The 2008 North Atlantic Bloom Experiment

Calibration Report #10

Calibration of the Optode Oxygen Sensors on Seagliders

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Summary

Oxygen data from the optodes on the 4 NAB seagliders was corrected for time lags in oxygen and temperature and by a gain and offset in oxygen. Values of these parameters were chosen to minimize the difference between oxygen on up and down casts, to minimize the difference in oxygen between different gliders and between gliders and float 48 on 40 nearby profiles and to minimize to difference in oxygen between gliders and Winkler bottle data on 4 glider calibration casts made from the *R.V. Knorr*. The resulting oxygen has an error of ±2 μMol kg^{-1}.

1. Oxygen Sensors, Mission and Errors

The four seagliders used in NAB08 each carried an Aanderaa 3830 optode. Seagliders [140 141 142 143] carried serial numbers [769 016 013 014] with foil batches [50005 1707 1707 1707] respectively. The optodes were mounted near the tail of the vehicle as shown in Fig. 1. The sampling interval varied from 5s to 85s, decreasing with depth, with the optodes turned off between 600dbar and 900 dbar starting on day 116. The gliders profiled to about 980 dbar.

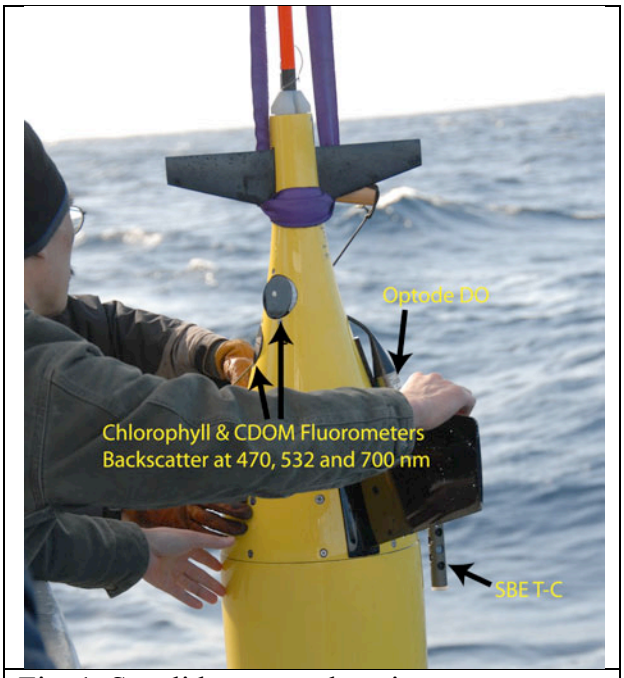


Fig. 1. Seaglider sensor locations

Data from data release 2.2 was used in this analysis. The optode computes dissolved oxygen from measurements of 'bphase' and temperature. Since the optode temperature is inferior to that measured by the Seabird sensors, dissolved oxygen is recomputed in the basic processing using the Seabird oxygen. All analysis here was done using this recomputed oxygen, variable *aanderaa3830_dissolved_oxygen* from data release v2.2;

3. Optode Calibration formula

Optode errors are due both to calibration errors in the sensor and to time lags in its oxgen and temperature responses. The optode is adjusted using the formula

$$[O_2]_{cal} = A + B*[O_2]_{in} + \tau \frac{d[O_2]_{in}}{dt} + C\frac{dT}{dt} \qquad (1)$$

Note that this is somewhat different than the formula used to adjust the float optode in NAB report #3. This may represent the greater importance of time lags in the glider data, since gliders move faster than floats, the different errors of the different sensors, or differing arbitrary empirical choices in the calibration processes.

4. Lag Correction *(updown2.m)*

The constants τ and *C* correct for the time response of the optode. They are computed by minimizing the difference between the up and down values of oxygen in the same glider dive using a straightforward least-squares minimization on the depth range of 0-100m. Using the full depth range does not change the answer significantly. Fig. 2 shows the result for glider 140. Results for the other gliders are shown in Appendix 1. The value of τ varies from 19s to 25s between gliders; the value of C varies by ±12%.

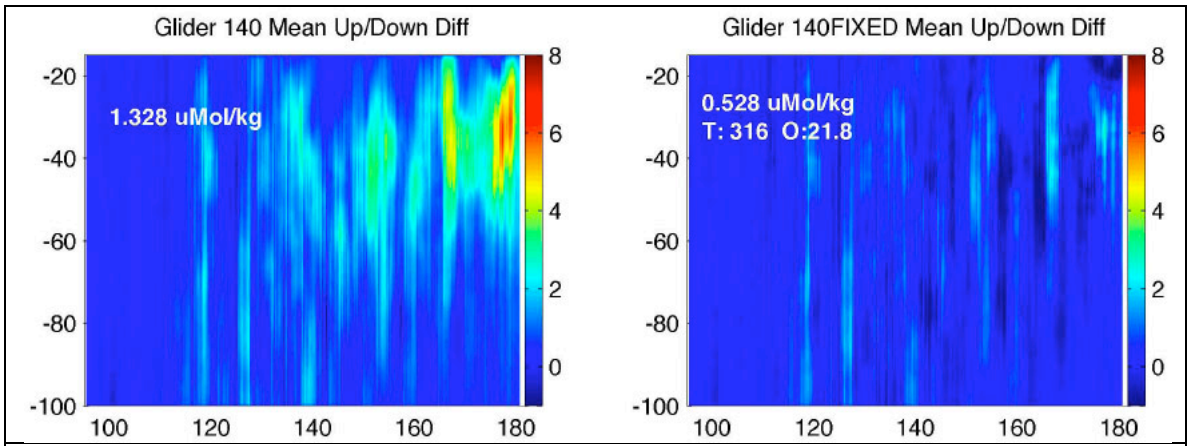


Fig. 2. Smoothed difference between up and down values of oxygen measured by the optode on glider 140. Left) Before lag correction. Right) After lag correction. RMS value, printed on plot, is decreased.

5. Calibration

The constants *A* and *B* are computed by minimizing the differences between optode oxygen on nearby gliders, between optode oxygen on gliders and calibrated oxygen on float 48 and between optode oxygen on gliders and Winkler bottle samples taken from the *R.V. Knorr*. The values were adjusted manually and included in the function *CorrectGliderOptode.m* listed below. The results after adjustment are shown here.

Intercomparison was done on 40 pairs of profiles in which two gliders or a float and glider were closer than 2 km. For each profile the mean and median differences between the oxygen values were computed in a depth range of 50-500m. A sample profile-profile intercomparison is shown in Fig. 3; the entire set is shown in Appendix 2.

The differences for all profile pairs are shown in Fig. 4. The depth-averaged differences between profiles is almost always less than ±2μMol kg^{-1}.

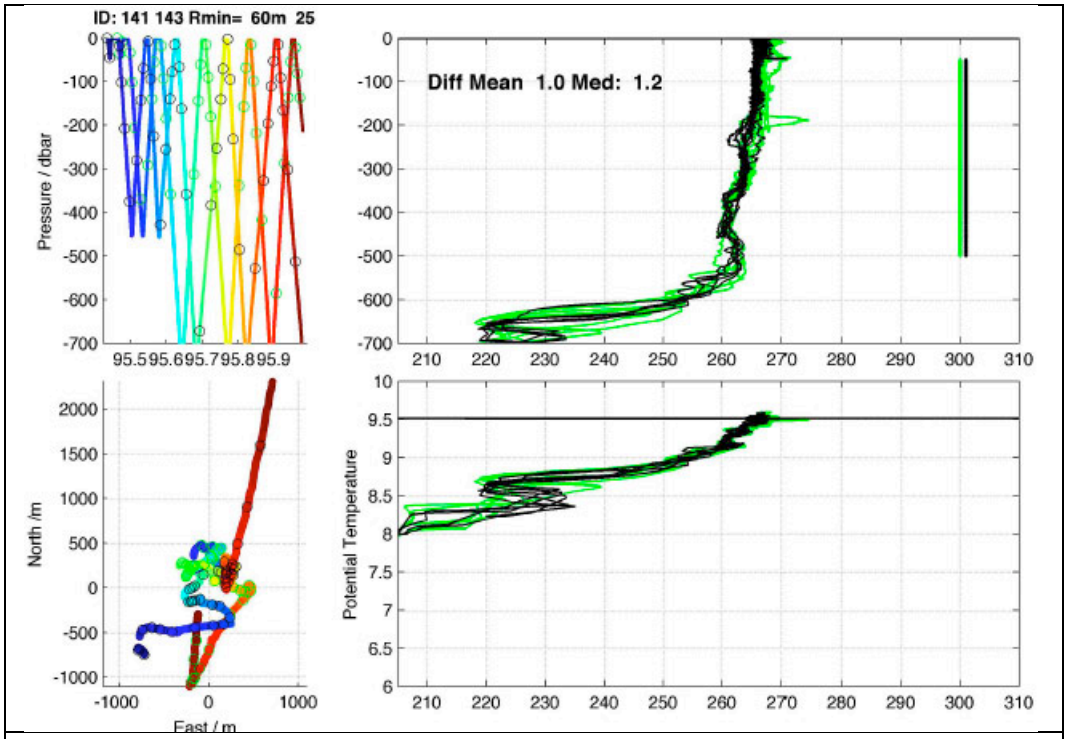


Fig. 3. Sample intercomparison cast between Seagliders 141 (green) and 143 (black). Upper Left: Depths of two gliders against time and colored by time. Lower Left: Positions of two gliders colored by time. Upper Right: Profiles of oxygen against depth. Lower Right: Profiles of oxygen against potential temperature. For this pair, the mean difference is 1.0 μMol kg^{-1}.

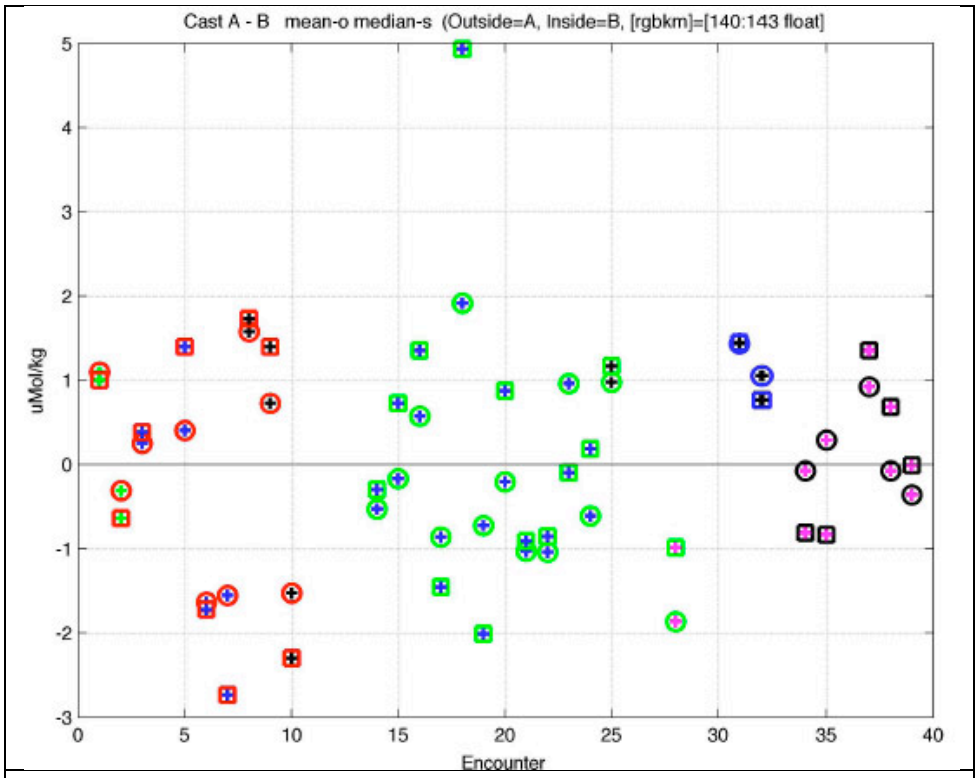


Fig. 4. Average profile differences A-B colored by pair type. Inside symbol indicates profile A; outside indicates B. Colors [red, green, blue, black, magenta] correspond to [gliders 140, 141, 142, 143, and float 48].

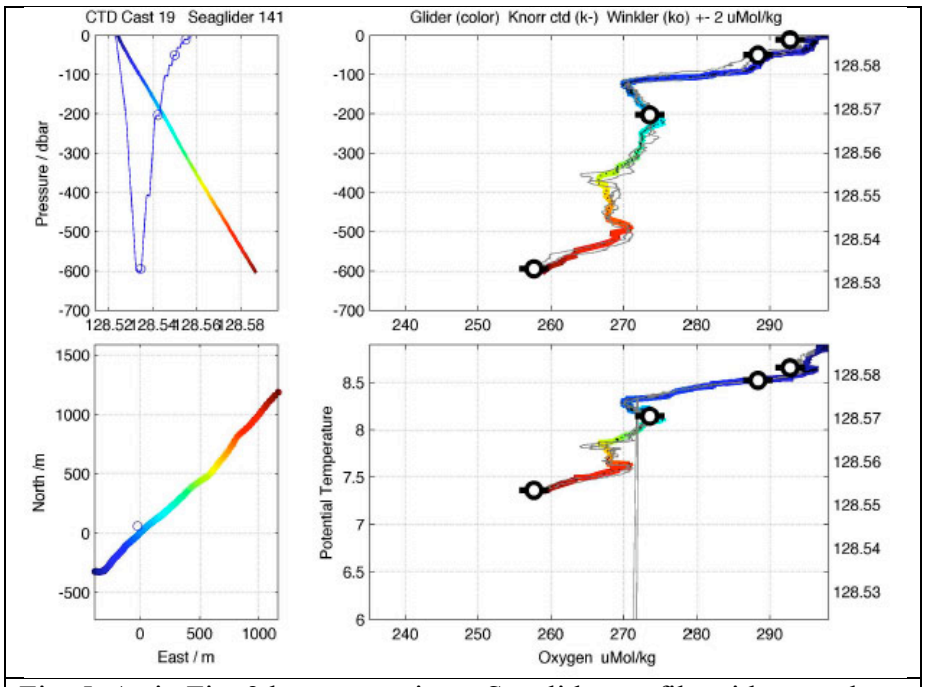


Fig. 5. As in Fig. 3 but comparing a Seaglider profile with a nearby R.V. Knorr CTD cast. Circles show Winkler bottle samples; horizontal bar is ±2μMol kg^{-1} .

Oxygen profiles at each of the 4 glider calibration casts from the *R.V. Knorr* were compared to Winkler oxygen samples taken on these casts. An example is shown in Fig. 4; all 4 casts are shown in Appendix 3. Most of the Winkler samples are within ±2μMol kg^{-1} of the glider measurement. The cast for glider 140 has significantly more error. This cold easily be due to the presence of a sharp water mass gradient in this vicinity, as can be seen, for example, in many of the other calibration casts in NAB report #3.

6. Deep Oxygen Values

Figure 5 compares the deep glider oxygen values with data from 4 WOCE cruises. At the coldest temperatures, the gliders are consistent to better than ±2μMol. All of the WOCE data collapses to a small region at potential temperatures near 3.5C. Although the glider data does not reach these cold temperatures, it clearly trends toward this point. These data indicate that there are no gross errors in the glider oxygen at the greatest depths.

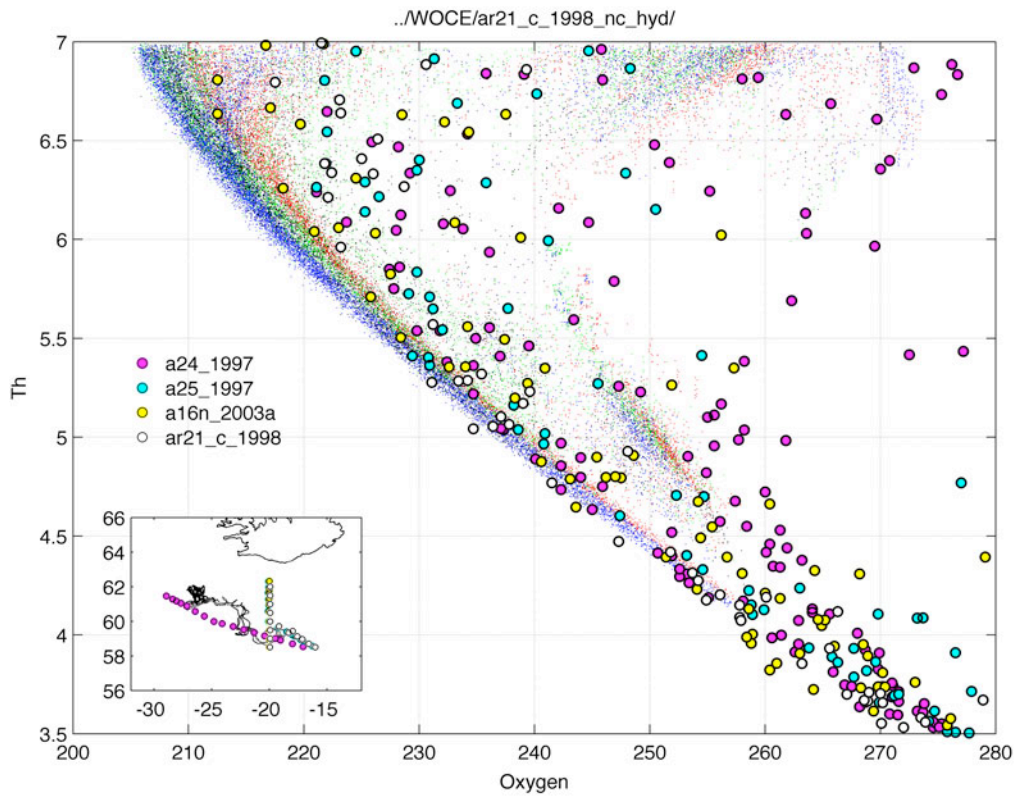


Fig. 5. Comparison of glider data (small dots color coded as in Fig. 3) with data from 4 WOCE cruises in this region (large circles). Data is plotted in potential temperature/oxygen coordinates.

