RESULTS OF FIELD TESTS OF THE NEW XCTD-2

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ABSTRACT

The eXpendable Conductivity, Temperature, and Depth profiler for temperature and salinity observations to a depth of 1,850 m (XCTD-2) was tested during the MR01-K04 cruise of the research vessel R/V MIRAI in the summer of 2001. The new, deep–water probe was recently developed by the Tsurumi-Seiki Co., LTD. Field tests of the XCTD-2 are indispensable for determining the depth-time equation and evaluating instrument accuracy. On the cruise, 12 probes were launched during CTD up-casts at 11 CTD stations. By using the pairs of XCTD and CTD profiles, the depth-time equation was estimated as $D = 3.4005t - 3.2 \times 10^{-4} t^2$, where D is the depth in meters and t is the elapsed time after the probe hits the sea surface. The temperature and salinity differences from CTD observations in the deep layer of 1000m to 1500m were -0.001^{0}C and -0.008psu respectively. Standard deviations were 0.018^{0}C and 0.013psu. These values indicate that the XCTD-2 is a useful addition to the XCTD system.

Introduction

The expendable conductivity temperature depth profiler (XCTD) system was developed in the 1990's and was released for general use for 1000m observation in 1997 by Tsurumi Seiki CO. LTD (TSK). At an early stage, a positive salinity bias and slow adjustment just after launch were recognized as points which should be improved (Mizuno and Watanabe, 1998). TSK has addressed these issues with significant design changes to the original XCTD observation system. TSK also received requests for development of a new model for deeper use and initiated development of an XCTD probe for 2000m observations (XCTD-2).

Field experiments of the XCTD-2 were conducted in the summer of 2001, taking advantage of participation in the MR01-K04 cruise of R/V Mirai conducted by

Japan Marine Science and Technology Center (JAMSTEC). This allowed comparison of profiles observed by XCTD-2 with high precision CTD profiles. The cruise was conducted to revisit the WHP-P17 and high precision CTD observations from the sea surface to the bottom were successfully performed at each station. The purposes of the field tests were to develop a depth-time equation for the new XCTD probe and to evaluate the accuracy of XCTD-2 observations.

Design of the XCTD-2 system

The basic structure of the XCTD-2 probe is very similar to the current model for 1000m-observation (XCTD-1) as shown in Mizuno and Watanabe (1998). The major differences are wire length and the wire diameter. The diameter of the wire is 0.07mm, which is 0.02mm thinner than that of the XCTD-1. The length of the wire stored in the canister and the probe are 1200m and 1900m, respectively. TSK estimated that the available observation depth was 1830m at 3.5 kt of ship speed. A highly efficient digital filter was installed in the MK-100 XCTD digital converter, in order to cope with the increased noise introduced by longer data transmission distances.

In-situ comparison tests

The MK-100 converter with revised ROM and a PC were placed in a room behind the ship wheelhouse. A hand launcher was installed at the stern, about 50m from the CTD. In order to make XCTD-CTD concurrent observations, the XCTD probes were launched when the CTD-sonde reached a depth range of from 500m to 300m during up-casts.

The tests were performed at CTD stations including two training points and nine WHP-P17 revisit stations along the 135°W meridian as shown in Figure 1. The information and results of the observations are summarized in Table 1.

Nine of the 12 tests were successful. One failure was due to operator error, one to hand launcher malfunction, and one to a wire break caused by the ship propeller.

Data processing

The software for the XCTD observation was a version of the current program revised to allow deeper profiles. Initially, the depth-time equation for the XCTD-1 was used. Later, using the XCTD and CTD profiles obtained at the first training station at 39N, 179W, a temporary depth-time equation was determined according to the method adopted by Hanawa et al. (1995).

Finally, all of the profiles were converted with the temporary depth-time equation and were then compared with CTD profiles. Again using the method adopted by Hanawa et al. (1995), the final depth-time equation was developed utilizing a comparison to the CTD standard gradient profiles to eliminate temperature errors. The method is based on minimizing the differences between the CTD and XCTD temperature gradient profiles at the center of fixed depth-window intervals. The least squares method was then used to determine the quadratic equation coefficients for each window and the mean of all the values was calculated to determine the general coefficients.

Depth-time equation

The depth-time equation is in the form, $D = at + bt^2$, where D is the depth in meters and t is the elapsed time in seconds after the probe hits the sea surface. The depth-time equation obtained for each test is shown in table 2. Averaged values of coefficients a and b were adopted for the general equation as described in the section above. The depth-time equation for XCTD-2 was then determined to be:

$$D = 3.4005t - 3.2 \times 10^{-4} t^2$$

Figure 2 shows the depth difference of each equation from the averaged equation. The standard deviation of the depth difference at 560 sec (about 1800m by averaged equation) is 14m and difference at 305 sec (about 1000m) is 4.2m.

Temperature/salinity comparison

Temperature and salinity profiles for all XCTD-2 data were calculated by using the depth-time equation. Each profile is shown in Figure 3 with the corresponding CTD profile and T-S diagrams are shown in Figure 4. As seen in figure 3, the XCTD-2 profiles follow the CTD profiles well. The temperature and salinity differences averaged for the deep layer from 1000m to 1500m were calculated and summarized in table 2. The mean value of differences was –0.001℃ for temperature and –0.008psu for salinity. The standard deviations were 0.018℃ and 0.013psu, respectively. These values are better than the initial evaluation of model XCTD-1 by Mizuno and Watanabe (1998). These statistical values meet the specification presented by the manufacturer.

