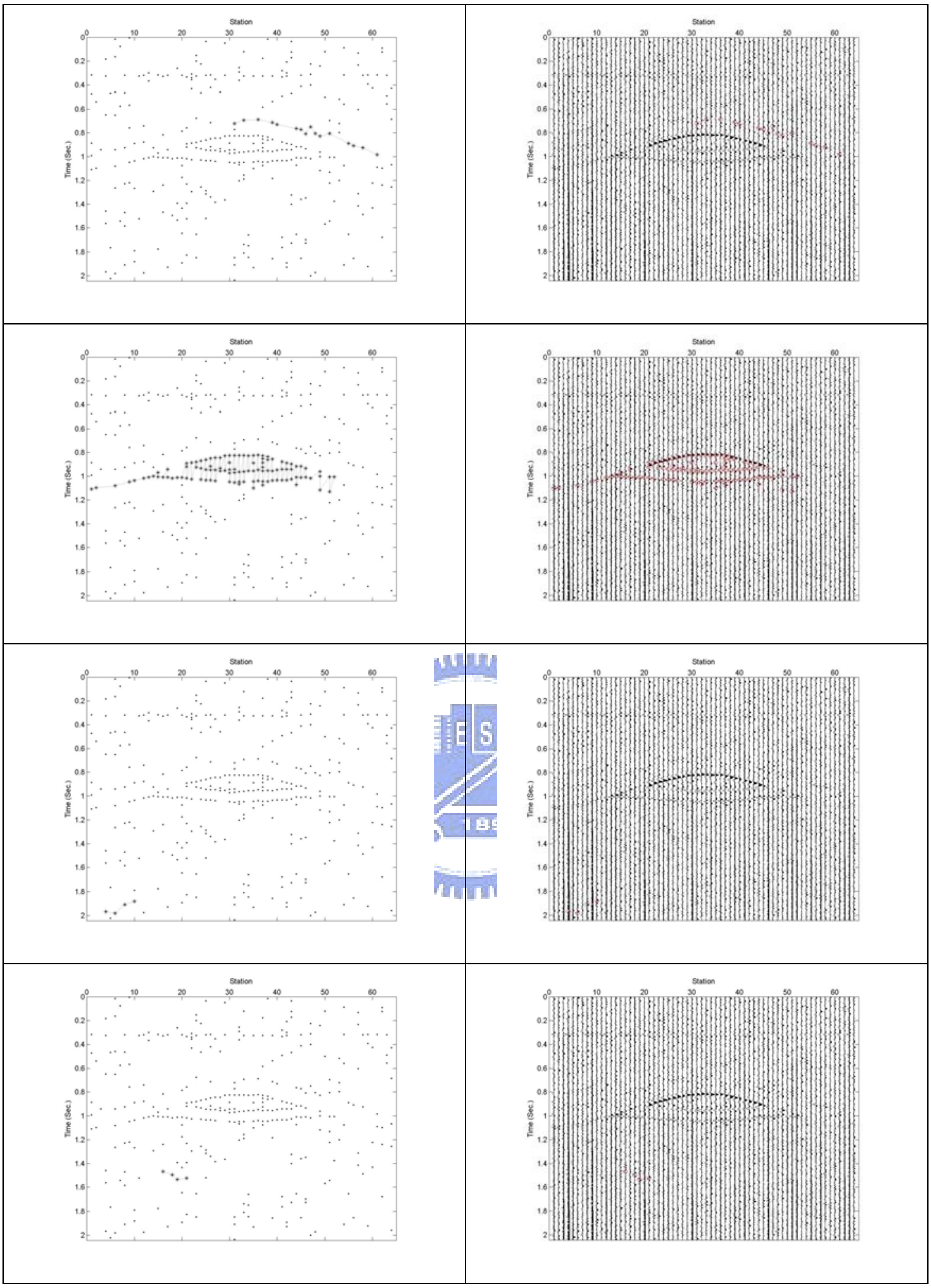


Figure 4.34. Update process from $t = 1$ to $t = 9$.