7. Conclusion

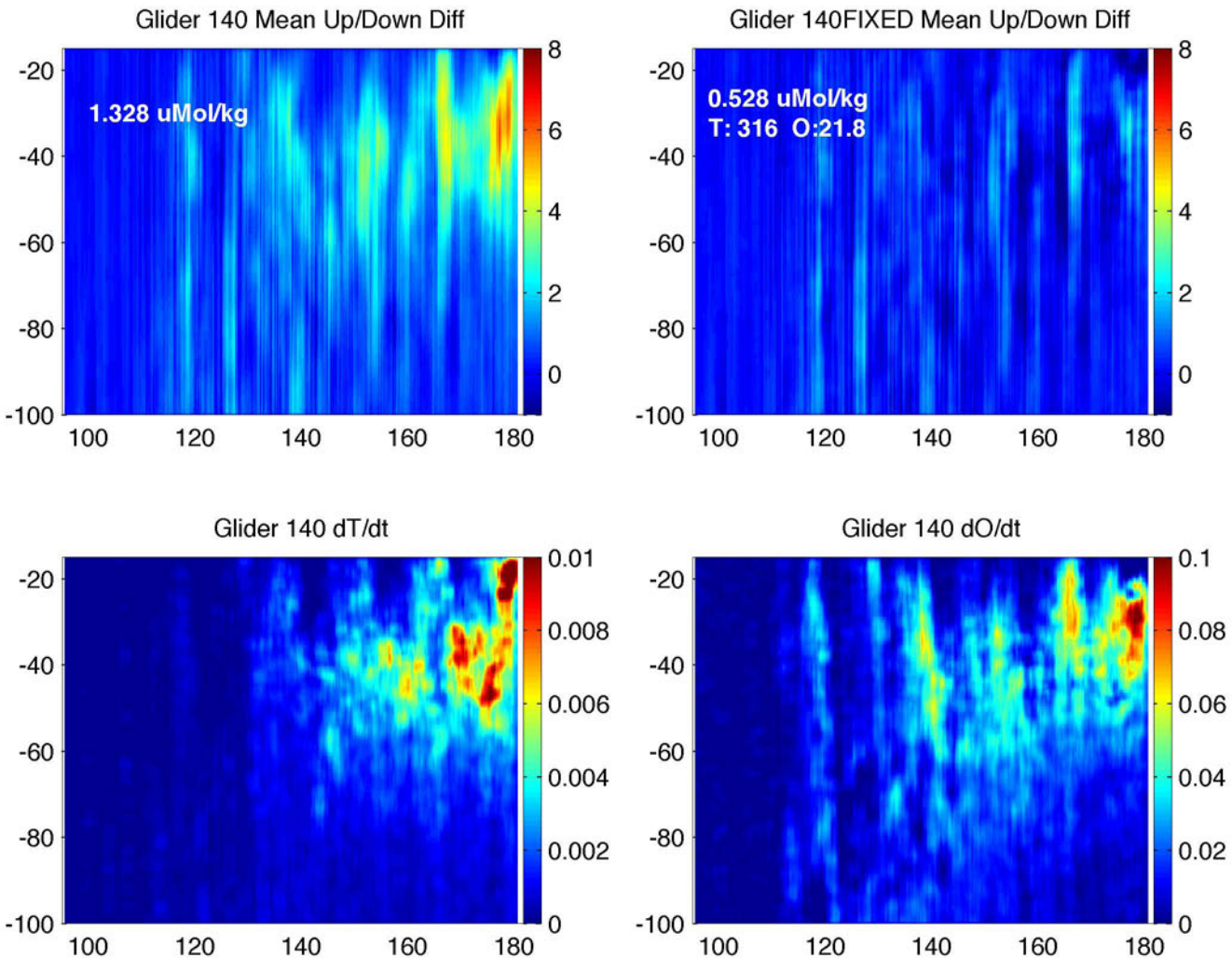
The following function brings the 4 glider optode oxygen sensors into agreement with each other and with the Winklers during the Knorr cruise to about 2 μMol/kg. These corrections are applied to release 3 of the glider data. The new oxygen variables are:

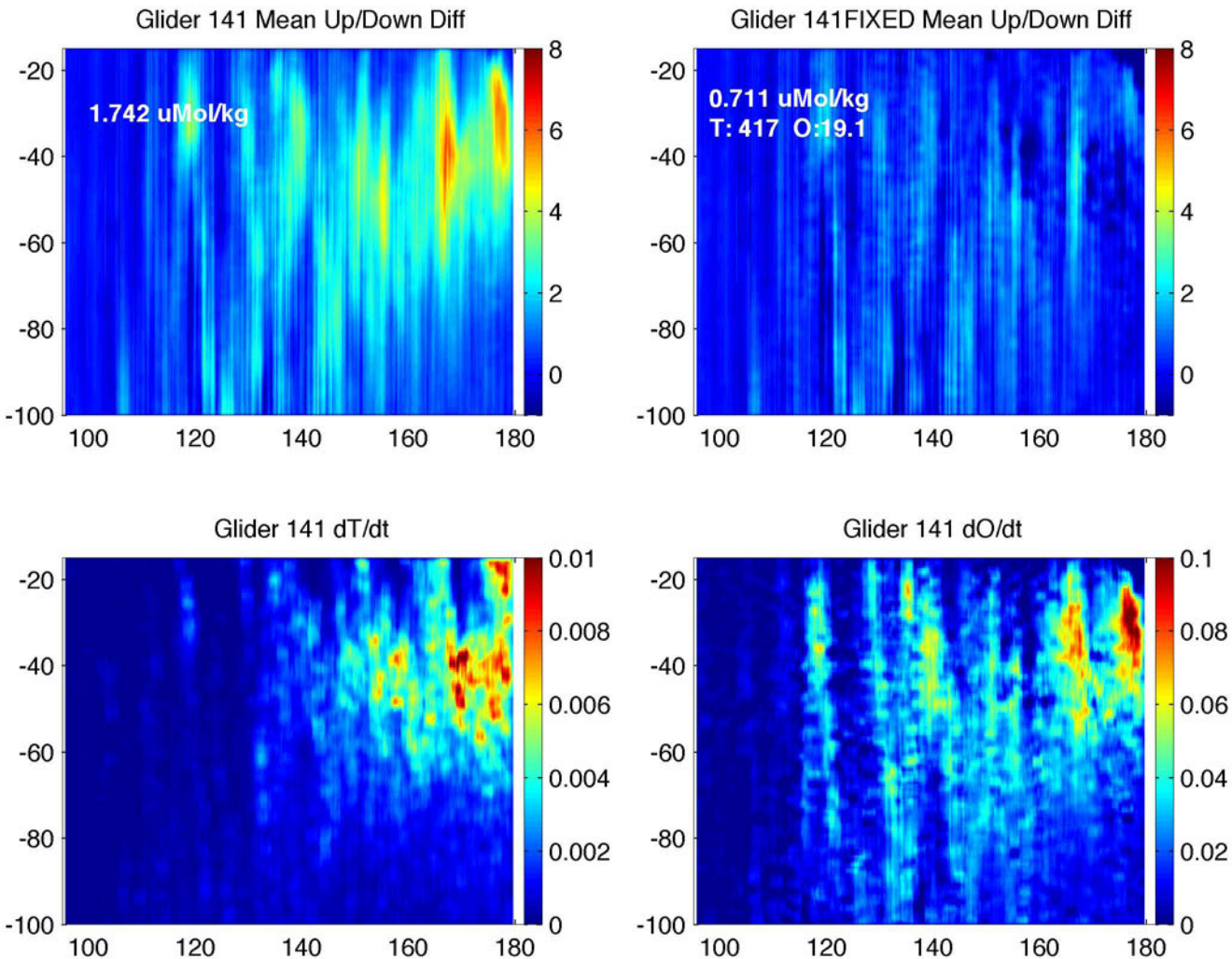
- oxycal0 – Oxygen concentration computed from release 2.2
- oxycal1 – time lags have been applied oxycal0
- oxycal2 – Slope and offset have been applied to oxycal1
- oxy - **Best glider oxygen**. Equals oxycal2 in this release

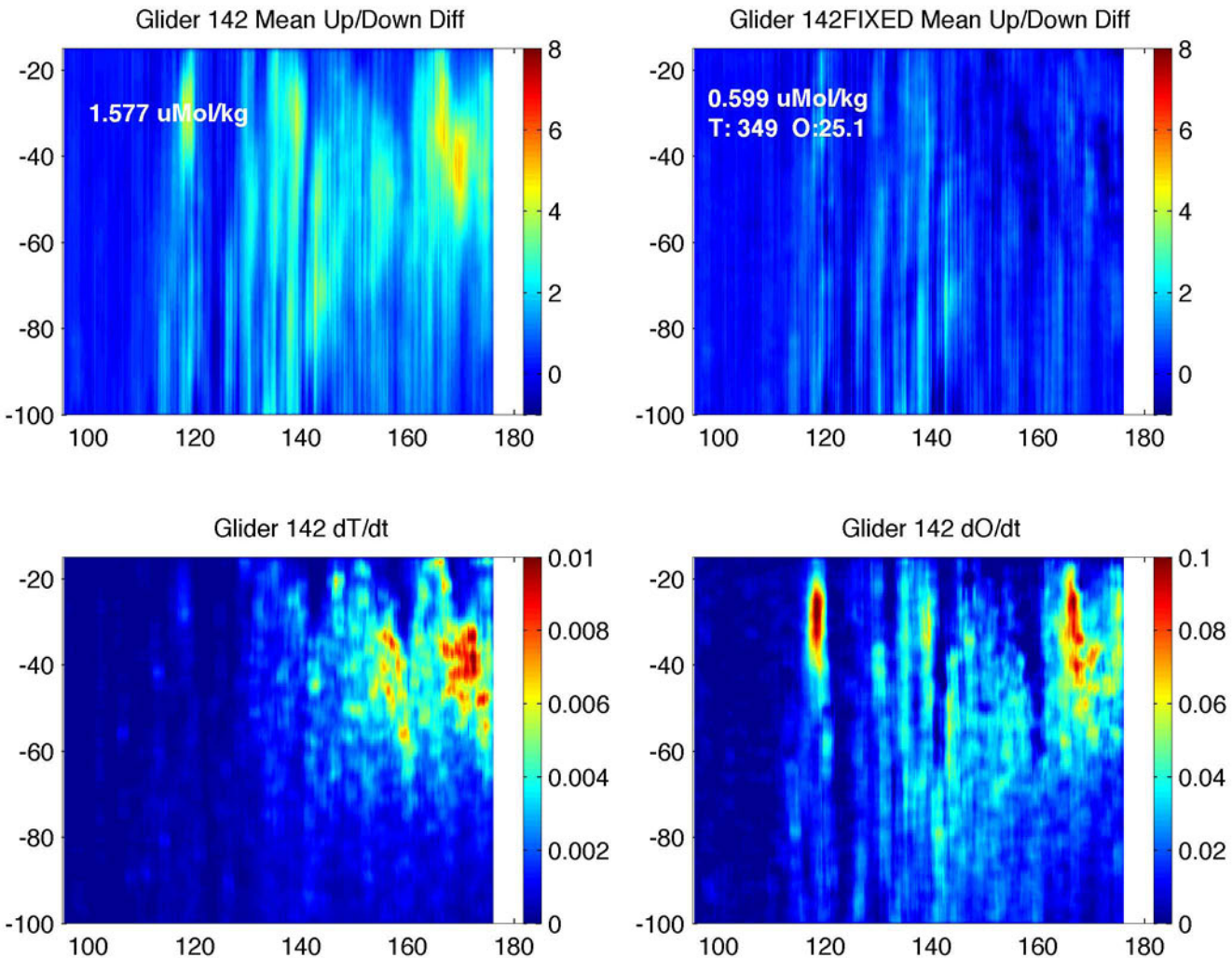
```
function  [oxycal0 oxycal1 oxycal2]=CorrectGliderOptodeNaN(num,oxy,S,T,P,yd)
% Correct oxygen values from NAB08 glider optodes to be
% consistent with CTD Winkler, calibrated float and historical data
% Input:
%       num - glider number  140, 141, 142 or 143
%       oxy - optode oxygen computed. Same as variable-
'aanderaa3830_dissolved_oxygen'
%               in data release 2.2
%       S,T,P - Salinity, Temperature (not potential) and Pressure on same timebase
%       yd -yearday
%
% Output: calibrated oxygen
%       oxycal0 - original oxygen values
%       oxycal1 - lags removed
%       oxycal2 - lags removed and calibrated
%
% Notes:
%       Gaps (NaNs) in the original oxy data are preserved, and oxy values
%       over 500 are removed (replaced with NaNs).
%
%  EAD - October 2010
%  graya - 21 Oct 2010

if num==140  % r
   O2off=4.0;Poff=0;Toff=0;Ogain=0.09;Cfix=[315  21.8];
elseif num==141  % g
   O2off= 0.2;Poff=0;Toff=0;Ogain=5/270;Cfix=[416  19.1];
elseif num==142  % b
   O2off=1;Poff=0;Toff=0;Ogain=12/270;Cfix=[349  25.2];
elseif num==143  % k
   O2off=8.5;Poff=0;Toff=0;Ogain= 0/270;Cfix=[383  19.6];
else
   error('No such glider %d',num);
end
```

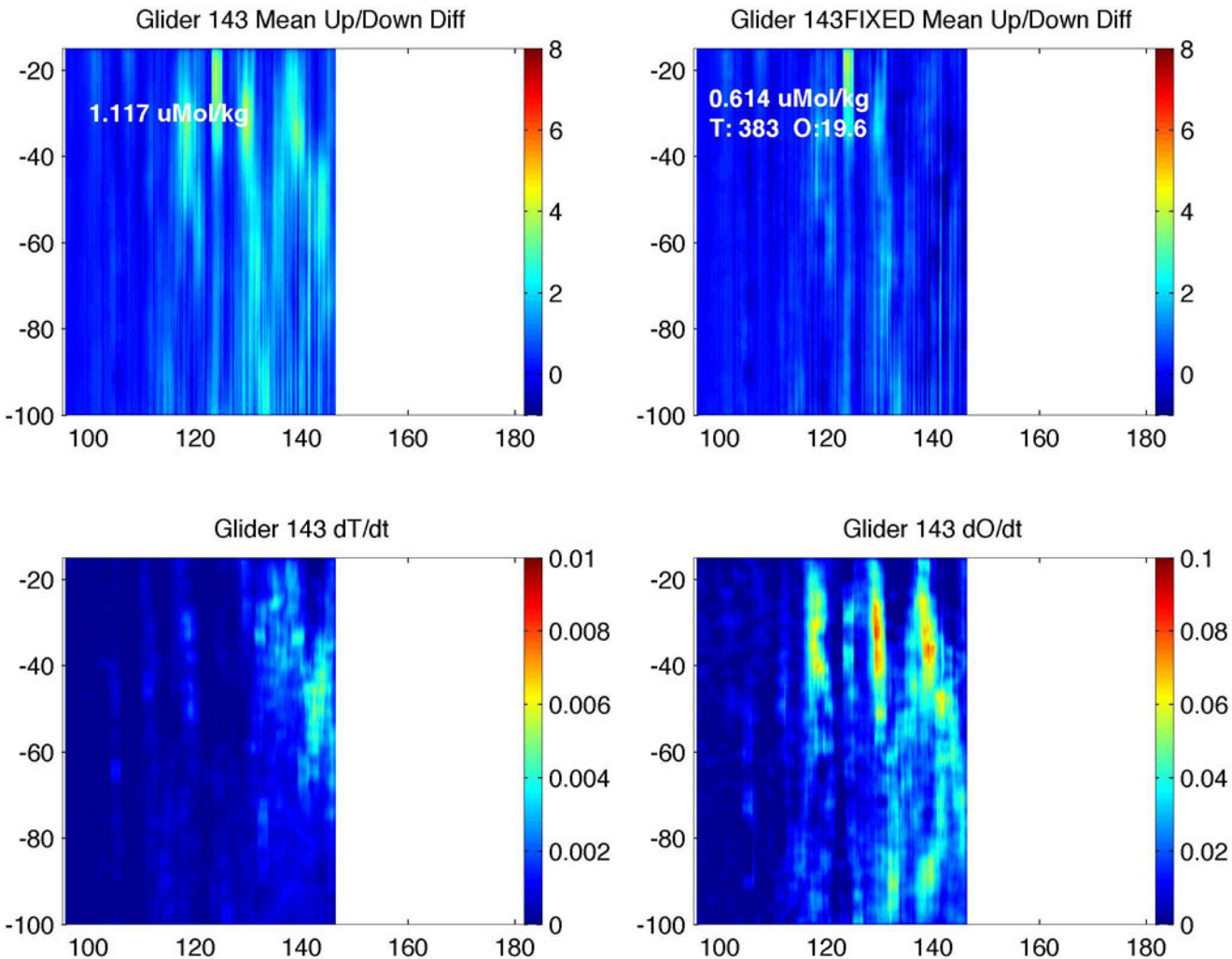
```
g = find(~isnan(oxy+T+S) & oxy<500);
b = find(isnan(oxy+T+S) | oxy>=500);

oxy(b) = NaN;
oxycal0 = oxy;

% perform calculations on the good values only
yd=yd(g);P=P(g);S=S(g);T=T(g);oxy=oxy(g);

% oxycal1: Optode lag correct
der = [-1 0 1]';
dTdt = conv2(T,der,'same')./conv2(yd*86400,der,'same');  % Temp change rate
dOdt = conv2(oxy,der,'same')./conv2(yd*86400,der,'same');  % Oxygen change rate
oxy = oxy+dTdt*Cfix(1)+dOdt*Cfix(2);  % Corrected data

oxycal1 = NaN*ones(size(oxycal0));
oxycal1(g) = oxy;

% oxycal2: Opotode calibration
oxy = oxy+O2off;
oxy = oxy+(500-P)/480*Poff;  % Pressure correction
oxy = oxy+Toff*(T-9.5);   % Temperature correction
oxy = oxy+Ogain*oxy; % Oxygen gain

oxycal2 = NaN*ones(size(oxycal0));
oxycal2(g) = oxy;
```

APPENDIX 1 – Time Lag Corrections

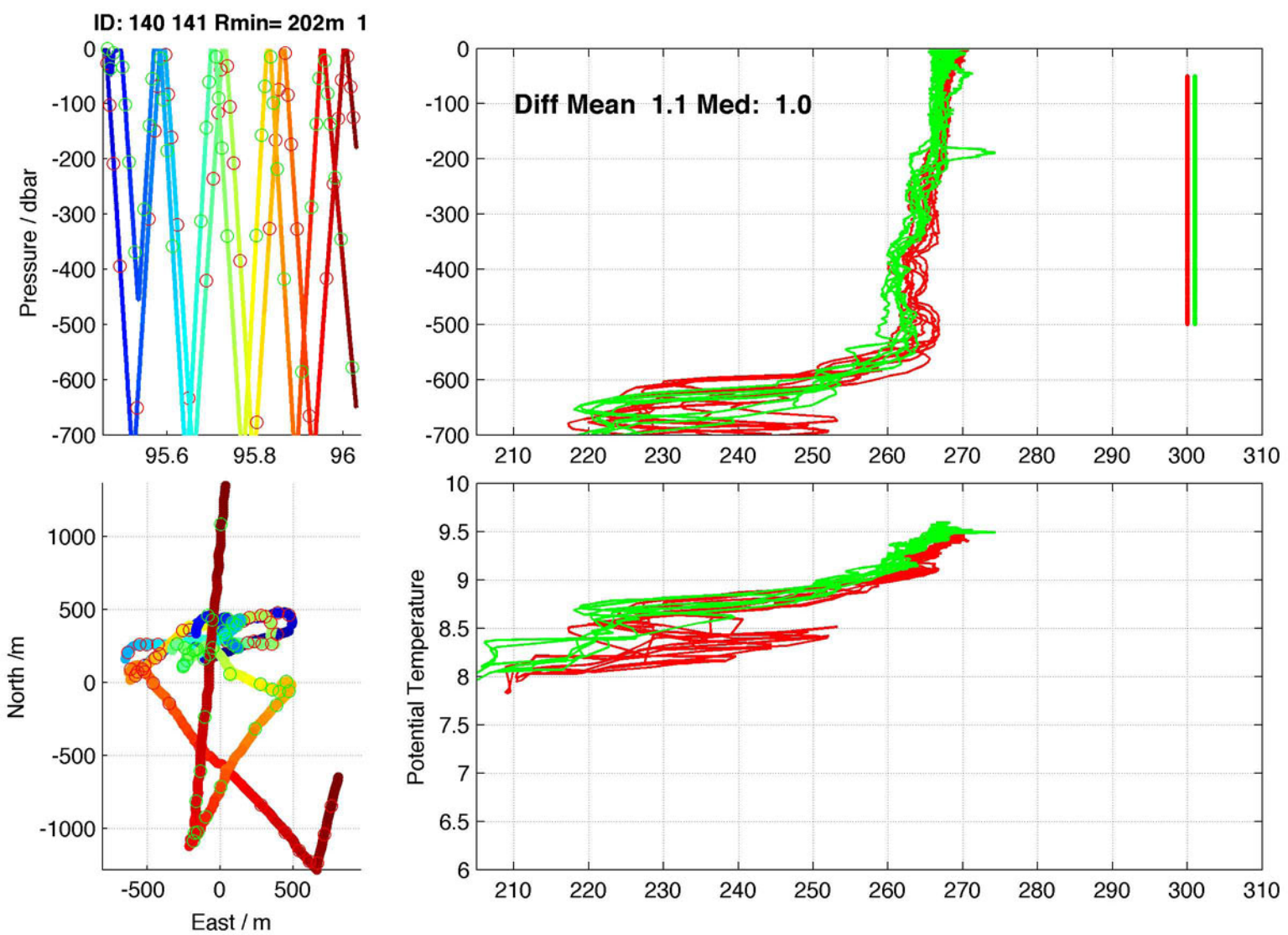

Glider 140 Mean Up/Down Diff
1.328 uMol/kg
Glider 140FIXED Mean Up/Down Diff
0.528 uMol/kg
T: 316 O:21.8
Glider 140 dT/dt
Glider 140 dO/dt
-20
-40
-60
-80
-100
100
120
140
160
180
8
6
4
2
0
0.01
0.008
0.006
0.004
0.002
0.1
0.08
0.06
0.04
0.02