The temperature and salinity sections observed by XCTD-2 along WHP-P17 line from 30°N to 41°N were constructed and are shown in figure 5 and 6. The CTD sections and the difference between the XCTD and CTD observations are attached for comparison. The detailed structure of subsurface temperature fields are captured quite well by the XCTD-2. As to the salinity field, the structure of the water mass distribution can be evaluated by XCTD salinity section. However, the influence of the variation in accuracy of each probe within the range +/-0.02 appears as an unnatural undulation of the 34.5 psu contour line in the deep layer. The salinity field in the deeper layer where the vertical gradient is small should be interpreted with careful consideration of the accuracy of the salinity measurement of the XCTD.

Acknowledgements

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References

Hanawa, K., P. Rual, R. Bailey, A. Sy and M. Szabados (1995): New depth-time equation for Sippican or TSK T-7, T-6, and T-4 expendable bathythermographs (XBT). Deep Sea Res., 42,1423-1451.

Mizuno, K. and T. Watanabe (1998): Preliminary Results of in-situ XCTD/CTD comparison test. J. Oceanogr. 54,373-380.

Table 1 XCTD-2 test stations

Station	Date (UT)	Time	Latitude		Longitude		S/N	Depth
TR01S02	2001/07/31	04:43	39-03.19	N	179-49.52	W	#01075609	1823
TR02S02	2001/08/04	16:03	31-01.88	N	150-01.40	W	#01075619	-
P17C26	2001/08/06	21:55	30-00.06	N	134-59.81	W	#01075620	1047
P17C23	2001/08/07	13:12	31-31.94	N	135-00.12	W	#01075618	1824
P17C21	2001/08/08	00:01	32-36.53	N	135-00.71	W	#01075615	405
P17C21	2001/08/08	00:11	32-36.59	N	135-00.74	W	#01075616	1819
P17C18	2001/08/08	15:48	34-04.47	N	134-59.78	W	#01075612	1810
P17N29	2001/08/09	02:49	34-59.36	N	135-01.01	W	#01075617	1824
P17N32	2001/08/10	01:26	36-30.01	N	135-00.68	W	#01075613	1842
P17N35	2001/08/10	18:18	38-00.34	N	135-00.99	W	#01075614	1803
P17N39	2001/08/11	15:03	39-37.17	N	135-01.20	W	#01075610	1833
P17N46	2001/08/13	00:29	40-58.83	N	134-58.60	W	#01075611	1824

Table 2. Depth-time equation for XCTD-2 and temperature and salinity differences between XCTD-2 and CTD observations averaged for the depth range 1000-1500m.

Station	Time-Depth Equation	Temp. dif.	Sal. Dif.	S/N
TR01S02	D = 3.40316t-0.00029t^2	-0.010	0.001	#01075609
TR02S02	----------------------	-------	--------	#01075619
P17C26	----------------------	-------	--------	#01075620
P17C23	D = 3.43509t-0.00044t^2	0.002	-0.001	#01075618
P17C21	----------------------	-------	--------	#01075615
P17C21	D = 3.44297t-0.00043t^2	0.004	-0.027	#01075616
P17C18	D = 3.40269t-0.00039t^2	0.021	-0.030	#01075612
P17N29	D = 3.37367t-0.00032t^2	0.018	-0.005	#01075617
P17N32	D = 3.40348t-0.00025t^2	-0.039	-0.010	#01075613
P17N35	D = 3.38351t-0.00027t^2	-0.012	0.013	#01075614
P17N39	D = 3.36603t-0.00023t^2	0.001	-0.017	#01075610
P17N46	D = 3.39365t-0.00030t^2	0.004	-0.017	#01075611
Mean	D = 3.40047t-0.00032t^2	-0.001	-0.008	
S.D.	(0.02565)(0.00008)	(0.018)	(0.013)	

Figure caption

Figure 1

Location of CTD/XCTD stations for XCTD-2 tests (●) and MR01-K04 stations (˙).

Figure 2

Difference from averaged depth-time equation.

Figure 3

Vertical temperature and salinity profiles of XCTD-2/CTD.

Figure 4

T-S diagrams for XCTD-2/CTD.

Figure 5

a) Vertical temperature section along 135W observed by XCTD-2.

b) Vertical temperature section along 135W observed by CTD.

c) Temperature difference section along 135W, XCTD-2 – CTD.