Part III: Pattern search

All horizons that have detected are shown in Figure 4.35.




Station
Time (Sec.)

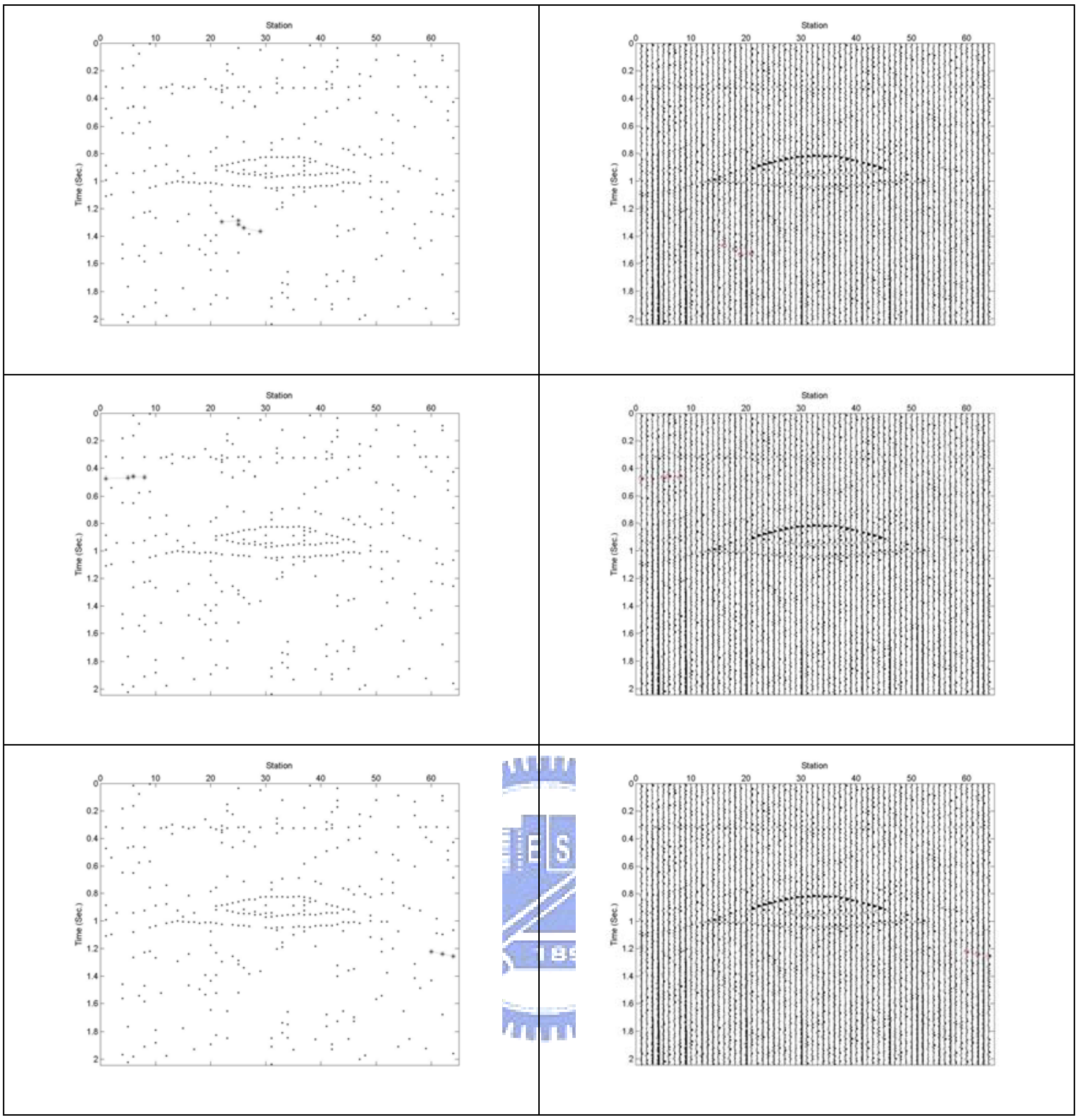


Figure 4.35.Pattern search results.