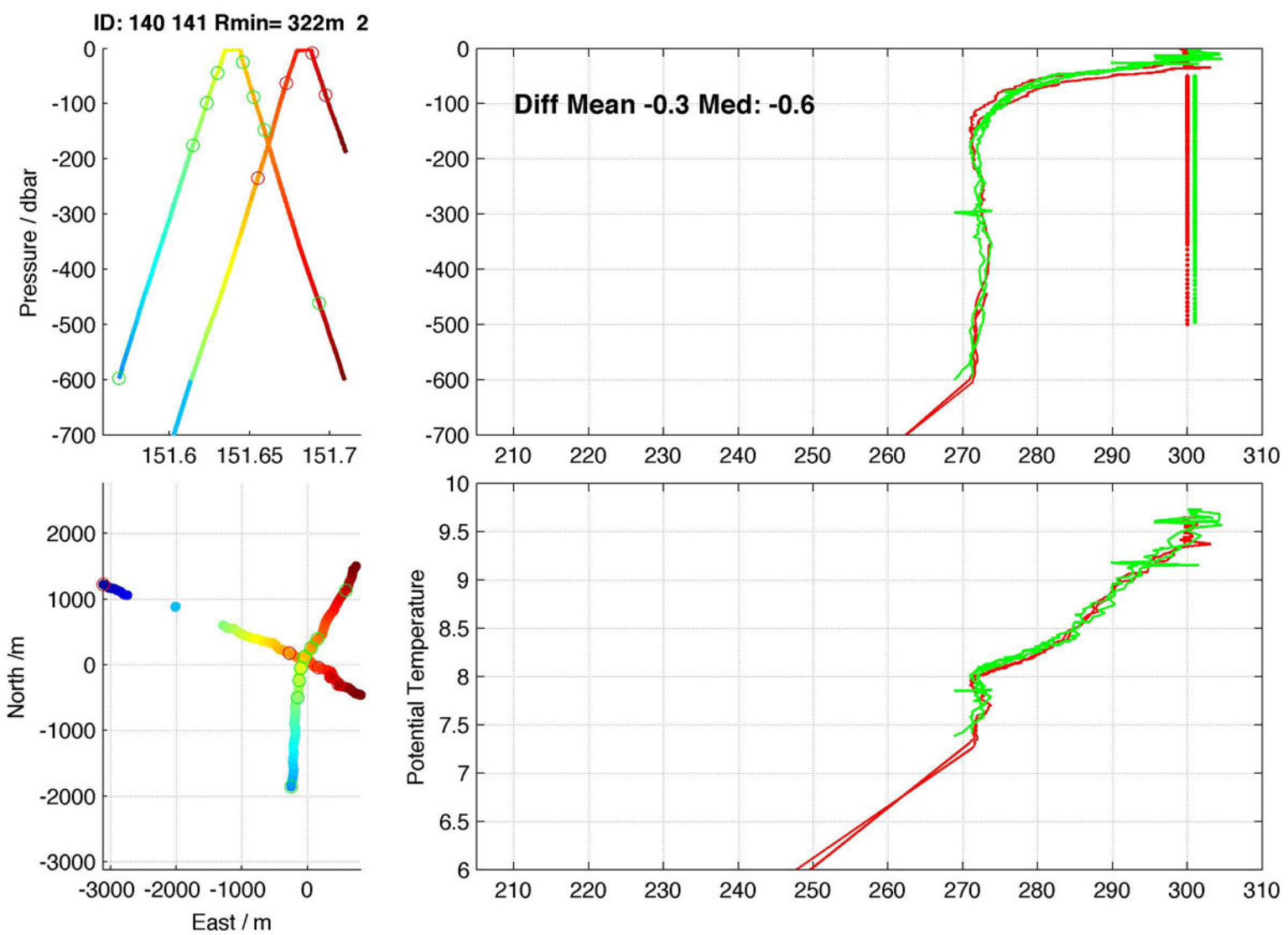

Glider 141 Mean Up/Down Diff
1.742 uMol/kg
Glider 141FIXED Mean Up/Down Diff
0.711 uMol/kg
T: 417 O:19.1
Glider 141 dT/dt
Glider 141 dO/dt
-20
-40
-60
-80
-100
100
120
140
160
180
8
6
4
2
0
0.01
0.008
0.006
0.004
0.002
0.1
0.08
0.06
0.04
0.02

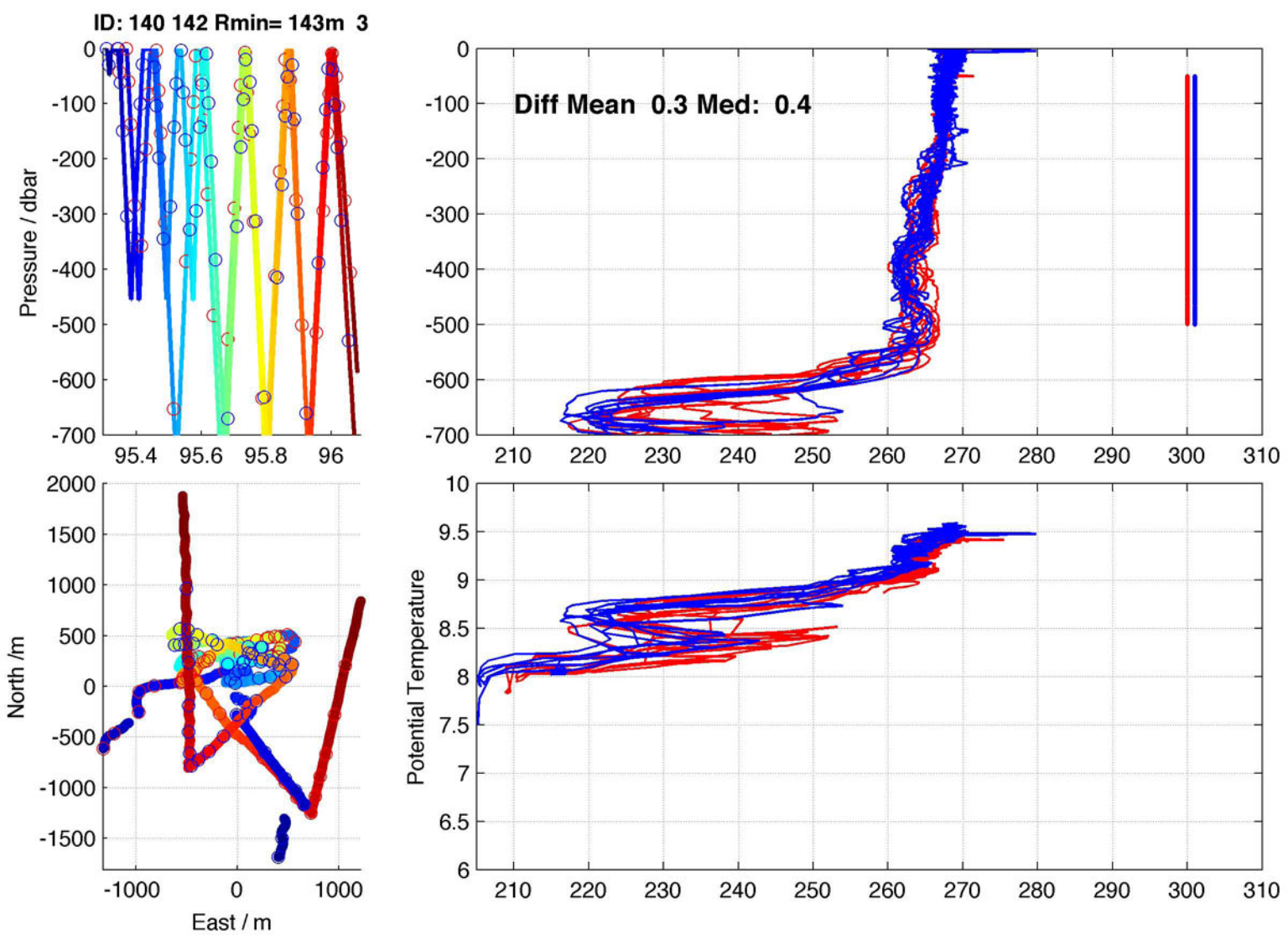

Glider 142 Mean Up/Down Diff
1.577 uMol/kg
Glider 142FIXED Mean Up/Down Diff
0.599 uMol/kg
T: 349 O:25.1
Glider 142 dT/dt
Glider 142 dO/dt
-20
-40
-60
-80
-100
100
120
140
160
180
8
6
4
2
0
0.01
0.008
0.006
0.004
0.002
0.1
0.08
0.06
0.04
0.02

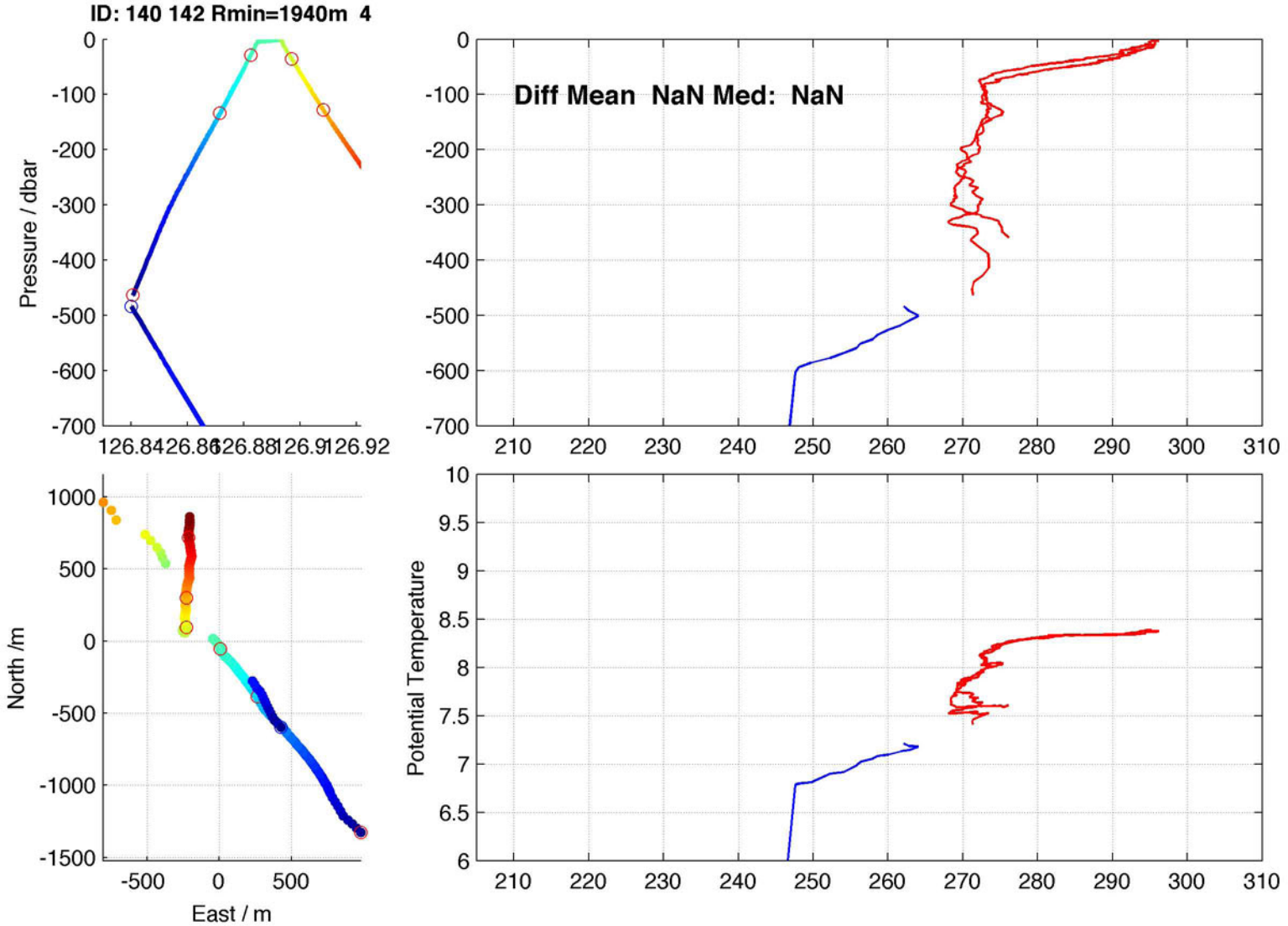

Glider 143 Mean Up/Down Diff
1.117 uMol/kg
Glider 143FIXED Mean Up/Down Diff
0.614 uMol/kg
T: 383 O:19.6
Glider 143 dT/dt
Glider 143 dO/dt
-20
-40
-60
-80
-100
100
120
140
160
180
8
6
4
2
0
0.01
0.008
0.006
0.004
0.002
0.1
0.08
0.06
0.04
0.02

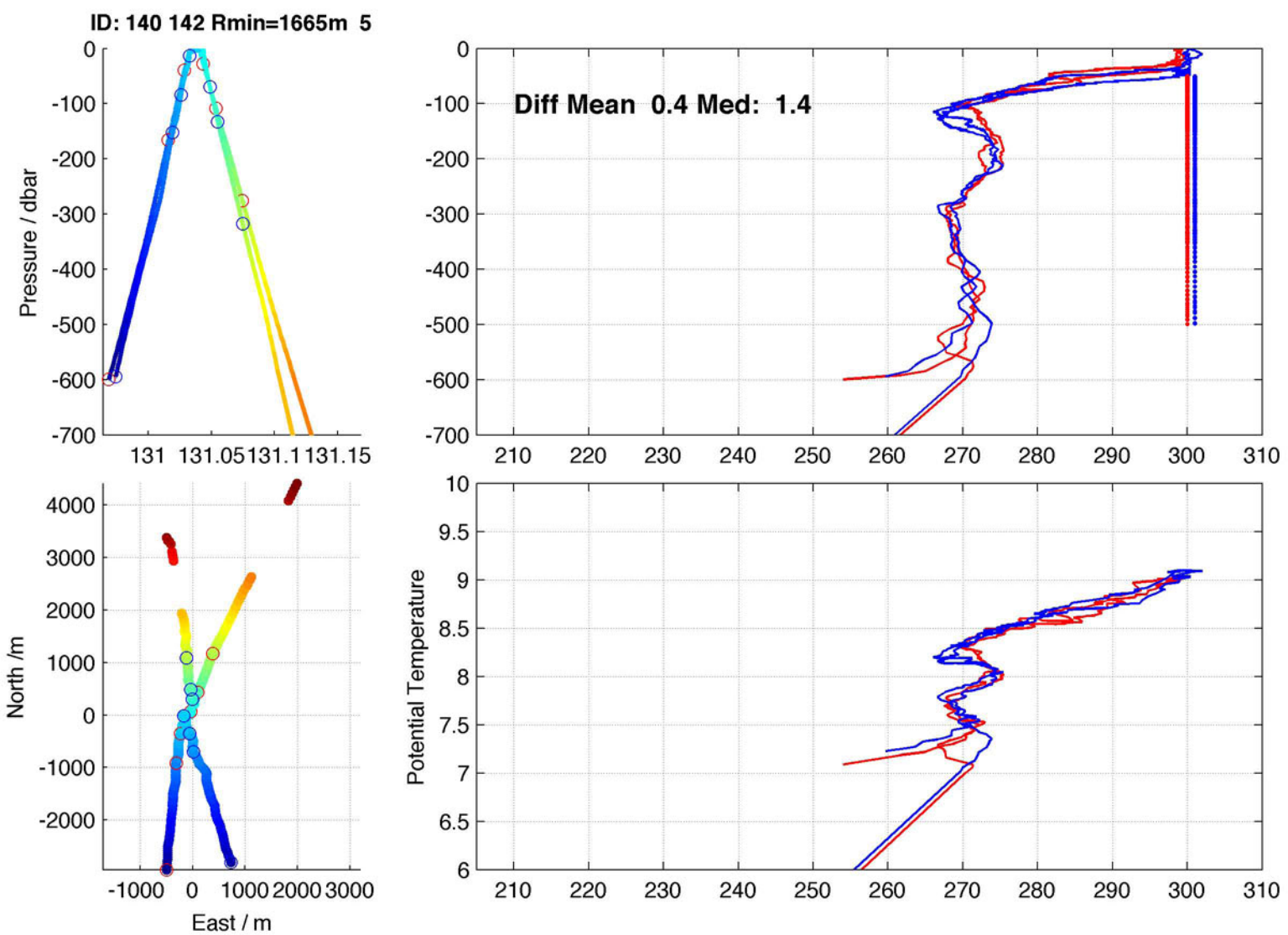
APPENDIX 2 – Glider-Glider and Glider-Float Intercalibrations

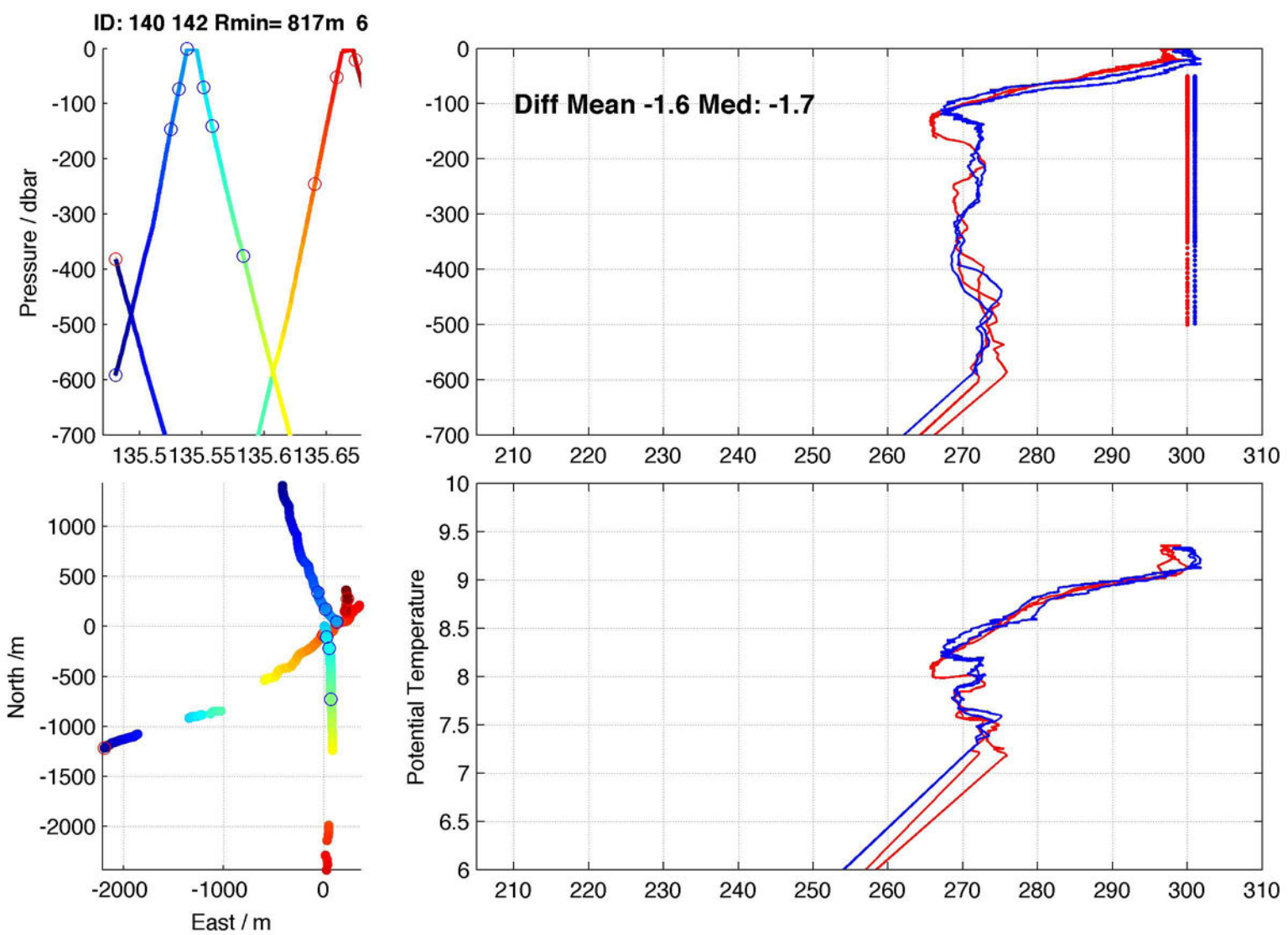

ID: 140 141 Rmin= 202m 1
Pressure / dbar
Diff Mean 1.1 Med: 1.0
North /m
East / m
Potential Temperature