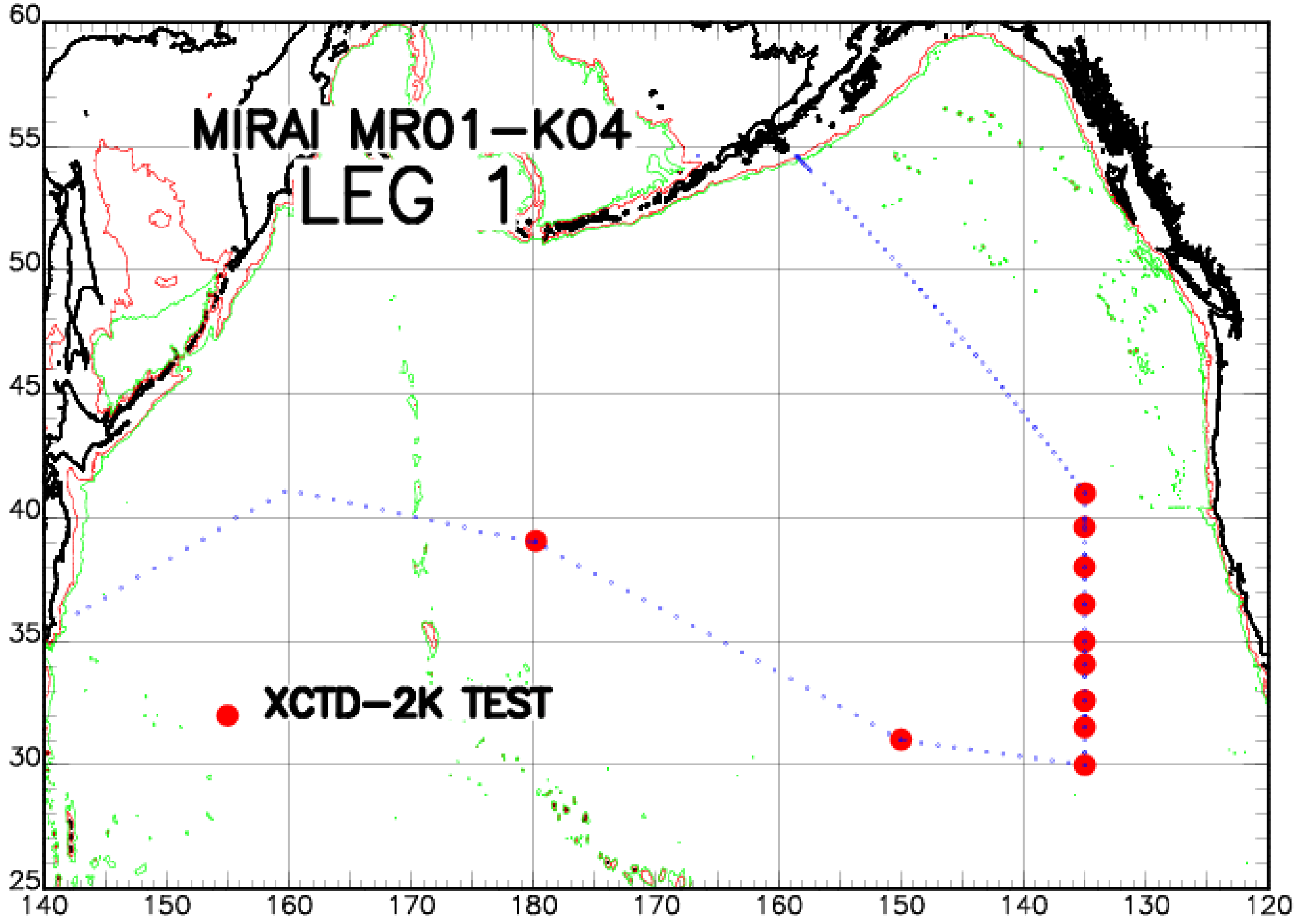
Figure 6

a) Vertical salinity section along 135W observed by XCTD-2.

b) Vertical salinity section along 135W observed by CTD.

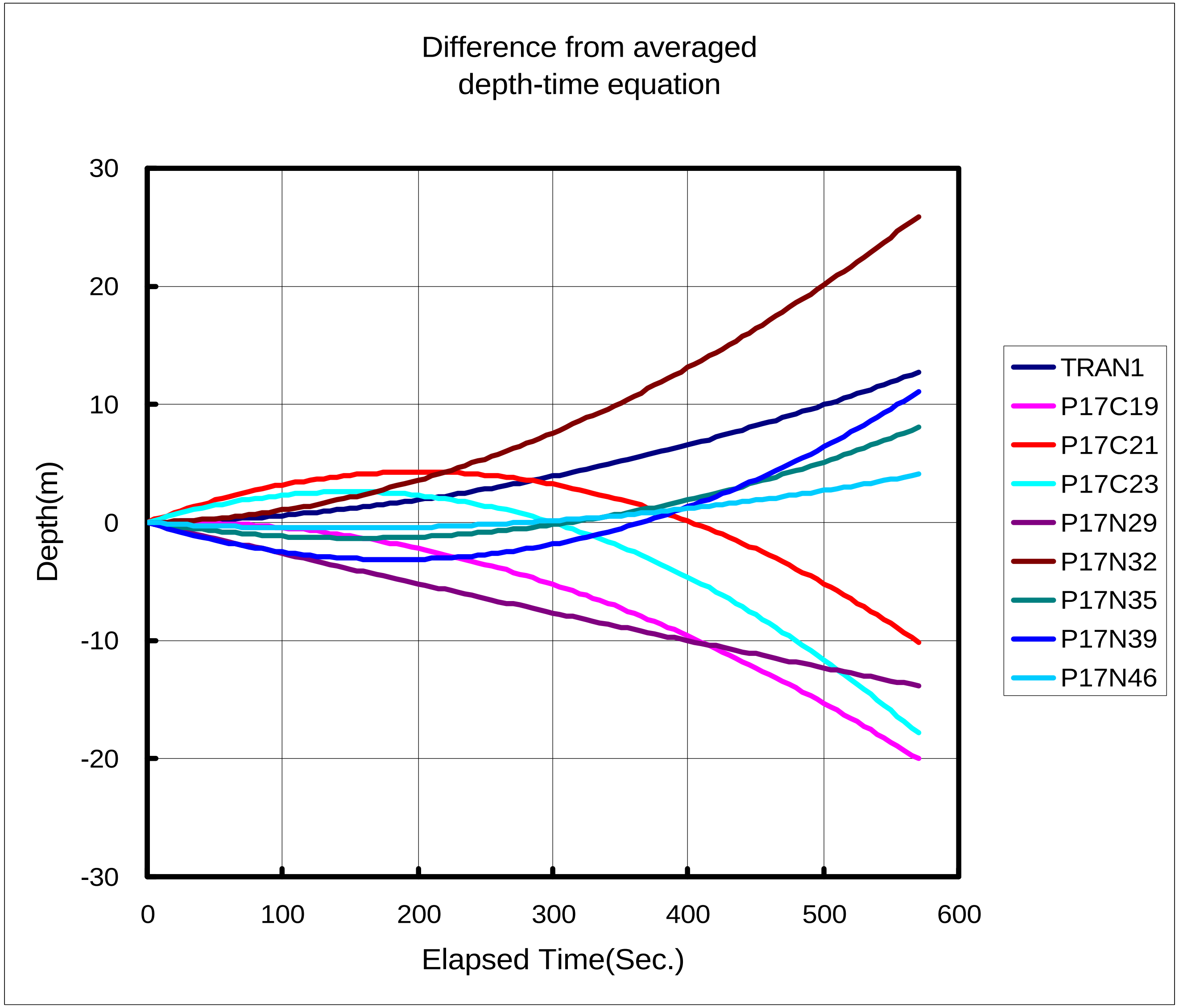
c) Salinity difference section along 135W, XCTD-2 – CTD.