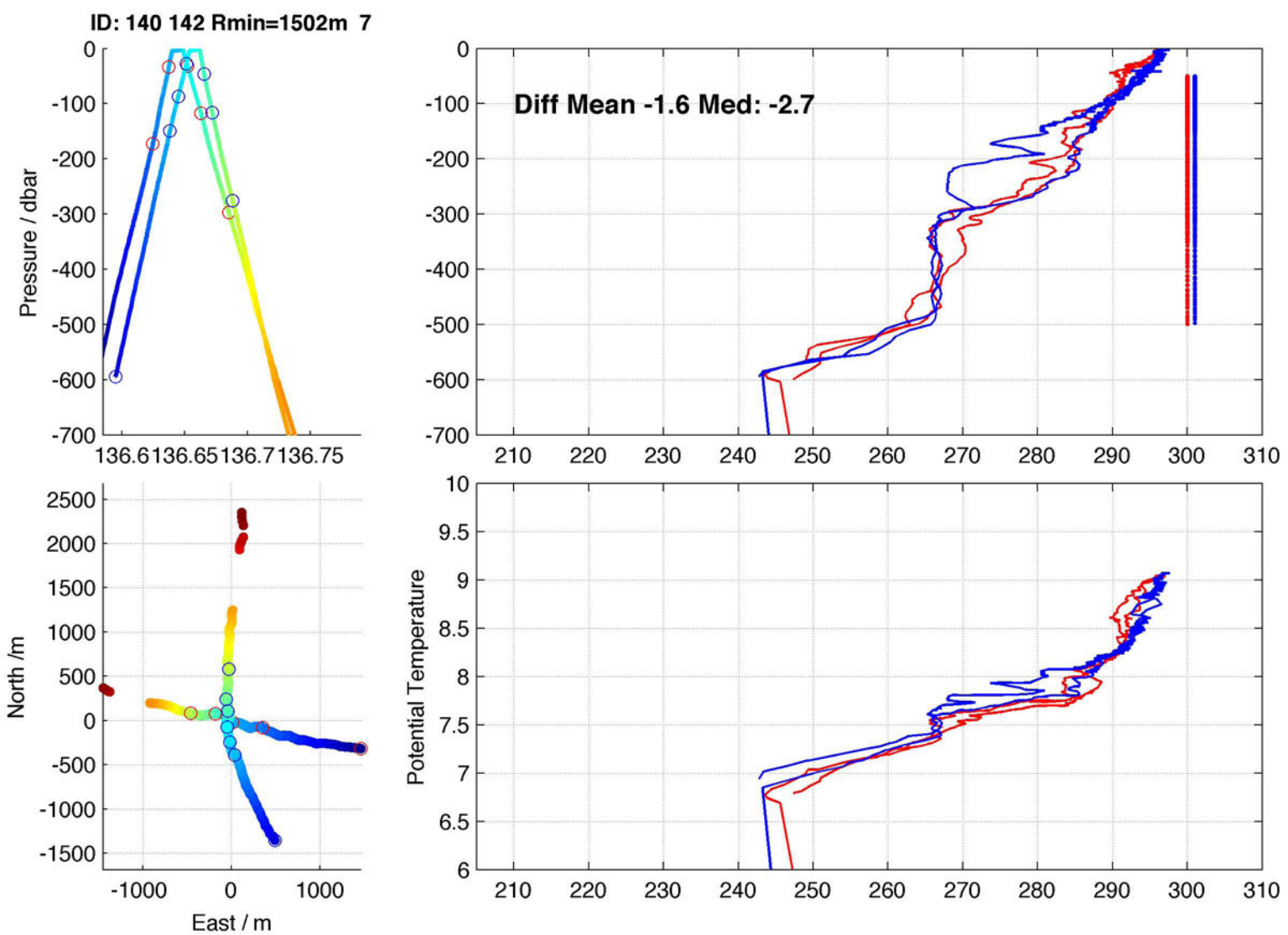

ID: 140 141 Rmin= 322m 2
Pressure / dbar
0
-100
-200
-300
-400
-500
-600
-700
151.6
151.65
151.7
Diff Mean -0.3 Med: -0.6
210
220
230
240
250
260
270
280
290
300
310
North /m
2000
1000
0
-1000
-2000
-3000
East / m
Potential Temperature
10
9.5
9
8.5
8
7.5
7
6.5
6

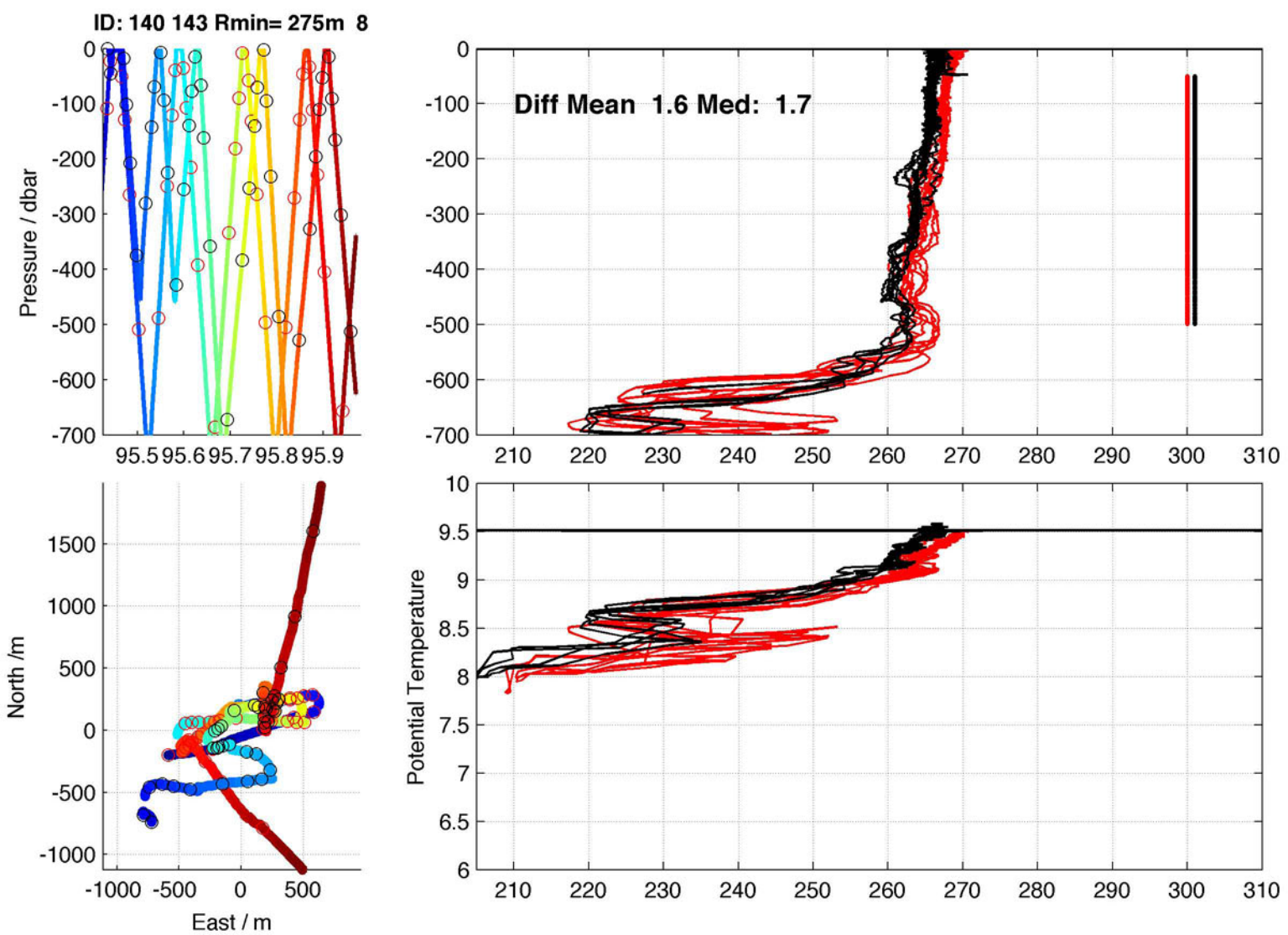

ID: 140 142 Rmin= 143m 3
Pressure / dbar
Diff Mean 0.3 Med: 0.4
North /m
East / m
Potential Temperature

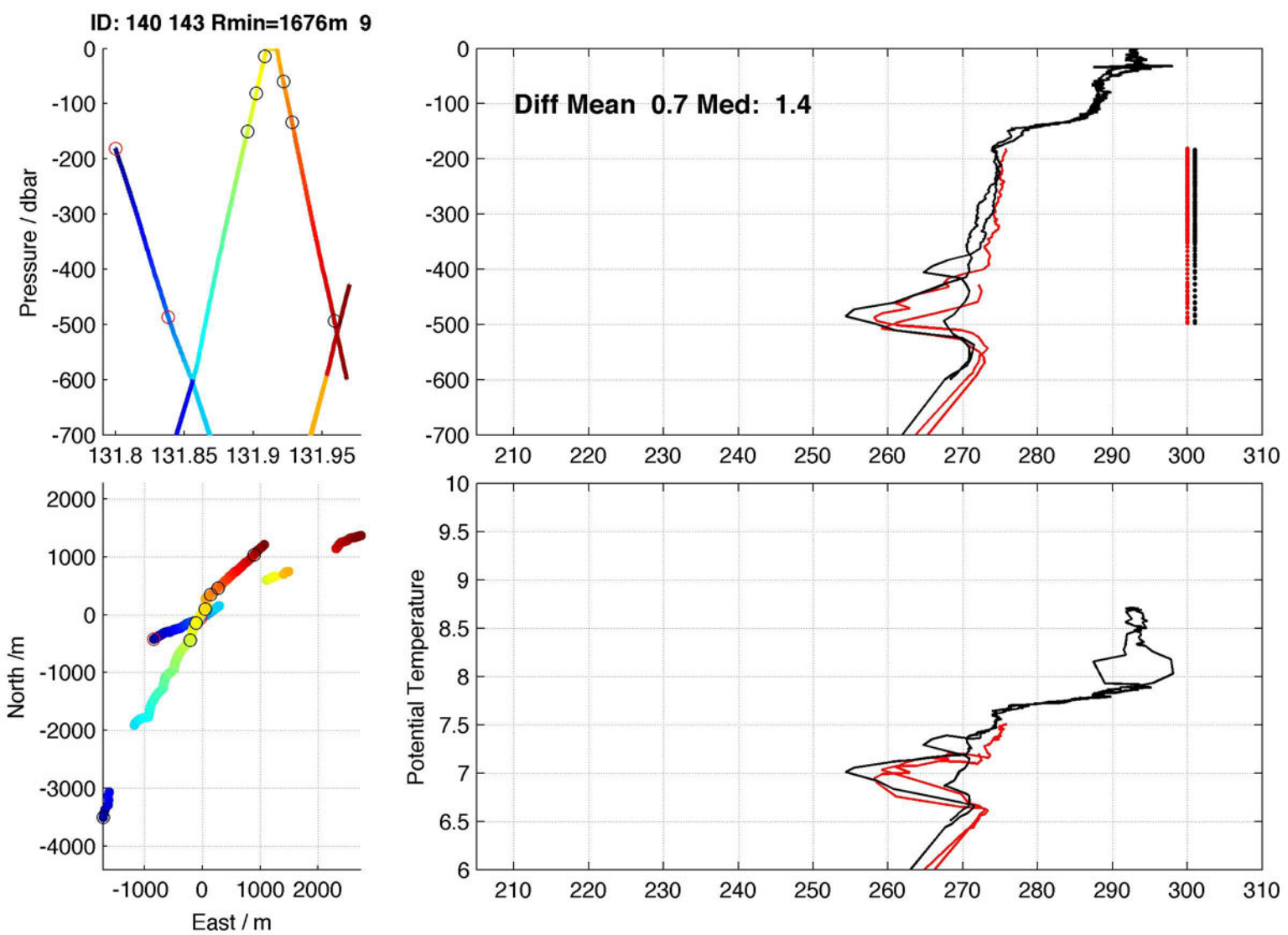

ID: 140 142 Rmin=1940m 4
Pressure / dbar
Diff Mean NaN Med: NaN
North /m
East / m
Potential Temperature

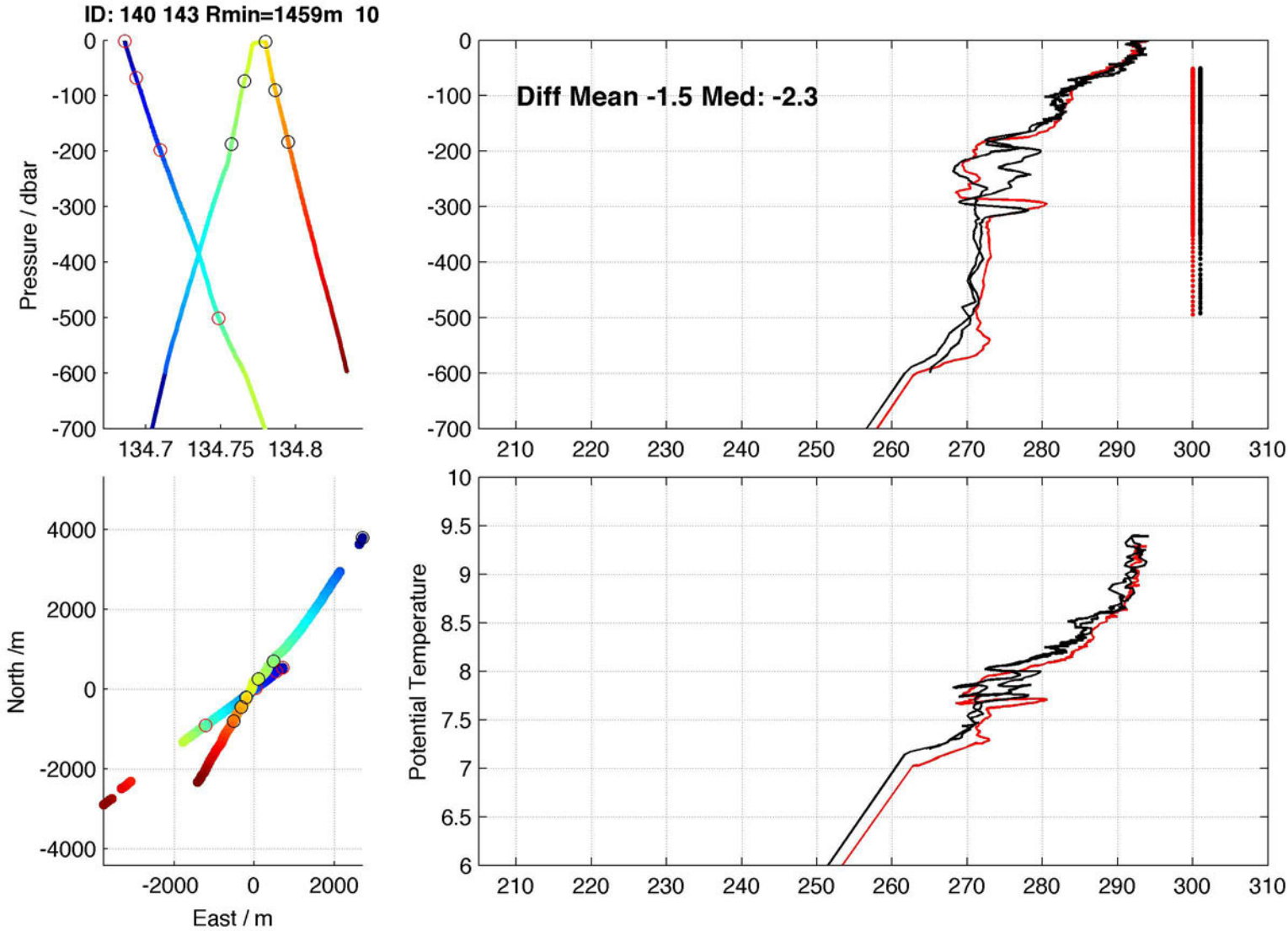

ID: 140 142 Rmin=1665m 5
Pressure / dbar
Diff Mean 0.4 Med: 1.4
North /m
East / m
Potential Temperature

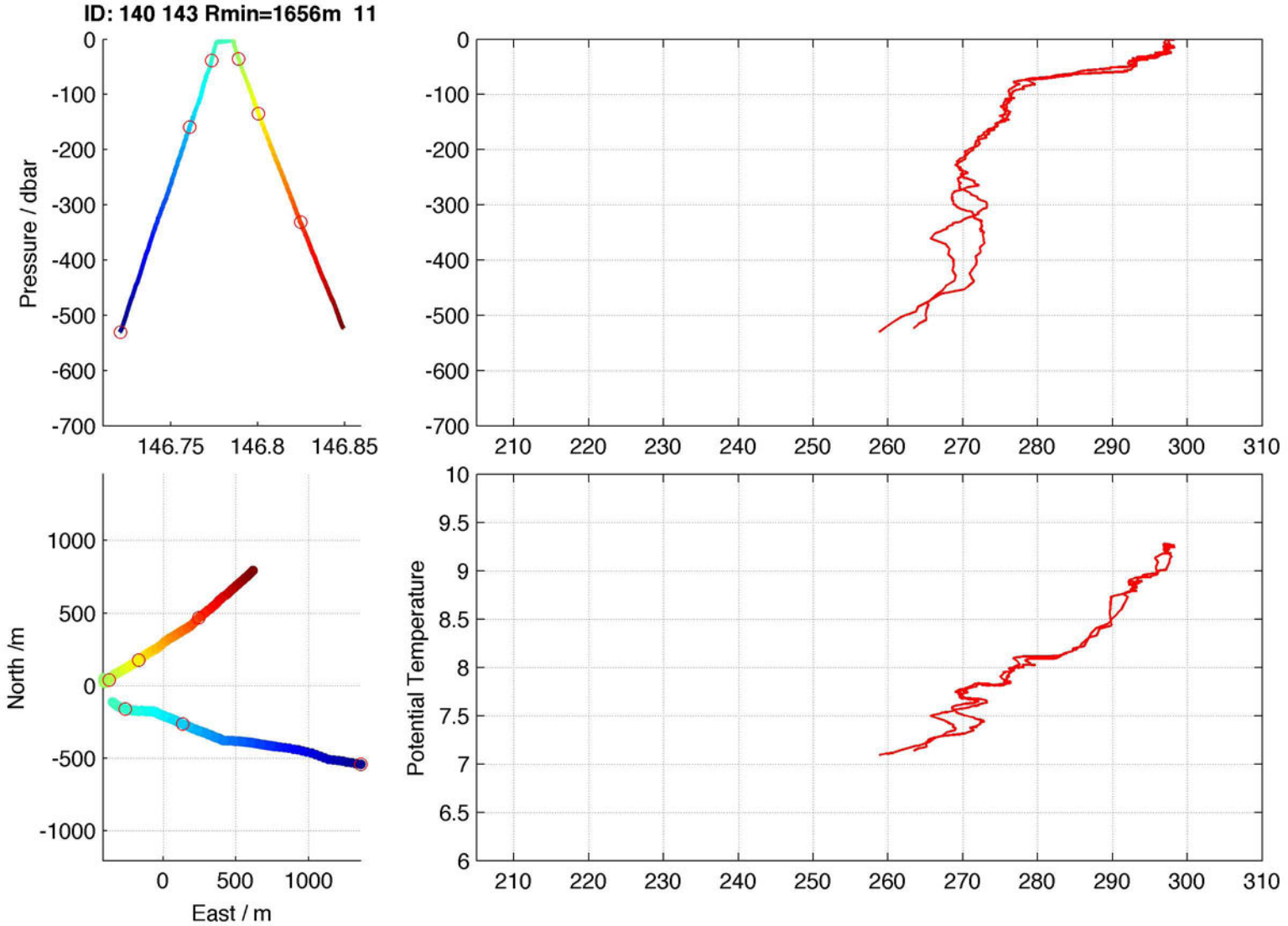

ID: 140 142 Rmin= 817m 6
Pressure / dbar
0
-100
-200
-300
-400
-500
-600
-700
135.5 135.55 135.6 135.65
Diff Mean -1.6 Med: -1.7
210 220 230 240 250 260 270 280 290 300 310
North /m
1000
500
0
-500
-1000
-1500
-2000
-2000 -1000 0
East / m
Potential Temperature
10
9.5
9
8.5
8
7.5
7
6.5
6