Figure 1



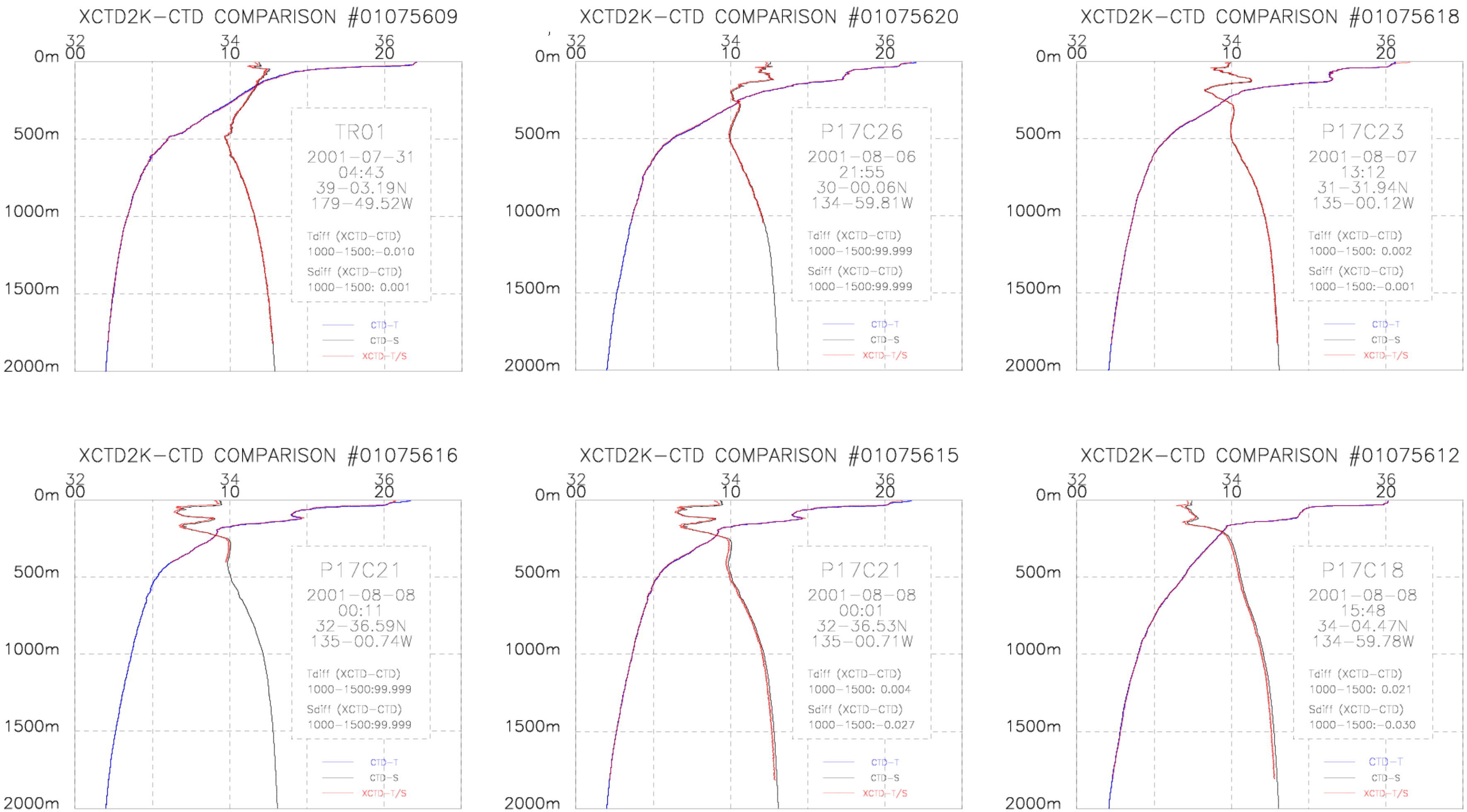
MIRAI MR01-K04
LEG 1
XCTD-2K TEST
60
55
50
45
40
35
30
25
140
150
160
170
180
170
160
150
140
130
120

Figure 2



Difference from averaged
depth-time equation
30
20
10
0
-10
-20
-30
Depth(m)
0
100
200
300
400
500
600
Elapsed Time(Sec.)
TRAN1
P17C19
P17C21
P17C23
P17N29
P17N32
P17N35
P17N39
P17N46

Figure 3



XCTD2K−CTD COMPARISON #01075609
32 00
34 10
36 20
0m
500m
1000m
1500m
2000m
TR01
2001−07−31
04:43
39−03.19N
179−49.52W
Tdiff (XCTD−CTD)
1000−1500:−0.010
Sdiff (XCTD−CTD)
1000−1500: 0.001
CTD−T
CTD−S
XCTD−T/S
XCTD2K−CTD COMPARISON #01075620
P17C26
2001−08−06
21:55
30−00.06N
134−59.81W
Tdiff (XCTD−CTD)
1000−1500:99.999
Sdiff (XCTD−CTD)
1000−1500:99.999
XCTD2K−CTD COMPARISON #01075618
P17C23
2001−08−07
13:12
31−31.94N
135−00.12W
Tdiff (XCTD−CTD)
1000−1500: 0.002
Sdiff (XCTD−CTD)
1000−1500:−0.001
XCTD2K−CTD COMPARISON #01075616
P17C21
2001−08−08
00:11
32−36.59N
135−00.74W
Tdiff (XCTD−CTD)
1000−1500:99.999
Sdiff (XCTD−CTD)
1000−1500:99.999
XCTD2K−CTD COMPARISON #01075615
P17C21
2001−08−08
00:01
32−36.53N
135−00.71W
Tdiff (XCTD−CTD)
1000−1500: 0.004
Sdiff (XCTD−CTD)
1000−1500:−0.027
XCTD2K−CTD COMPARISON #01075612
P17C18
2001−08−08
15:48
34−04.47N
134−59.78W
Tdiff (XCTD−CTD)
1000−1500: 0.021
Sdiff (XCTD−CTD)
1000−1500:−0.030

Figure 3

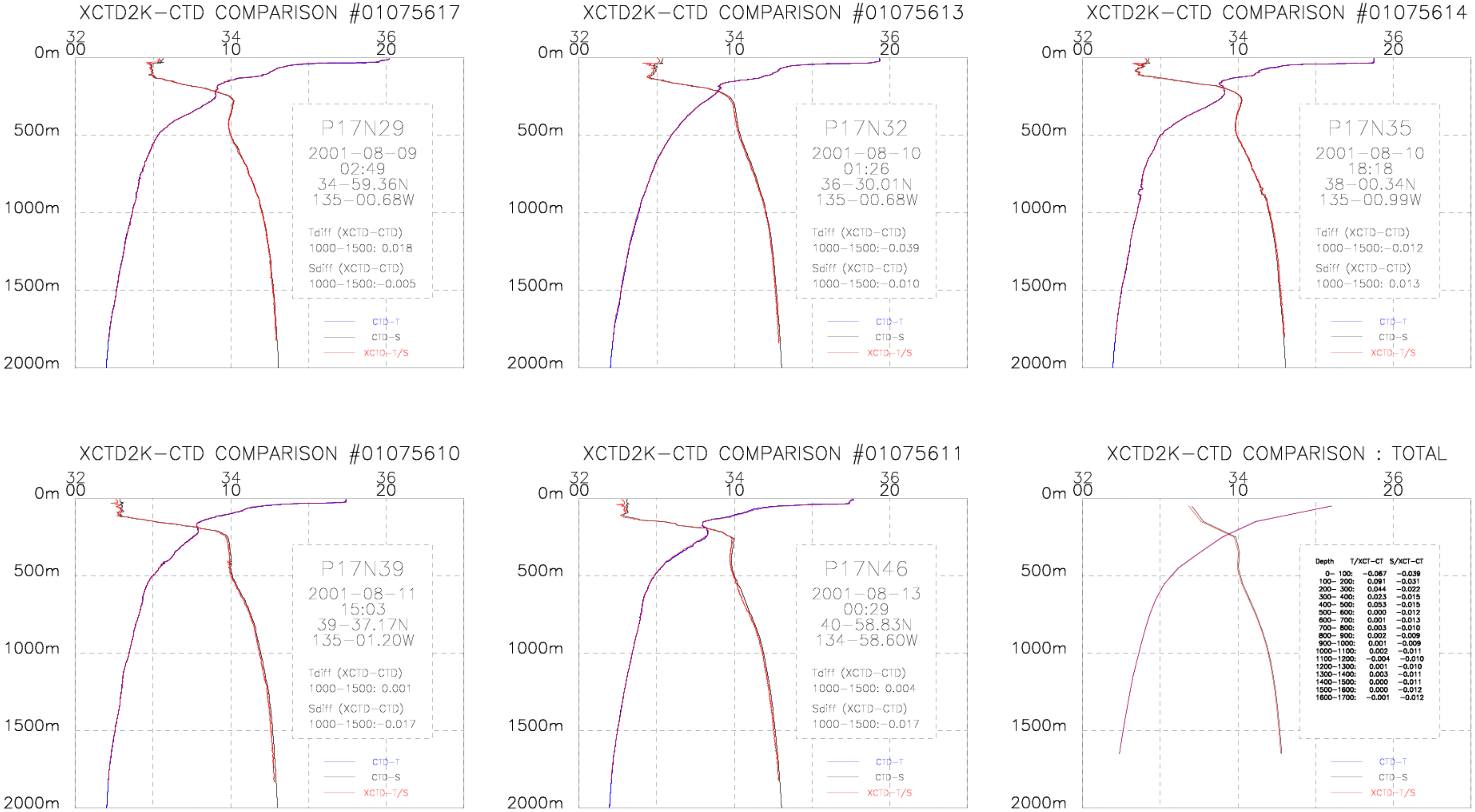

XCTD2K−CTD COMPARISON #01075617
P17N29
2001−08−09
02:49
34−59.36N
135−00.68W
Tdiff (XCTD−CTD)
1000−1500: 0.018
Sdiff (XCTD−CTD)
1000−1500: −0.005
XCTD2K−CTD COMPARISON #01075613
P17N32
2001−08−10
01:26
36−30.01N
135−00.68W
Tdiff (XCTD−CTD)
1000−1500: −0.039
Sdiff (XCTD−CTD)
1000−1500: −0.010
XCTD2K−CTD COMPARISON #01075614
P17N35
2001−08−10
18:18
38−00.34N
135−00.99W
Tdiff (XCTD−CTD)
1000−1500: −0.012
Sdiff (XCTD−CTD)
1000−1500: 0.013
XCTD2K−CTD COMPARISON #01075610
P17N39
2001−08−11
15:03
39−37.17N
135−01.20W
Tdiff (XCTD−CTD)
1000−1500: 0.001
Sdiff (XCTD−CTD)
1000−1500: −0.017
XCTD2K−CTD COMPARISON #01075611
P17N46
2001−08−13
00:29
40−58.83N
134−58.60W
Tdiff (XCTD−CTD)
1000−1500: 0.004
Sdiff (XCTD−CTD)
1000−1500: −0.017
XCTD2K−CTD COMPARISON : TOTAL
Depth T/XCT−CT S/XCT−CT
0− 100: −0.067 −0.039
100− 200: 0.091 −0.031
200− 300: 0.044 −0.022
300− 400: 0.023 −0.015
400− 500: 0.053 −0.015
500− 600: 0.000 −0.012
600− 700: 0.001 −0.013
700− 800: 0.003 −0.010
800− 900: 0.002 −0.009
900−1000: 0.001 −0.009
1000−1100: 0.002 −0.011
1100−1200: −0.004 −0.010
1200−1300: 0.001 −0.010
1300−1400: 0.003 −0.011
1400−1500: 0.000 −0.011
1500−1600: 0.000 −0.012
1600−1700: −0.001 −0.012
32 34 36
00 10 20
0m
500m
1000m
1500m
2000m
CTD−T
CTD−S
XCTD−T/S