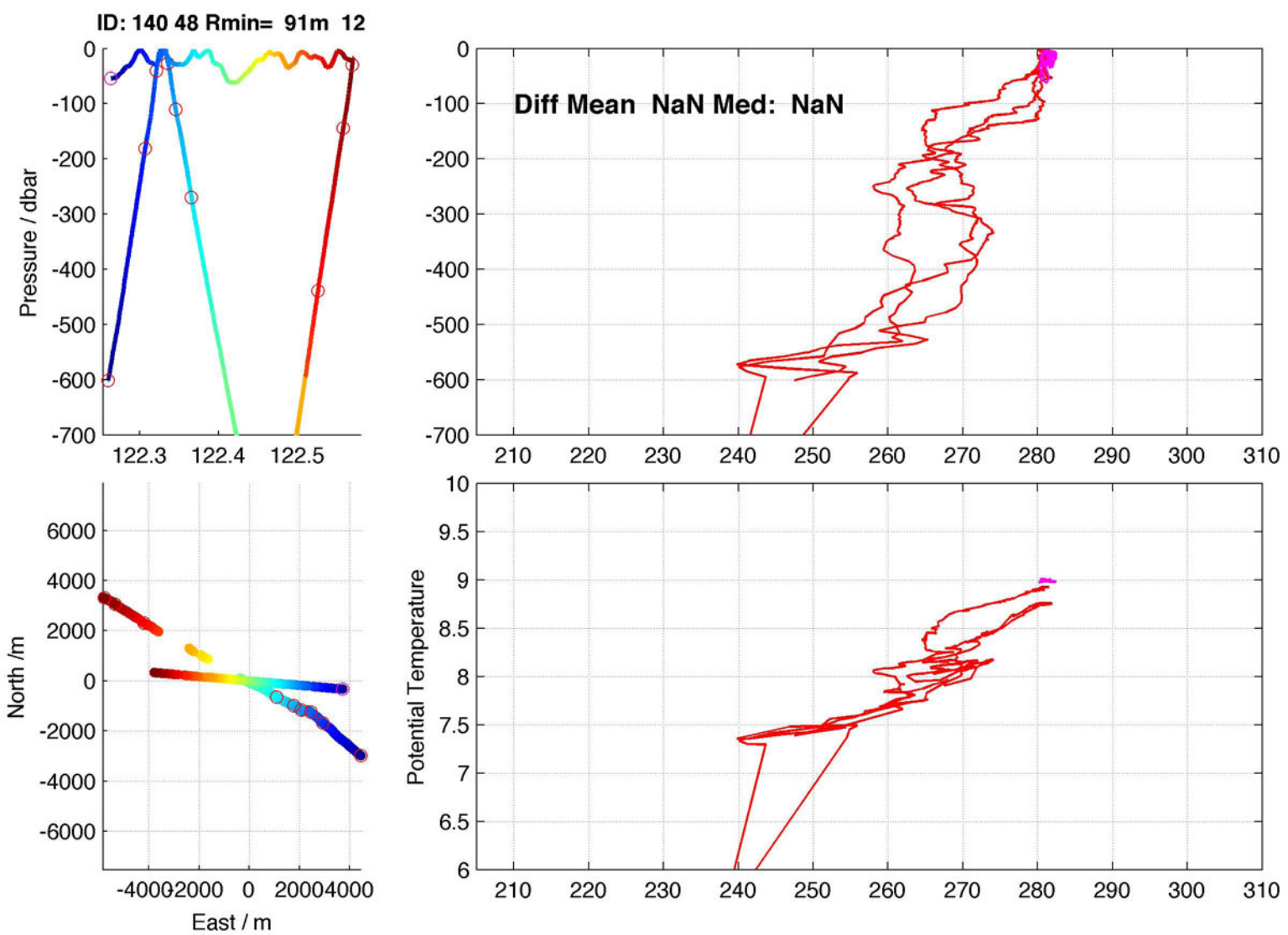

ID: 140 142 Rmin=1502m 7
Pressure / dbar
Diff Mean -1.6 Med: -2.7
North /m
East / m
Potential Temperature

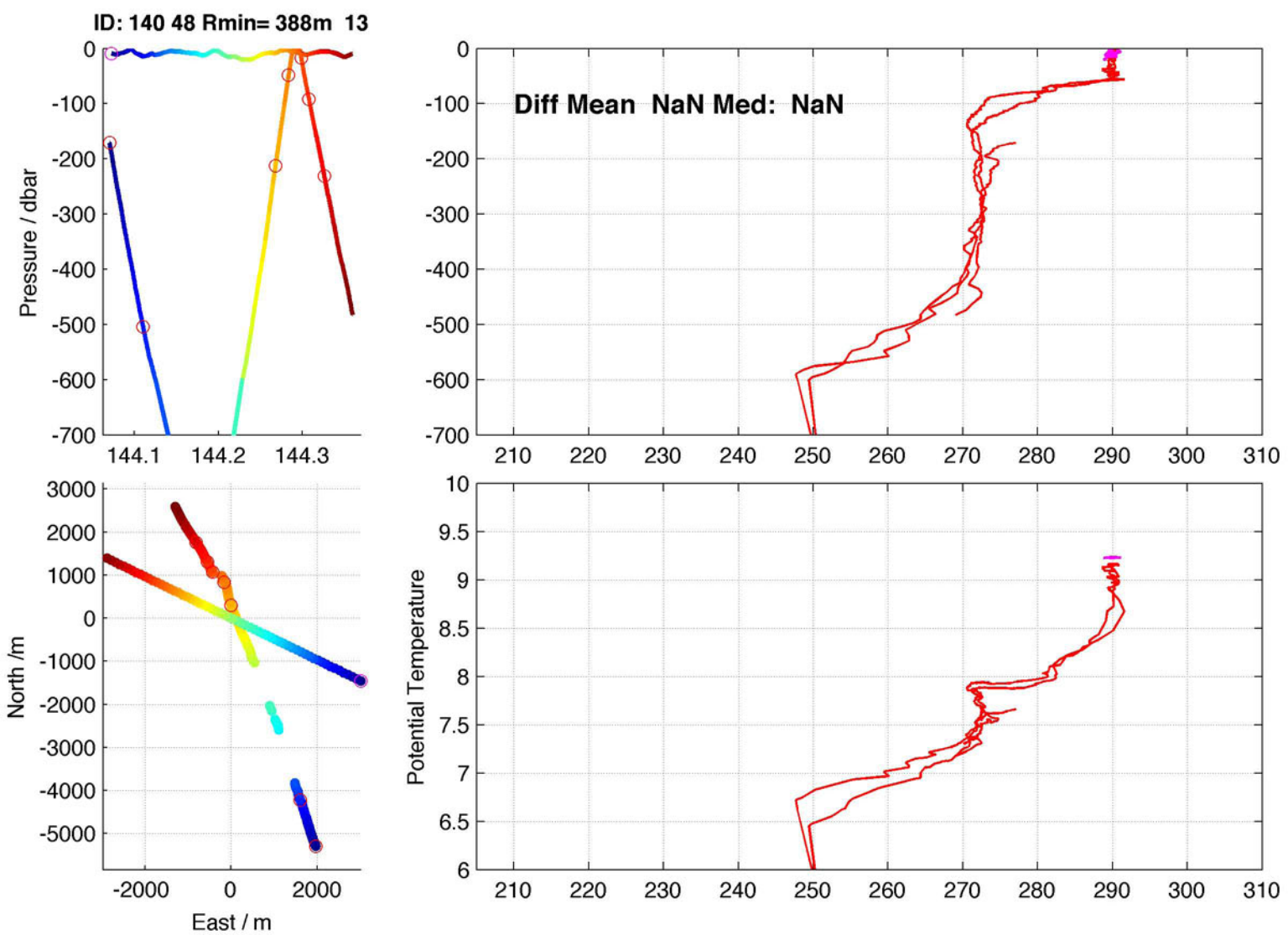

ID: 140 143 Rmin= 275m 8
Pressure / dbar
Diff Mean 1.6 Med: 1.7
North /m
East / m
Potential Temperature

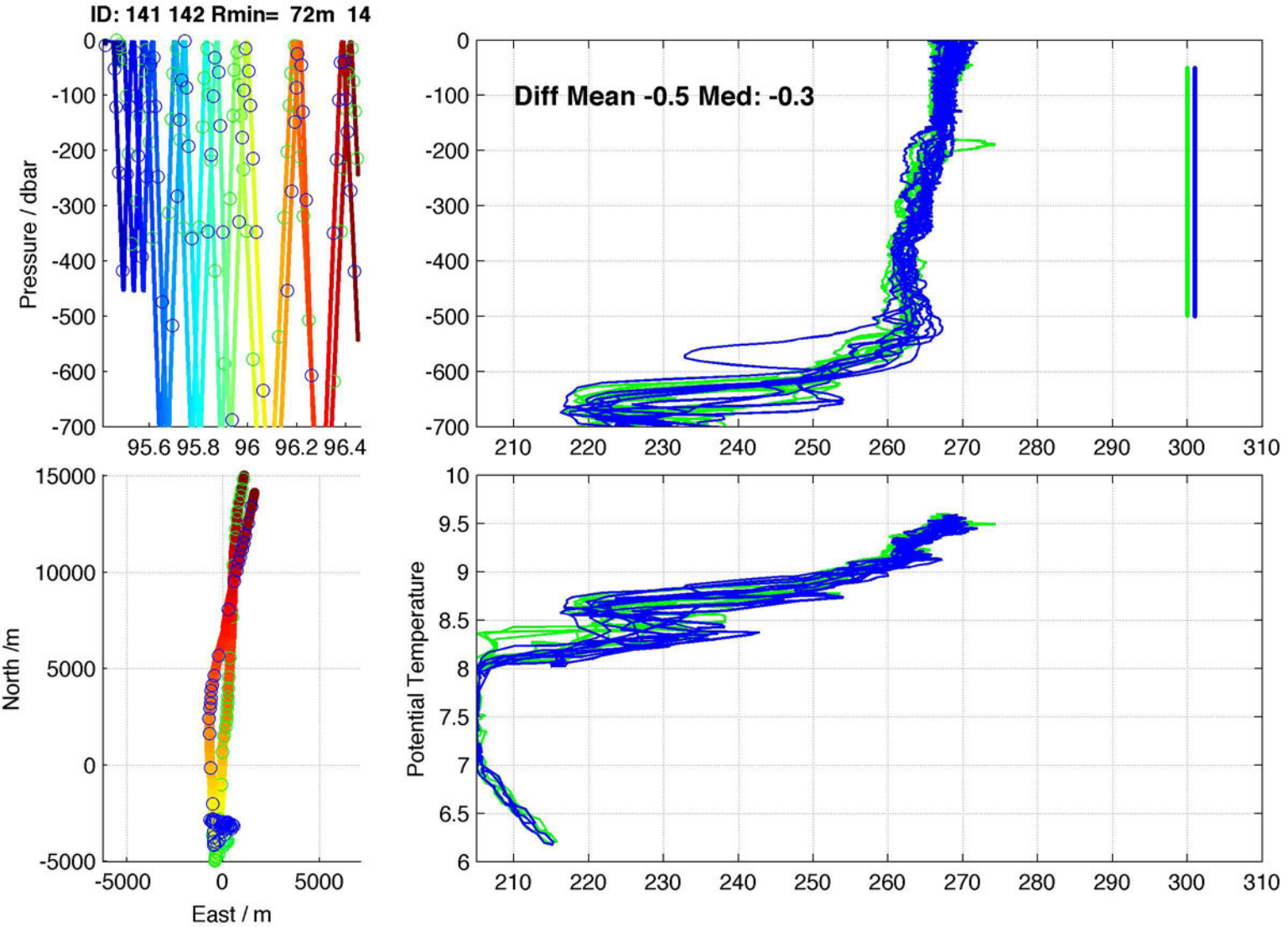

ID: 140 143 Rmin=1676m 9
Pressure / dbar
Diff Mean 0.7 Med: 1.4
North /m
East / m
Potential Temperature

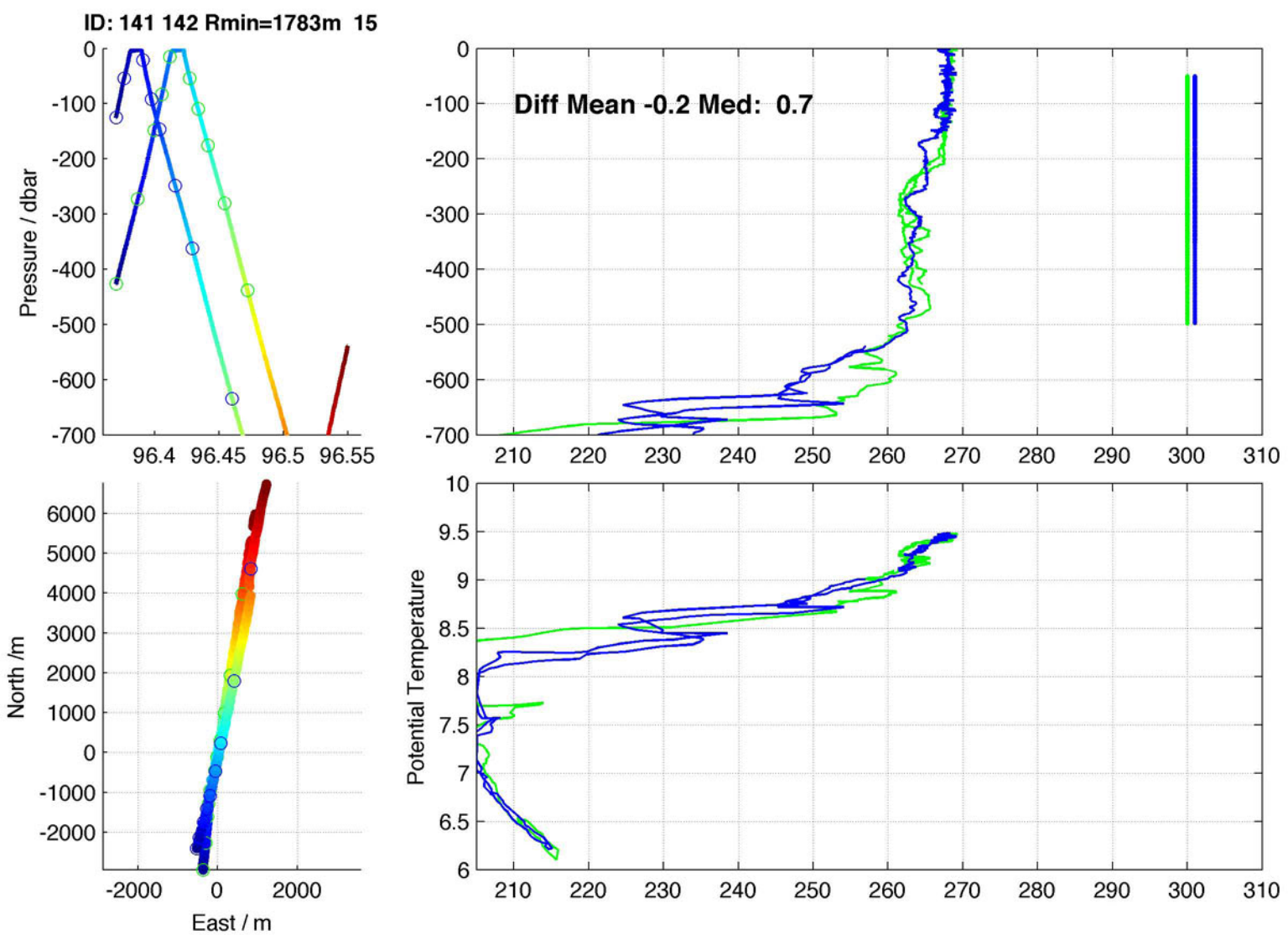

ID: 140 143 Rmin=1459m 10
Pressure / dbar
0
-100
-200
-300
-400
-500
-600
-700
134.7
134.75
134.8
Diff Mean -1.5 Med: -2.3
210
220
230
240
250
260
270
280
290
300
310
North /m
4000
2000
0
-2000
-4000
East / m
Potential Temperature
10
9.5
9
8.5
8
7.5
7
6.5
6