Figure 4

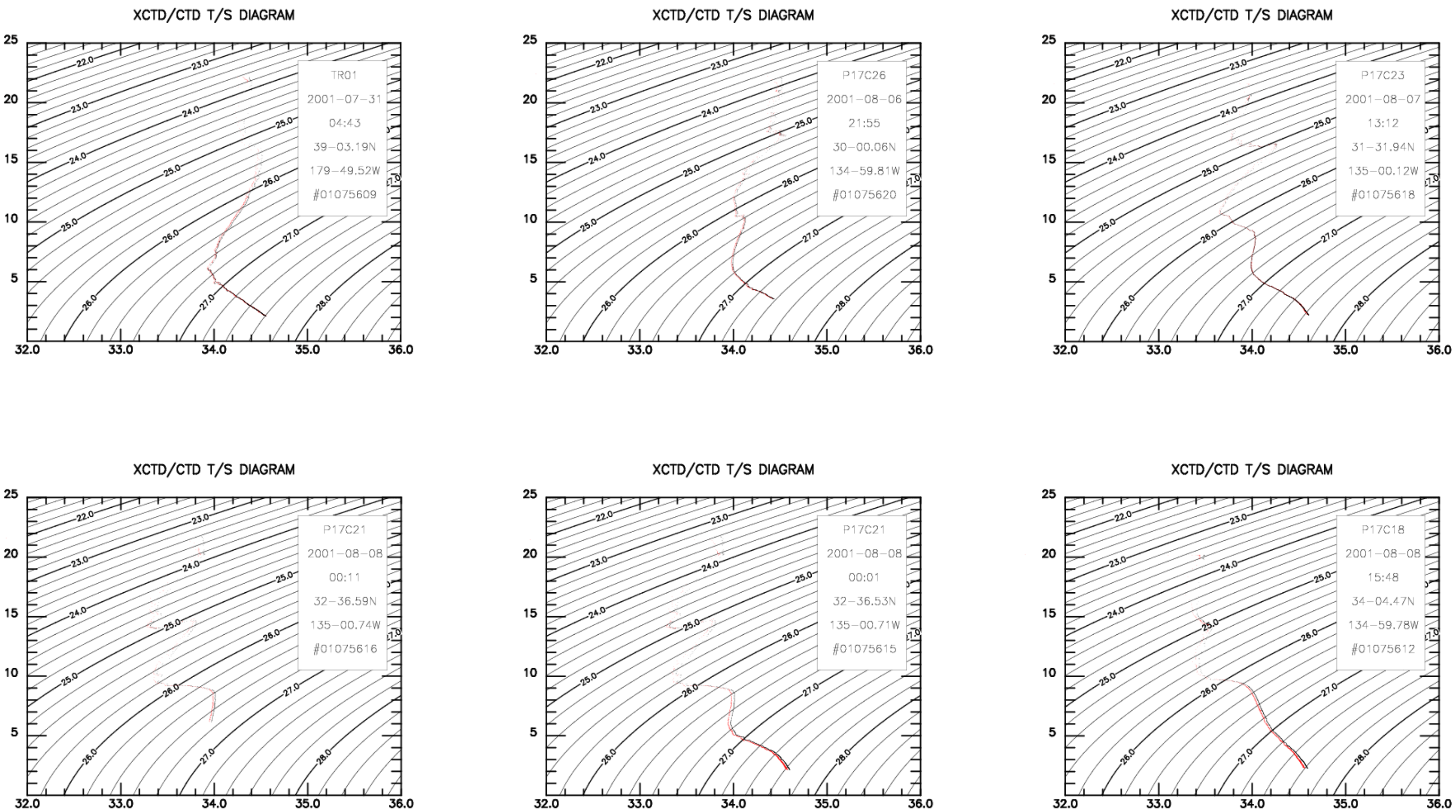

XCTD/CTD T/S DIAGRAM
TR01
2001-07-31
04:43
39-03.19N
179-49.52W
#01075609
XCTD/CTD T/S DIAGRAM
P17C26
2001-08-06
21:55
30-00.06N
134-59.81W
#01075620
XCTD/CTD T/S DIAGRAM
P17C23
2001-08-07
13:12
31-31.94N
135-00.12W
#01075618
XCTD/CTD T/S DIAGRAM
P17C21
2001-08-08
00:11
32-36.59N
135-00.74W
#01075616
XCTD/CTD T/S DIAGRAM
P17C21
2001-08-08
00:01
32-36.53N
135-00.71W
#01075615
XCTD/CTD T/S DIAGRAM
P17C18
2001-08-08
15:48
34-04.47N
134-59.78W
#01075612

Figure 4

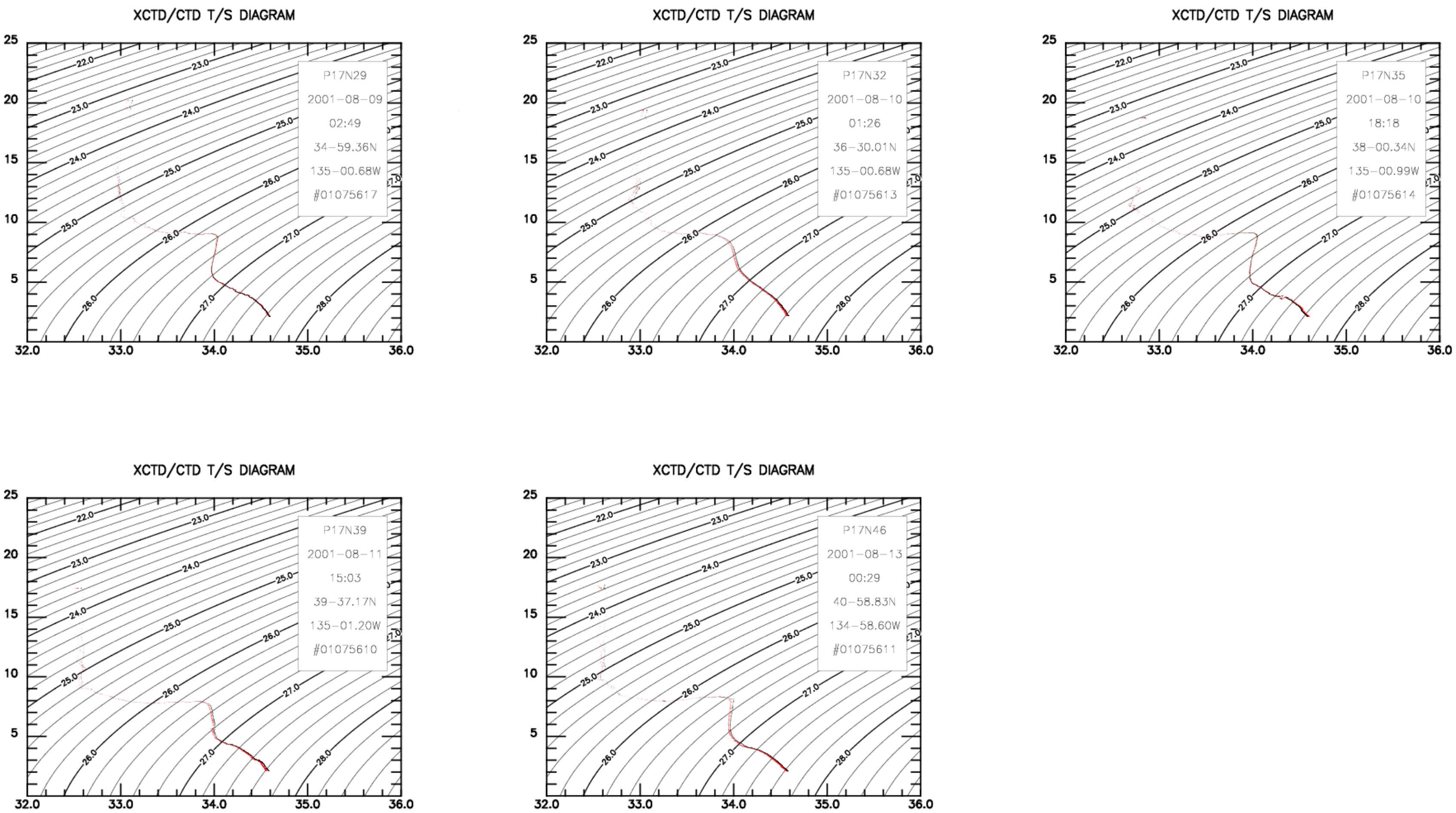

XCTD/CTD T/S DIAGRAM
P17N29
2001-08-09
02:49
34-59.36N
135-00.68W
#01075617
XCTD/CTD T/S DIAGRAM
P17N32
2001-08-10
01:26
36-30.01N
135-00.68W
#01075613
XCTD/CTD T/S DIAGRAM
P17N35
2001-08-10
18:18
38-00.34N
135-00.99W
#01075614
XCTD/CTD T/S DIAGRAM
P17N39
2001-08-11
15:03
39-37.17N
135-01.20W
#01075610
XCTD/CTD T/S DIAGRAM
P17N46
2001-08-13
00:29
40-58.83N
134-58.60W
#01075611