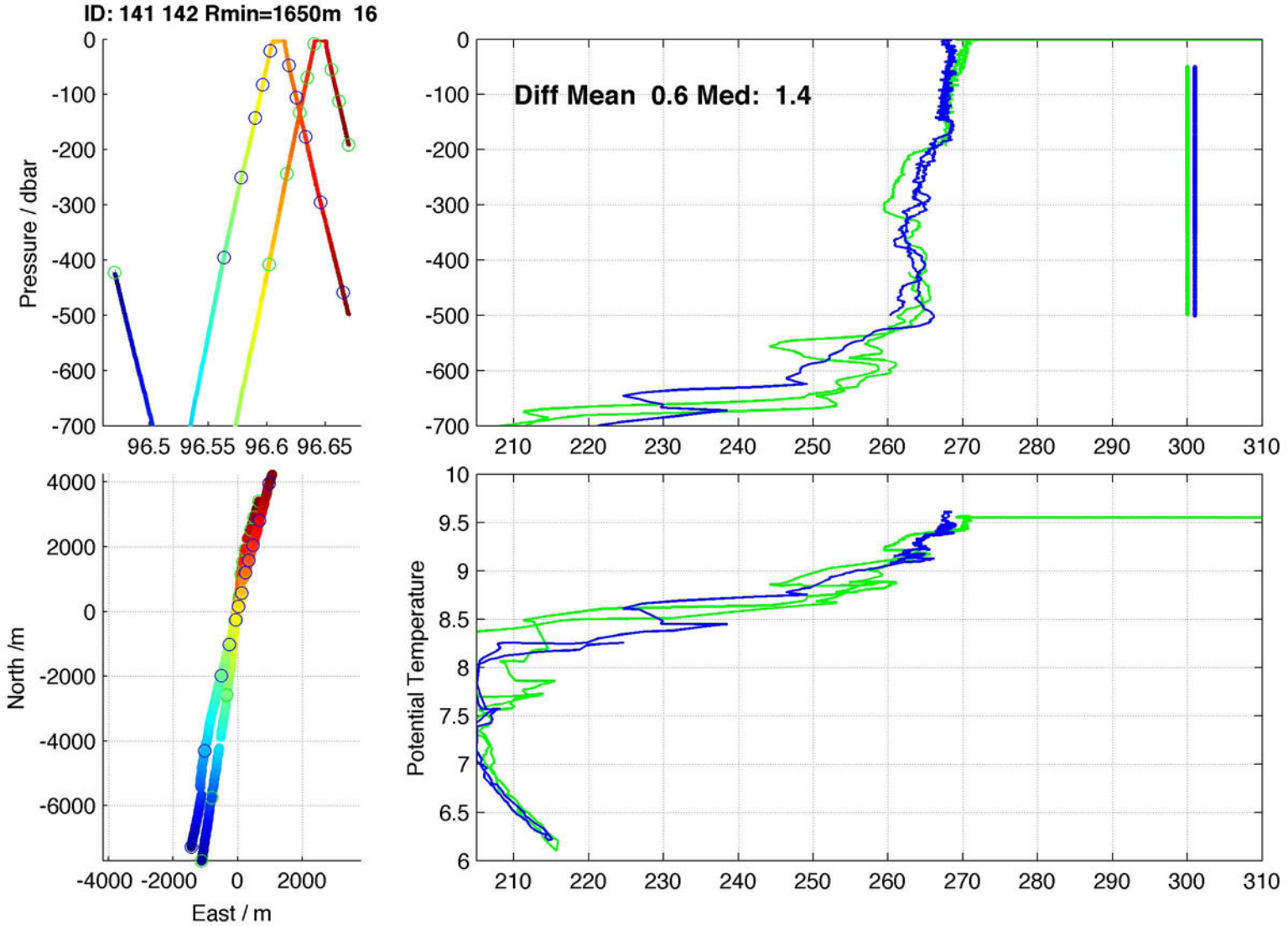

ID: 140 143 Rmin=1656m 11
Pressure / dbar
0
-100
-200
-300
-400
-500
-600
-700
146.75
146.8
146.85
210
220
230
240
250
260
270
280
290
300
310
North /m
1000
500
0
-500
-1000
East / m
Potential Temperature
10
9.5
9
8.5
8
7.5
7
6.5
6

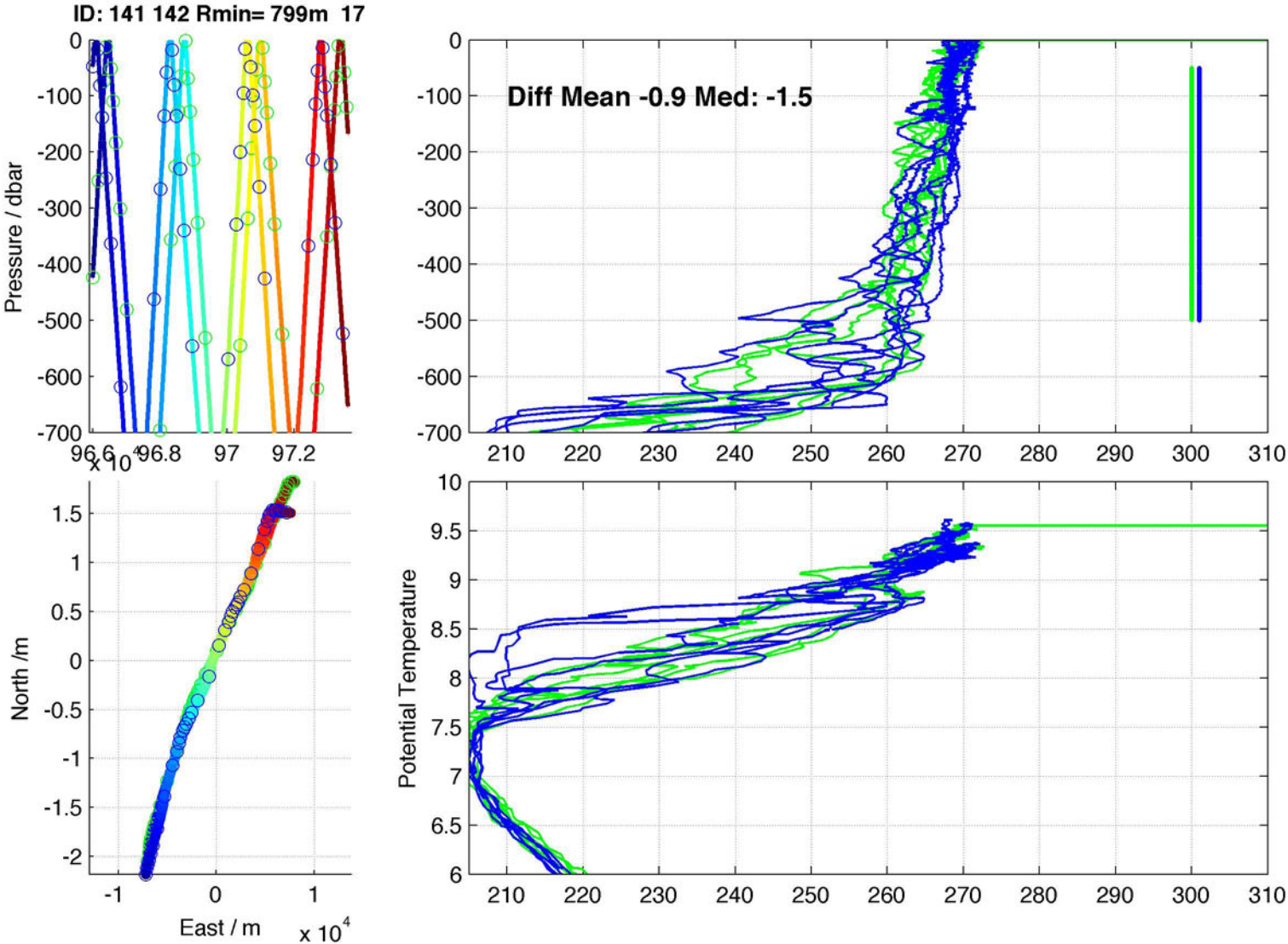

ID: 140 48 Rmin= 91m 12
Pressure / dbar
Diff Mean NaN Med: NaN
North /m
East / m
Potential Temperature

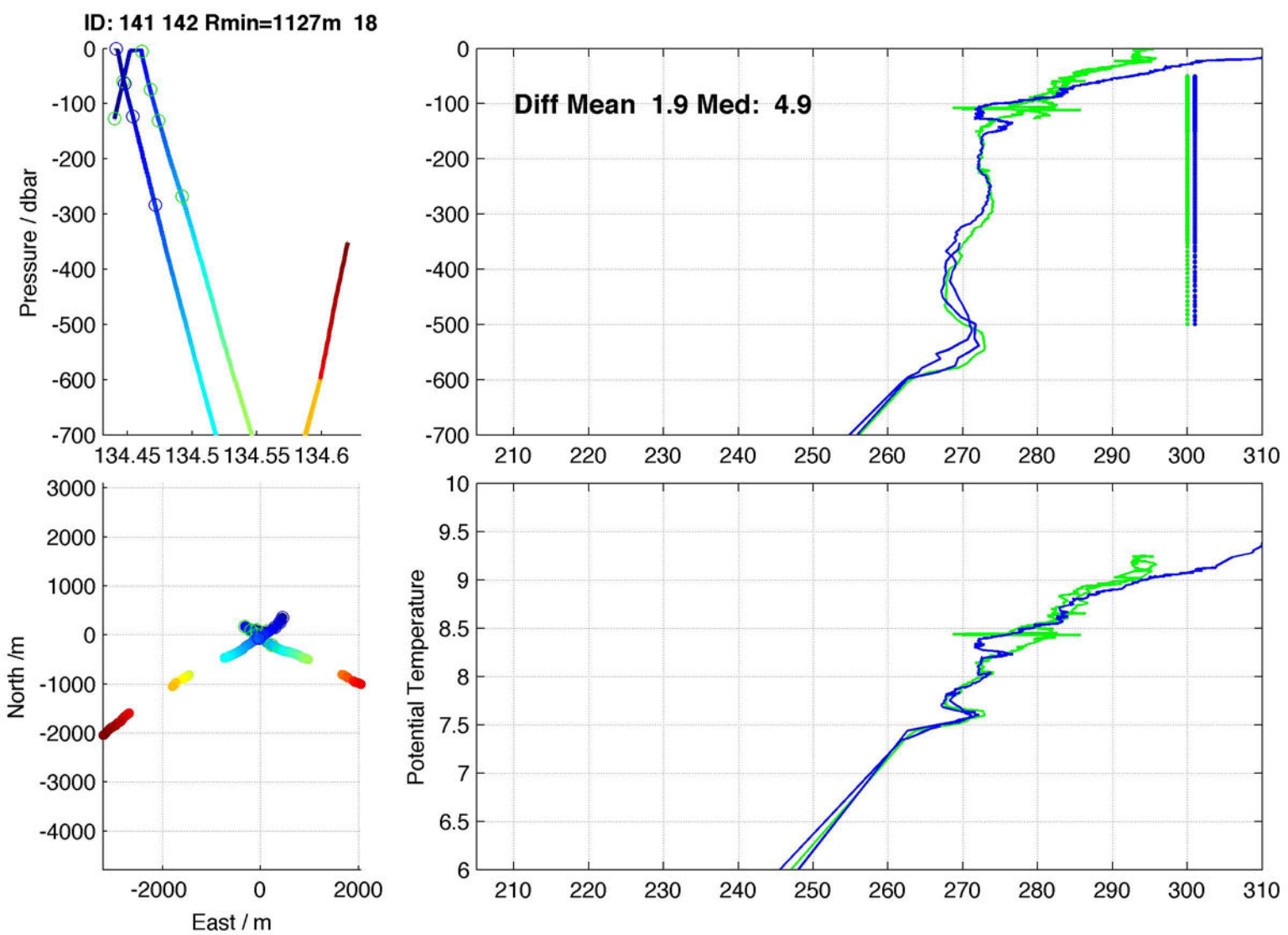

ID: 140 48 Rmin= 388m 13
Pressure / dbar
0
-100
-200
-300
-400
-500
-600
-700
144.1
144.2
144.3
Diff Mean NaN Med: NaN
210
220
230
240
250
260
270
280
290
300
310
North /m
3000
2000
1000
0
-1000
-2000
-3000
-4000
-5000
-2000
0
2000
East / m
Potential Temperature
10
9.5
9
8.5
8
7.5
7
6.5
6

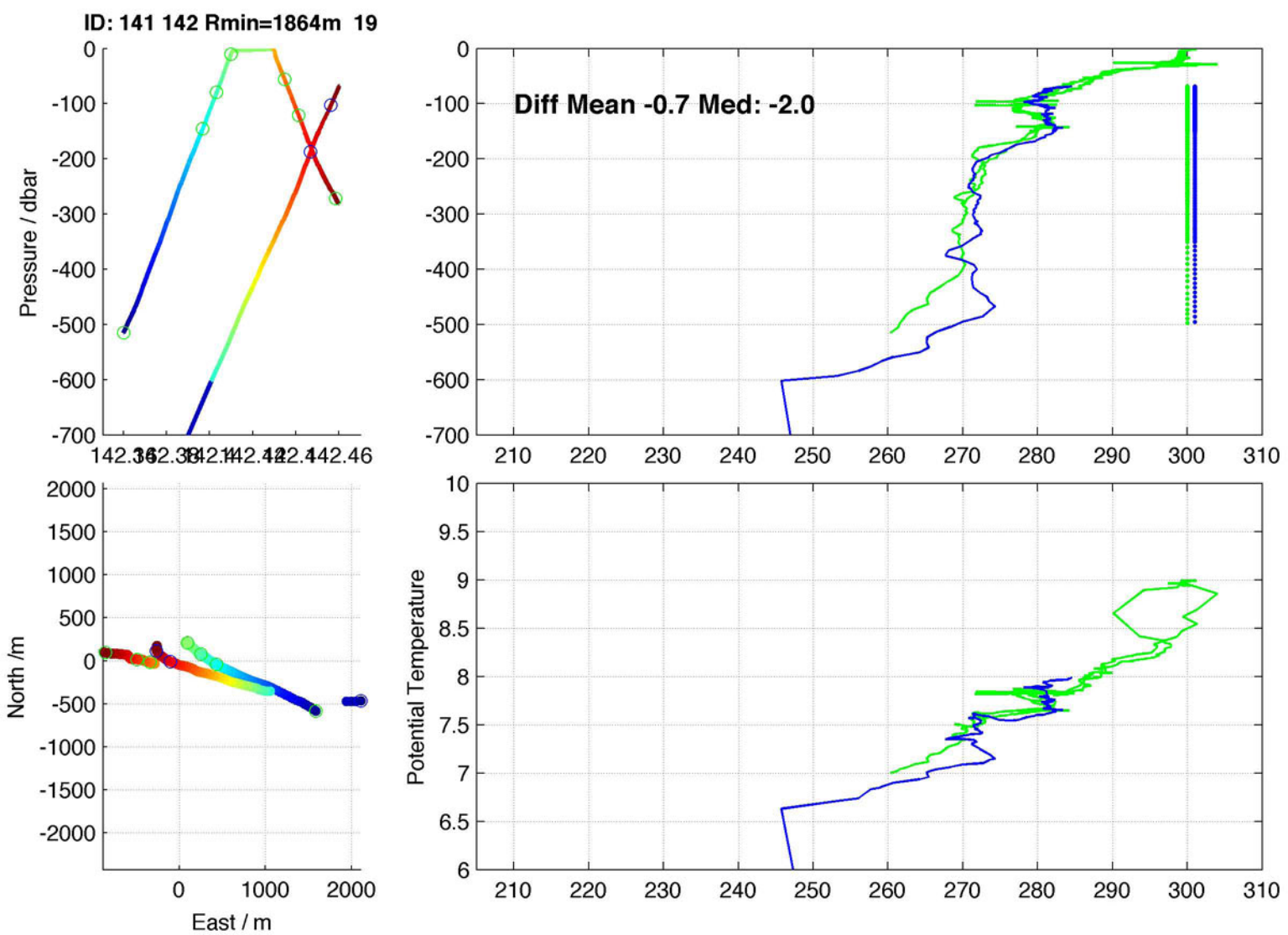

ID: 141 142 Rmin= 72m 14
Pressure / dbar
0
-100
-200
-300
-400
-500
-600
-700
95.6 95.8 96 96.2 96.4
Diff Mean -0.5 Med: -0.3
210 220 230 240 250 260 270 280 290 300 310
North /m
15000
10000
5000
0
-5000
-5000 0 5000
East / m
Potential Temperature
10
9.5
9
8.5
8
7.5
7
6.5
6

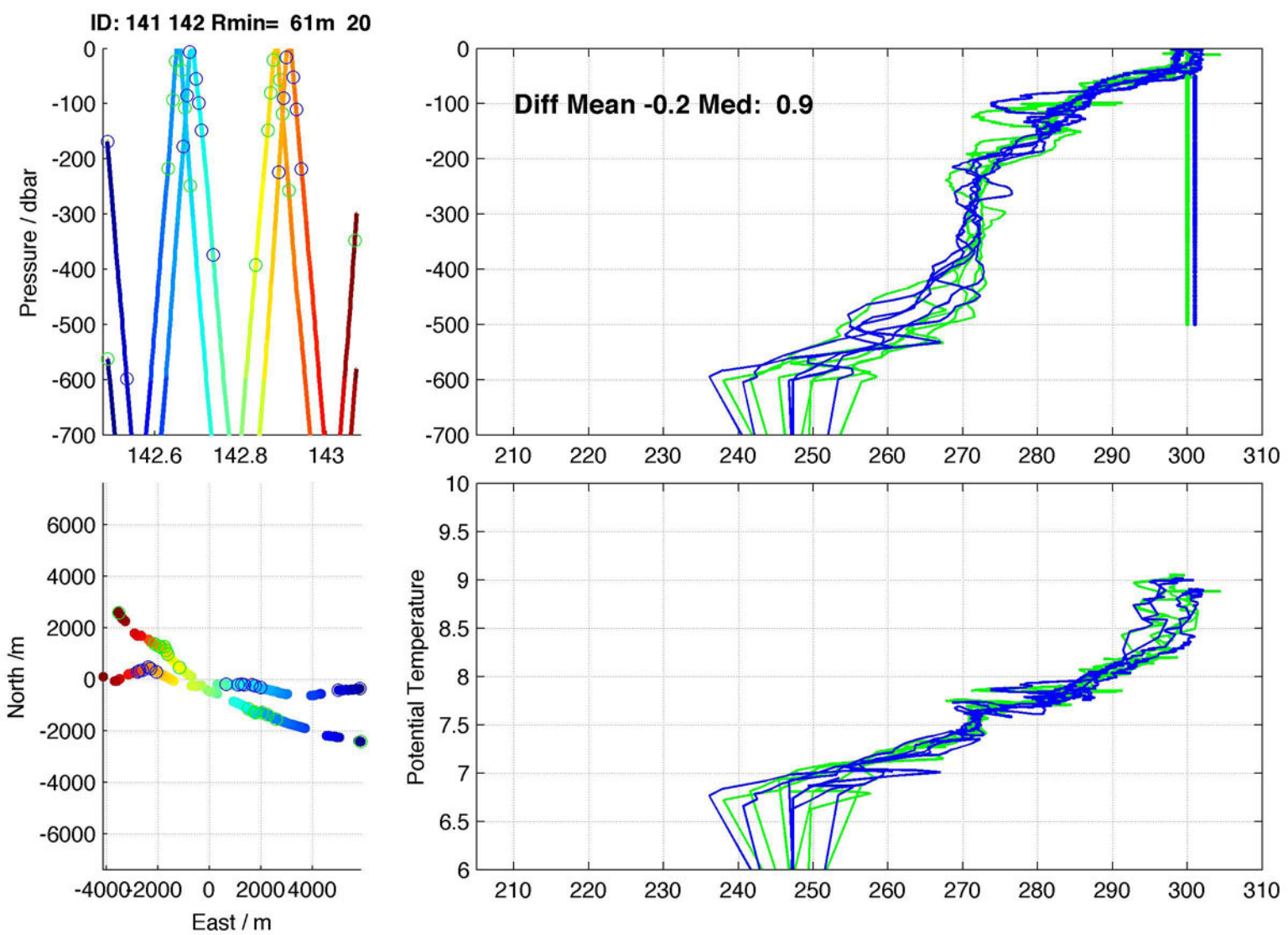

ID: 141 142 Rmin=1783m 15
Pressure / dbar
Diff Mean -0.2 Med: 0.7
North /m
East / m
Potential Temperature