Figure 5

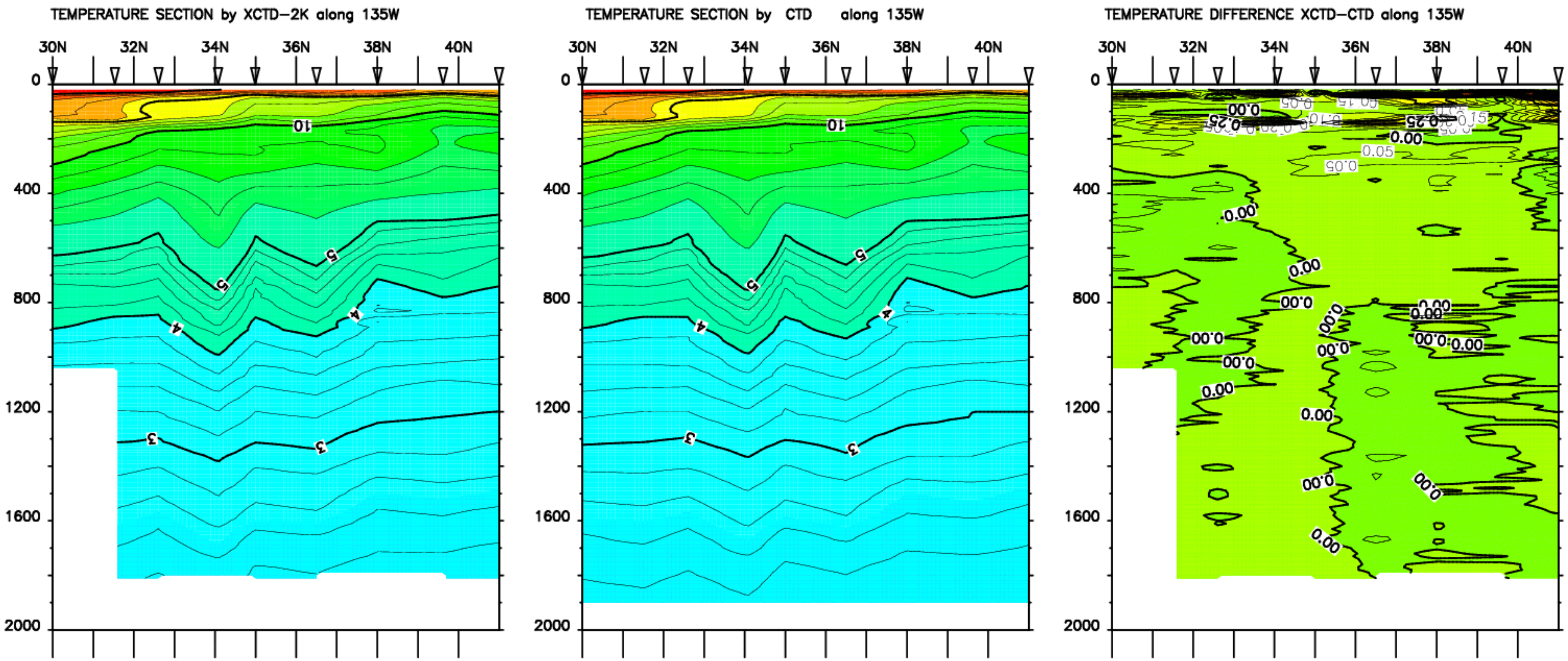
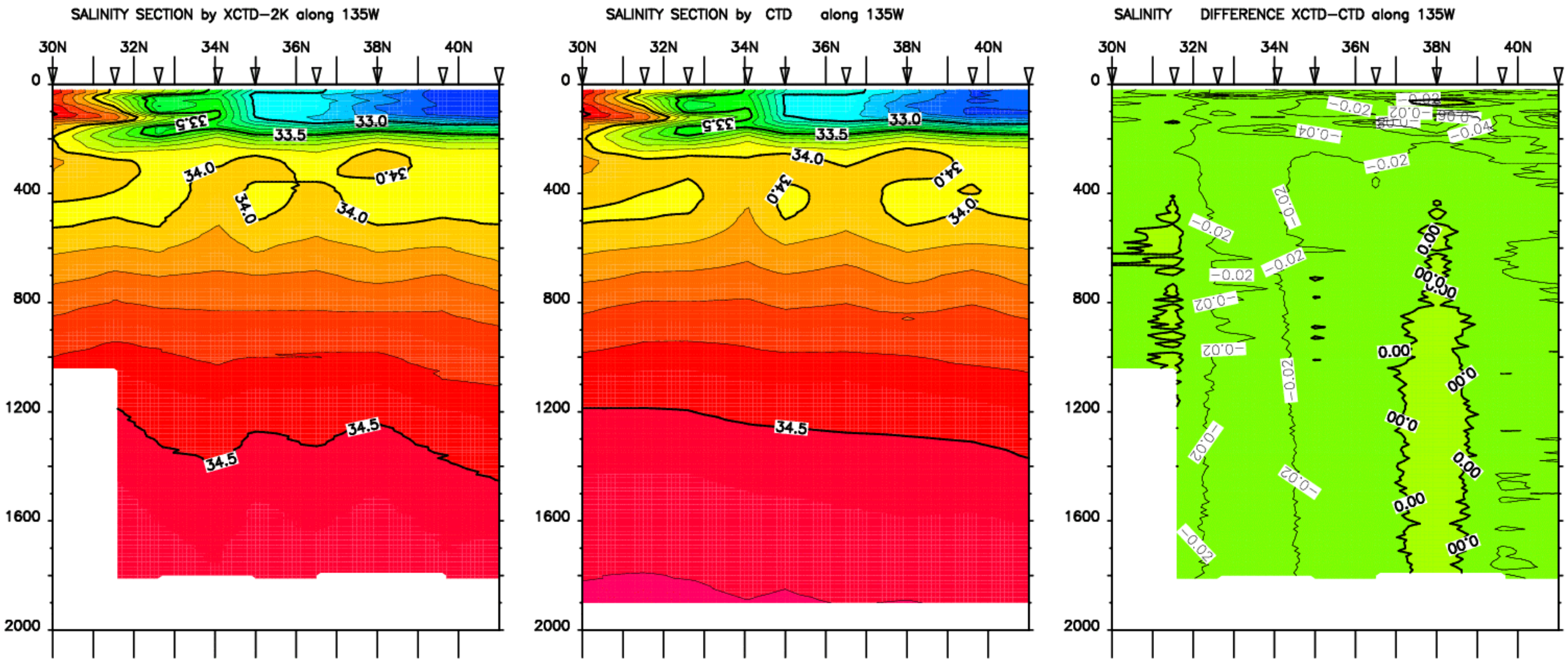

TEMPERATURE SECTION by XCTD-2K along 135W
TEMPERATURE SECTION by CTD along 135W
TEMPERATURE DIFFERENCE XCTD-CTD along 135W
30N
32N
34N
36N
38N
40N
0
400
800
1200
1600
2000

Figure 6


SALINITY SECTION by XCTD-2K along 135W
SALINITY SECTION by CTD along 135W
SALINITY DIFFERENCE XCTD-CTD along 135W
30N
32N
34N
36N
38N
40N
0
400
800
1200
1600
2000
33.0
33.5
34.0
34.5
-0.02
-0.04
0.00