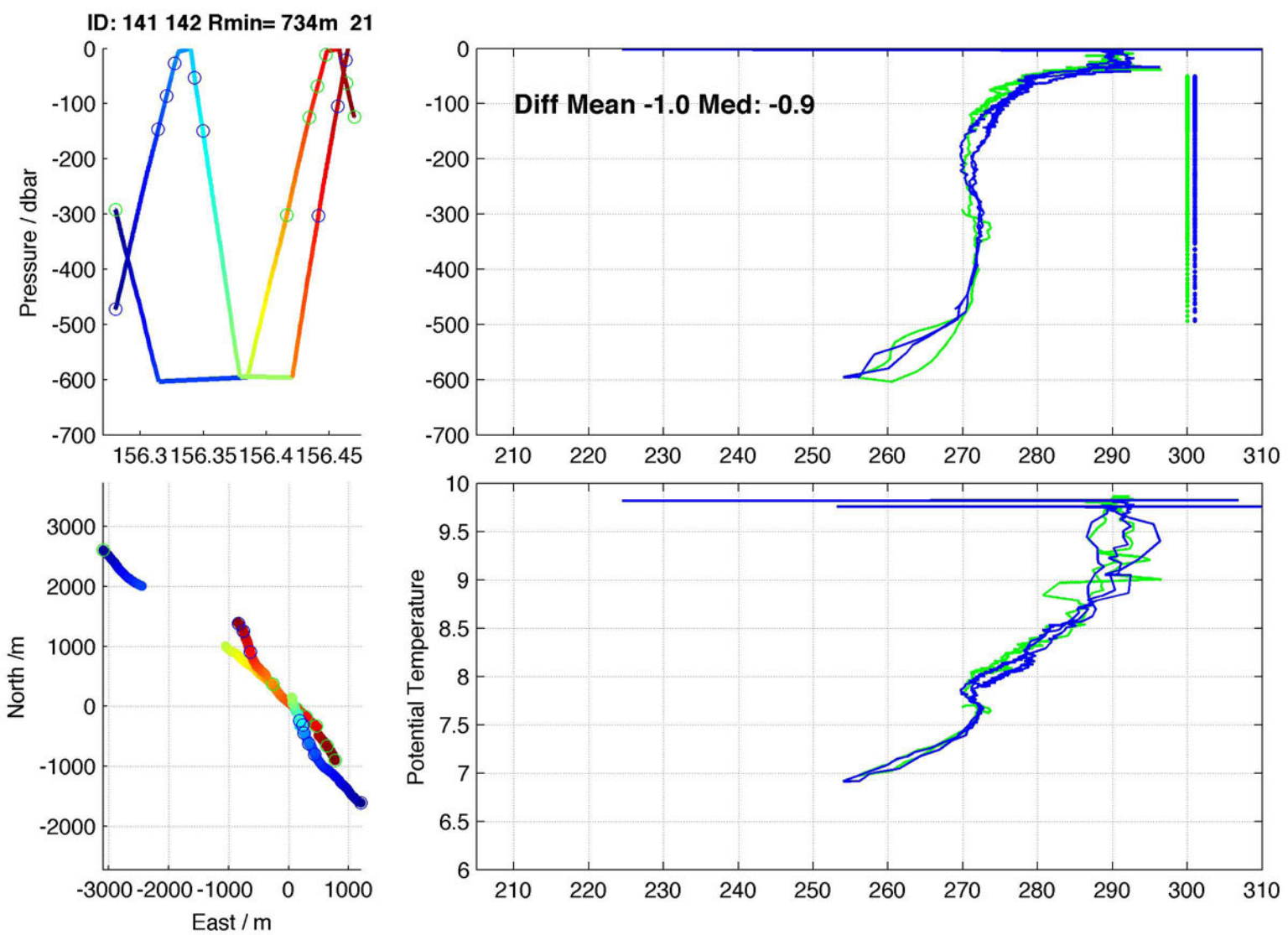

ID: 141 142 Rmin=1650m 16
Pressure / dbar
Diff Mean 0.6 Med: 1.4
North /m
East / m
Potential Temperature

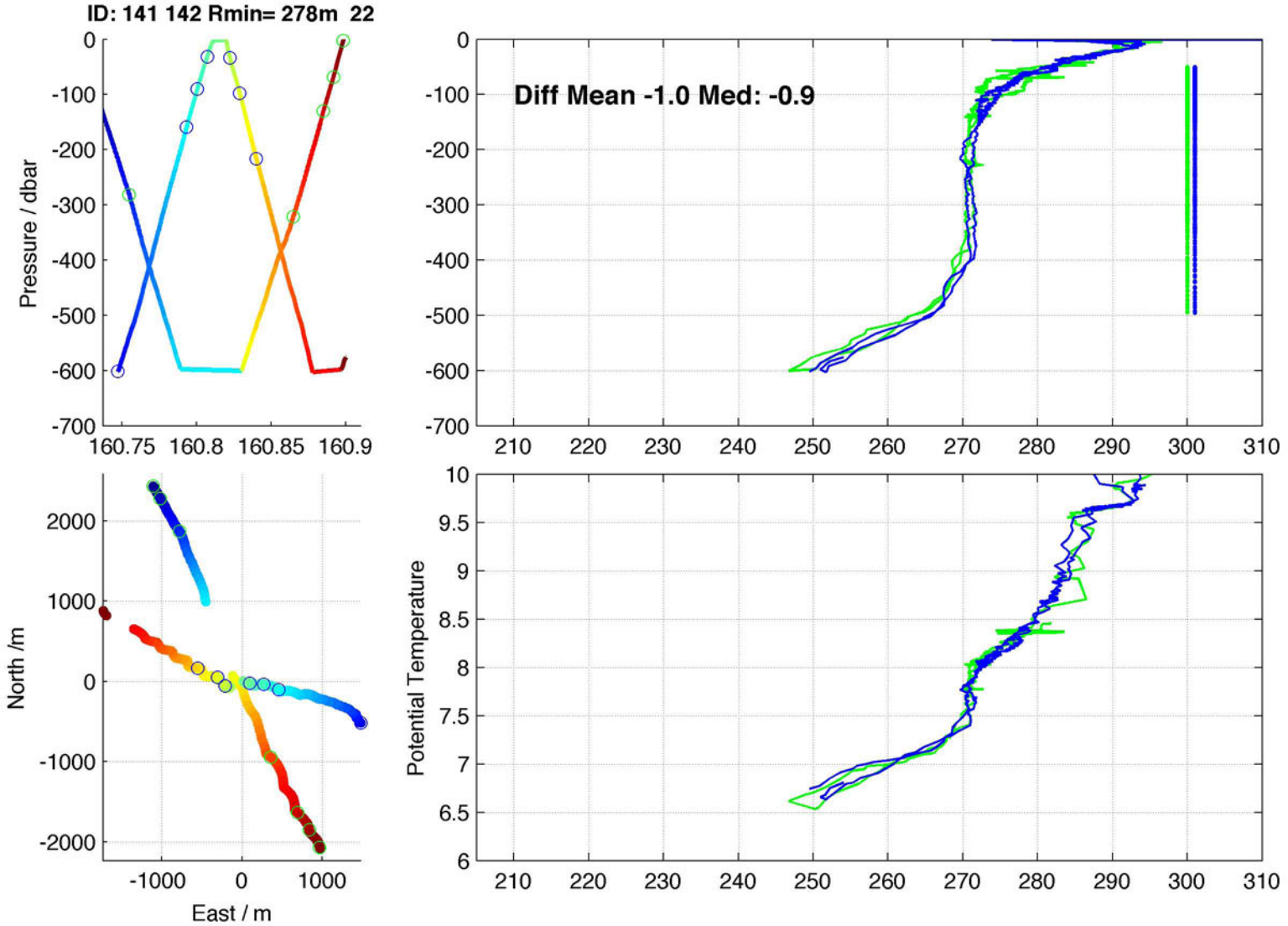

ID: 141 142 Rmin= 799m 17
Pressure / dbar
x 10
Diff Mean -0.9 Med: -1.5
North /m
East / m
x 10^4
Potential Temperature

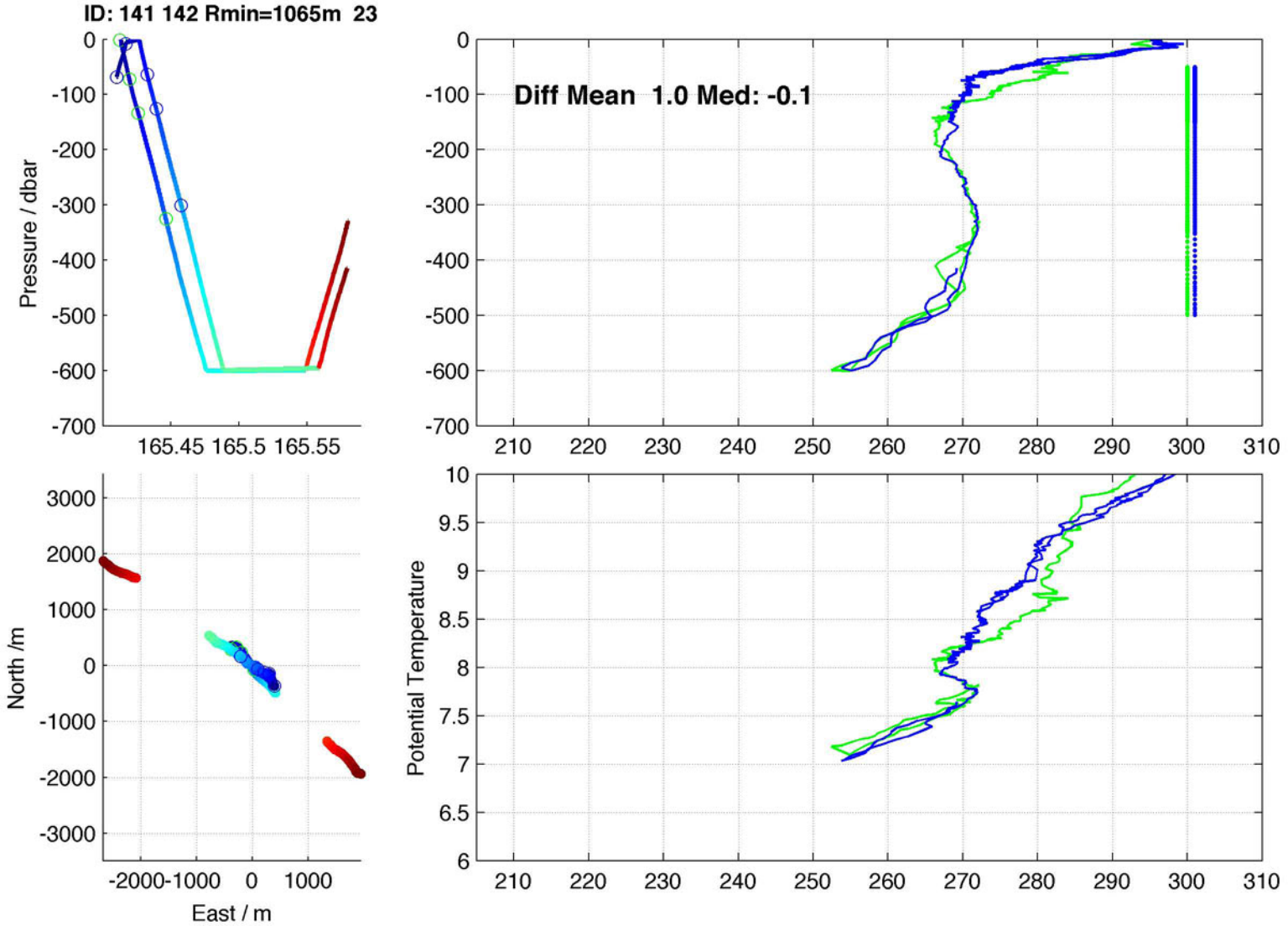

ID: 141 142 Rmin=1127m 18
Pressure / dbar
0
-100
-200
-300
-400
-500
-600
-700
134.45 134.5 134.55 134.6
Diff Mean 1.9 Med: 4.9
210 220 230 240 250 260 270 280 290 300 310
North /m
3000
2000
1000
0
-1000
-2000
-3000
-4000
-2000 0 2000
East / m
Potential Temperature
10
9.5
9
8.5
8
7.5
7
6.5
6

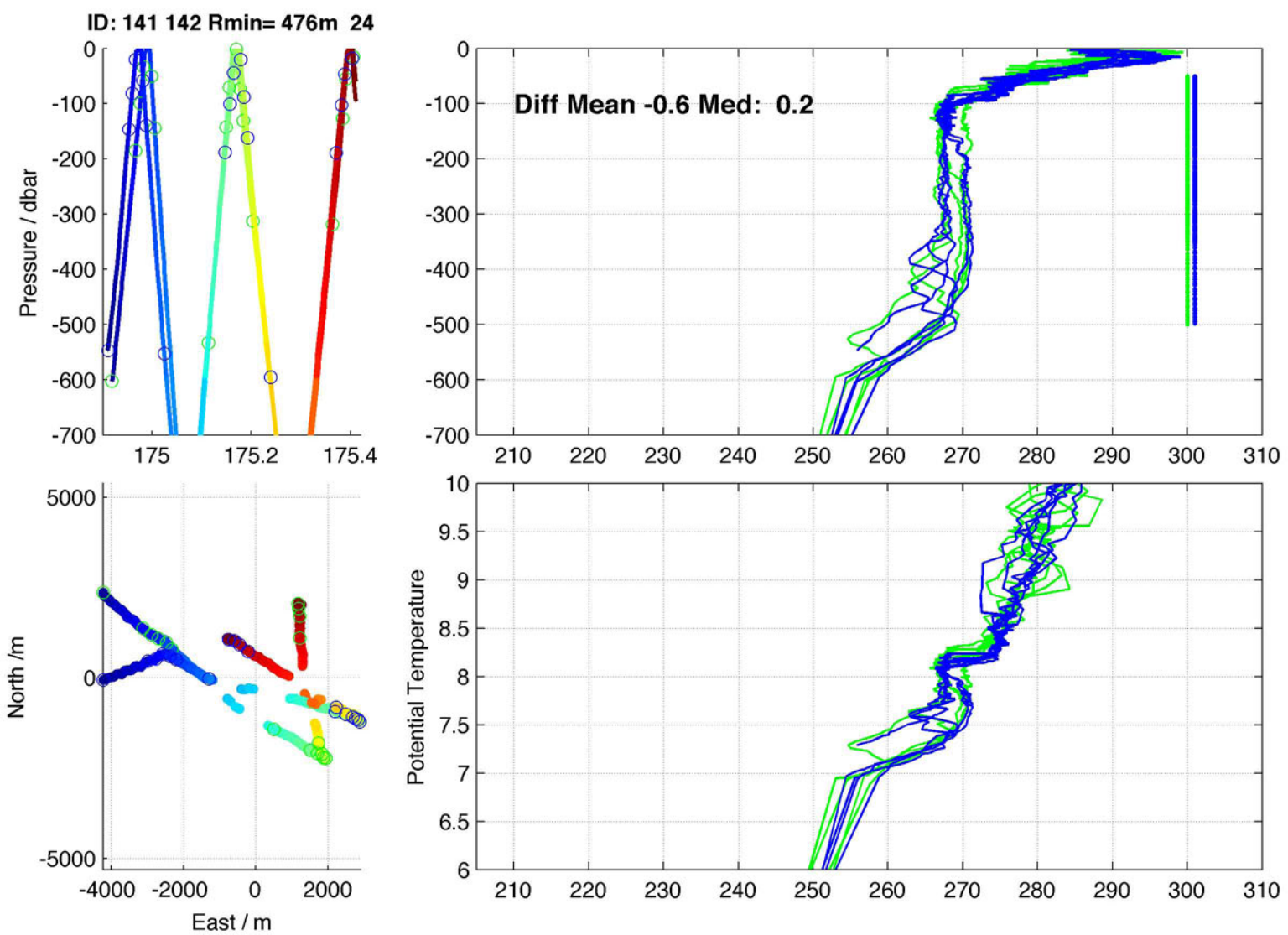

ID: 141 142 Rmin=1864m 19
Pressure / dbar
Diff Mean -0.7 Med: -2.0
North /m
East / m
Potential Temperature

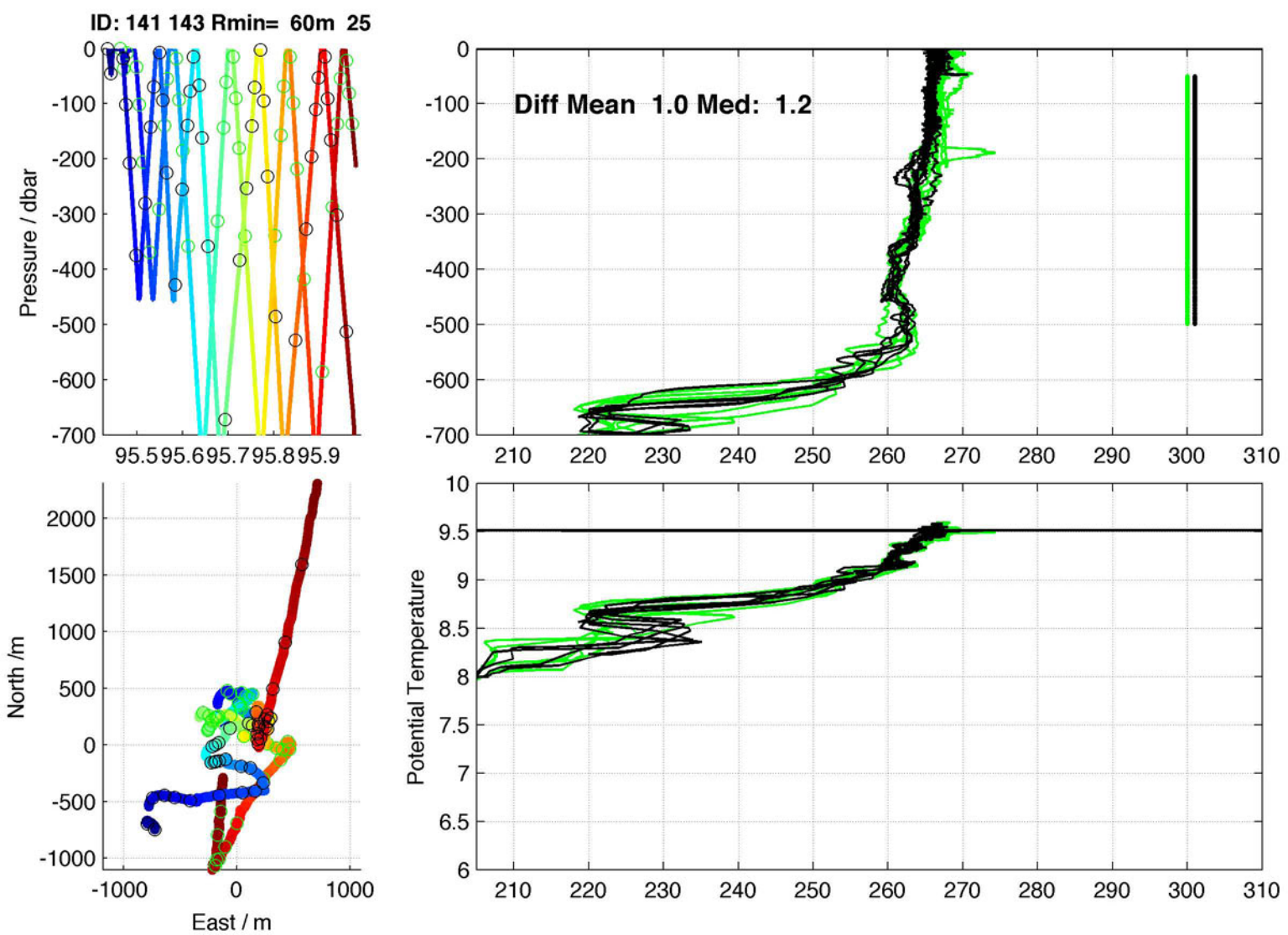

ID: 141 142 Rmin= 61m 20
Pressure / dbar
0
-100
-200
-300
-400
-500
-600
-700
142.6
142.8
143
Diff Mean -0.2 Med: 0.9
210
220
230
240
250
260
270
280
290
300
310
North /m
6000
4000
2000
0
-2000
-4000
-6000
-4000
-2000
0
2000
4000
East / m
Potential Temperature
10
9.5
9
8.5
8
7.5
7
6.5
6

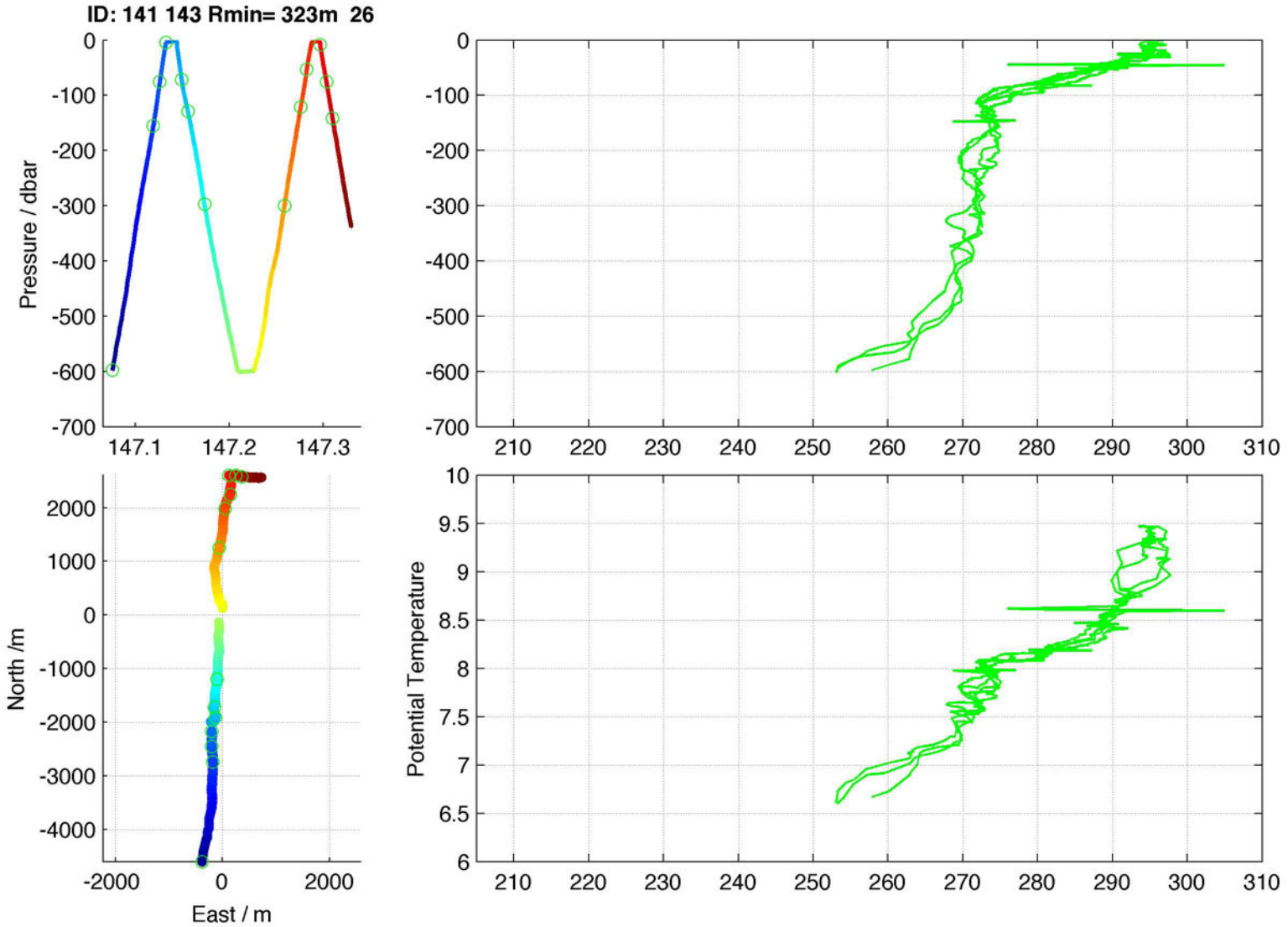

ID: 141 142 Rmin= 734m 21
Pressure / dbar
Diff Mean -1.0 Med: -0.9
North /m
East / m
Potential Temperature

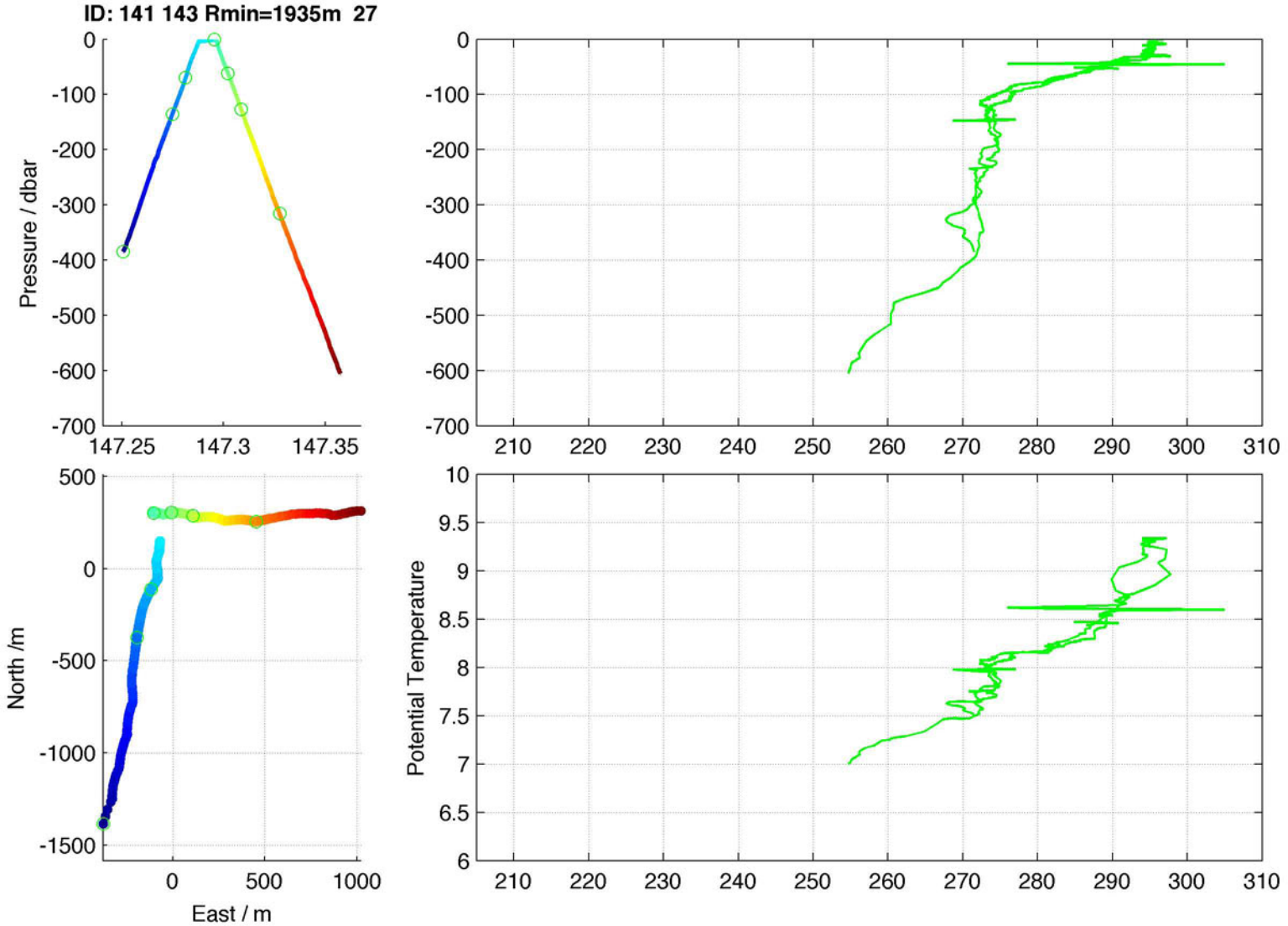

ID: 141 142 Rmin= 278m 22
Pressure / dbar
Diff Mean -1.0 Med: -0.9
North /m
East / m
Potential Temperature

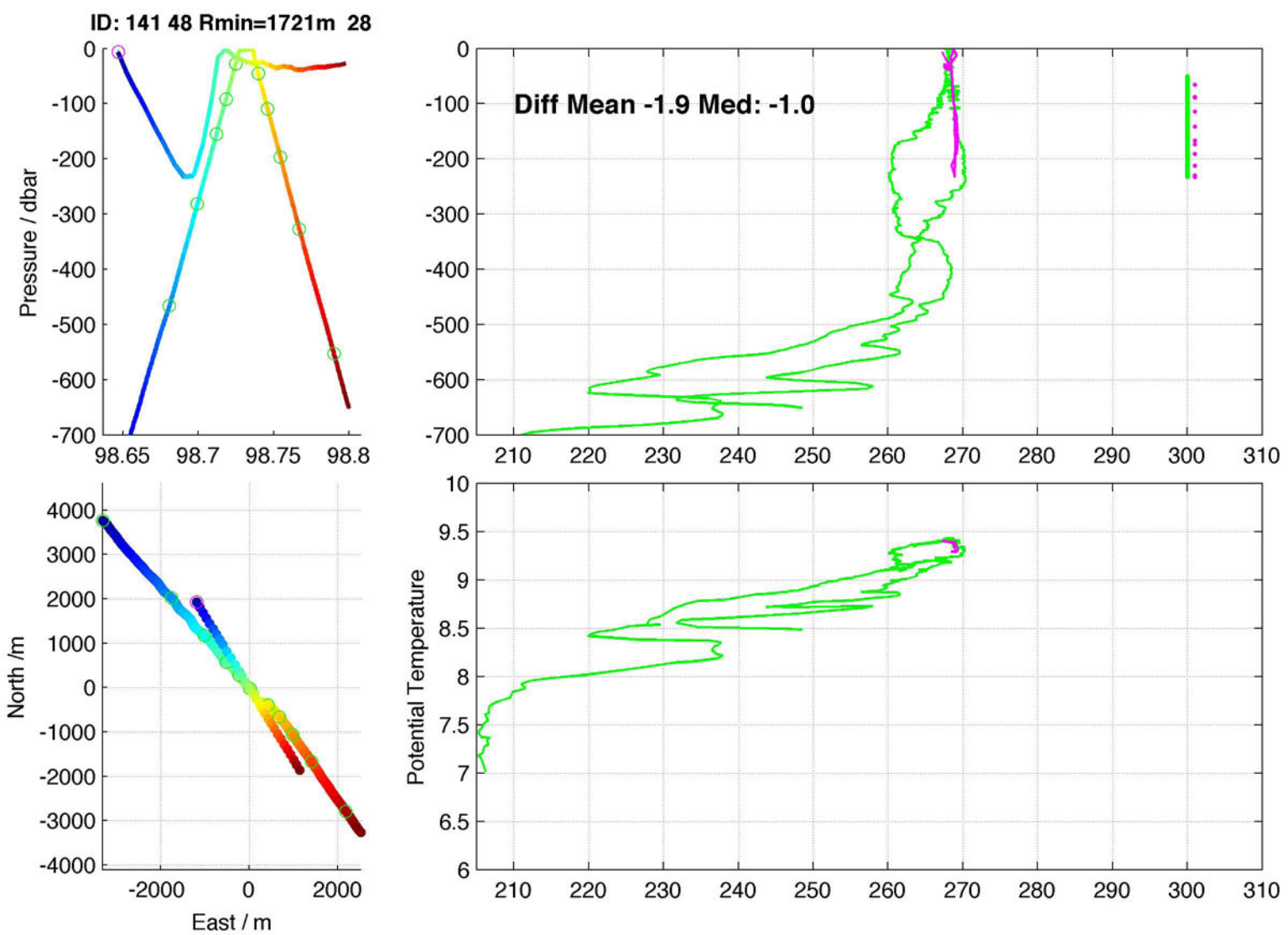

ID: 141 142 Rmin=1065m 23
Pressure / dbar
0
-100
-200
-300
-400
-500
-600
-700
165.45 165.5 165.55
Diff Mean 1.0 Med: -0.1
210 220 230 240 250 260 270 280 290 300 310
North /m
3000
2000
1000
0
-1000
-2000
-3000
-2000-1000 0 1000
East / m
Potential Temperature
10
9.5
9
8.5
8
7.5
7
6.5
6

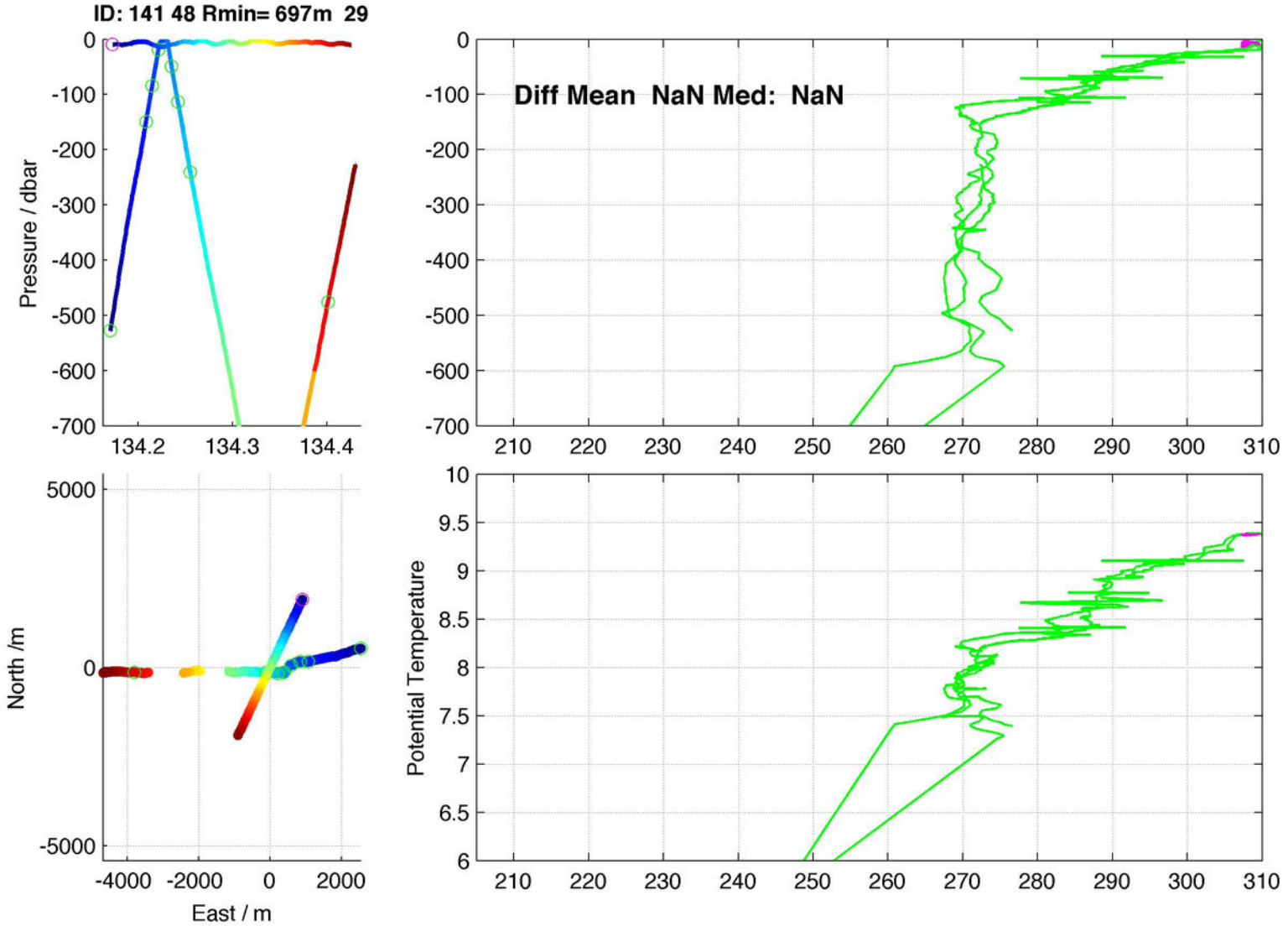

ID: 141 142 Rmin= 476m 24
Pressure / dbar
0
-100
-200
-300
-400
-500
-600
-700
175
175.2
175.4
Diff Mean -0.6 Med: 0.2
210
220
230
240
250
260
270
280
290
300
310
North /m
5000
0
-5000
-4000
-2000
0
2000
East / m
Potential Temperature
10
9.5
9
8.5
8
7.5
7
6.5
6

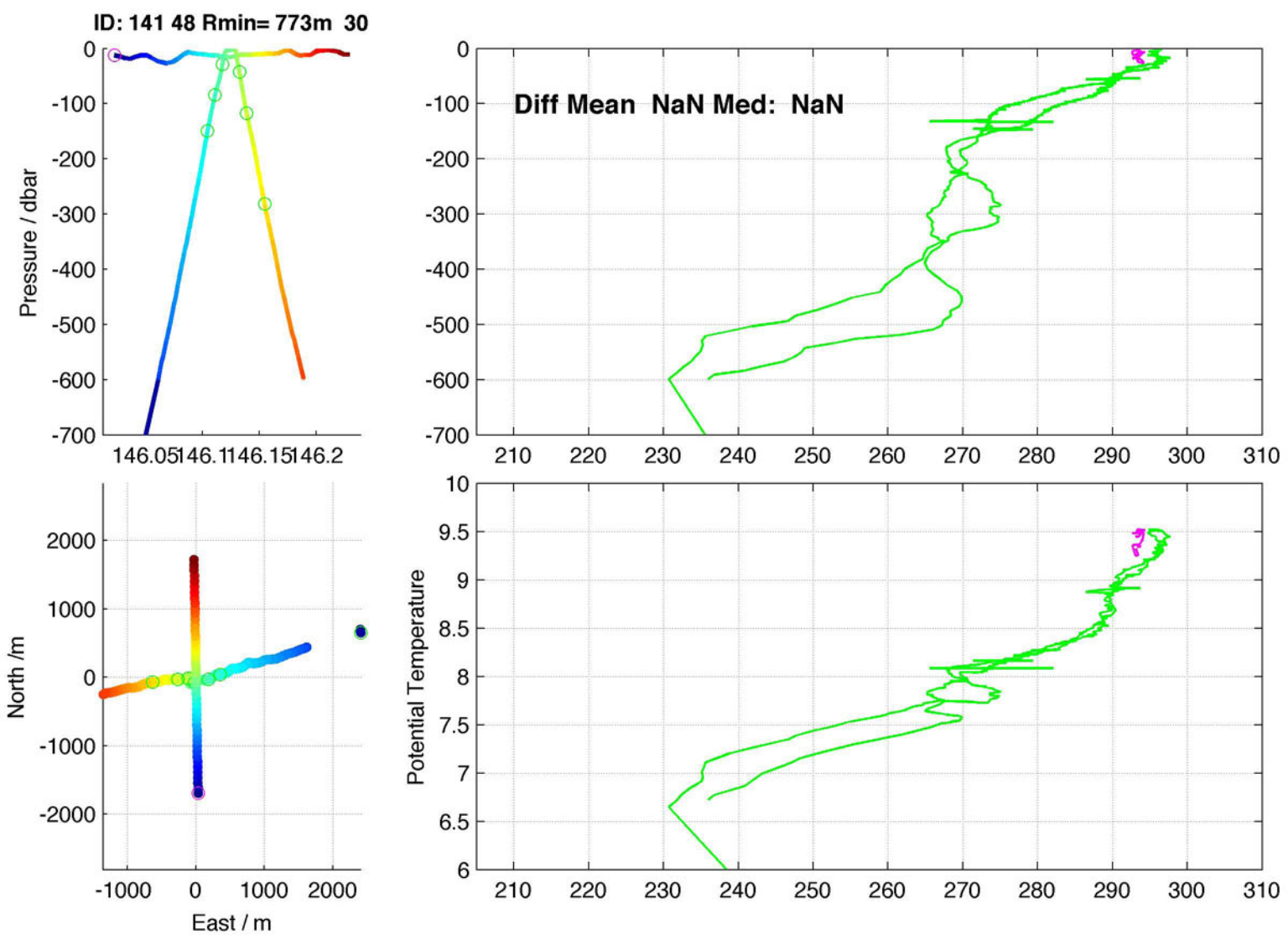

ID: 141 143 Rmin= 60m 25
Pressure / dbar
Diff Mean 1.0 Med: 1.2
North /m
East / m
Potential Temperature

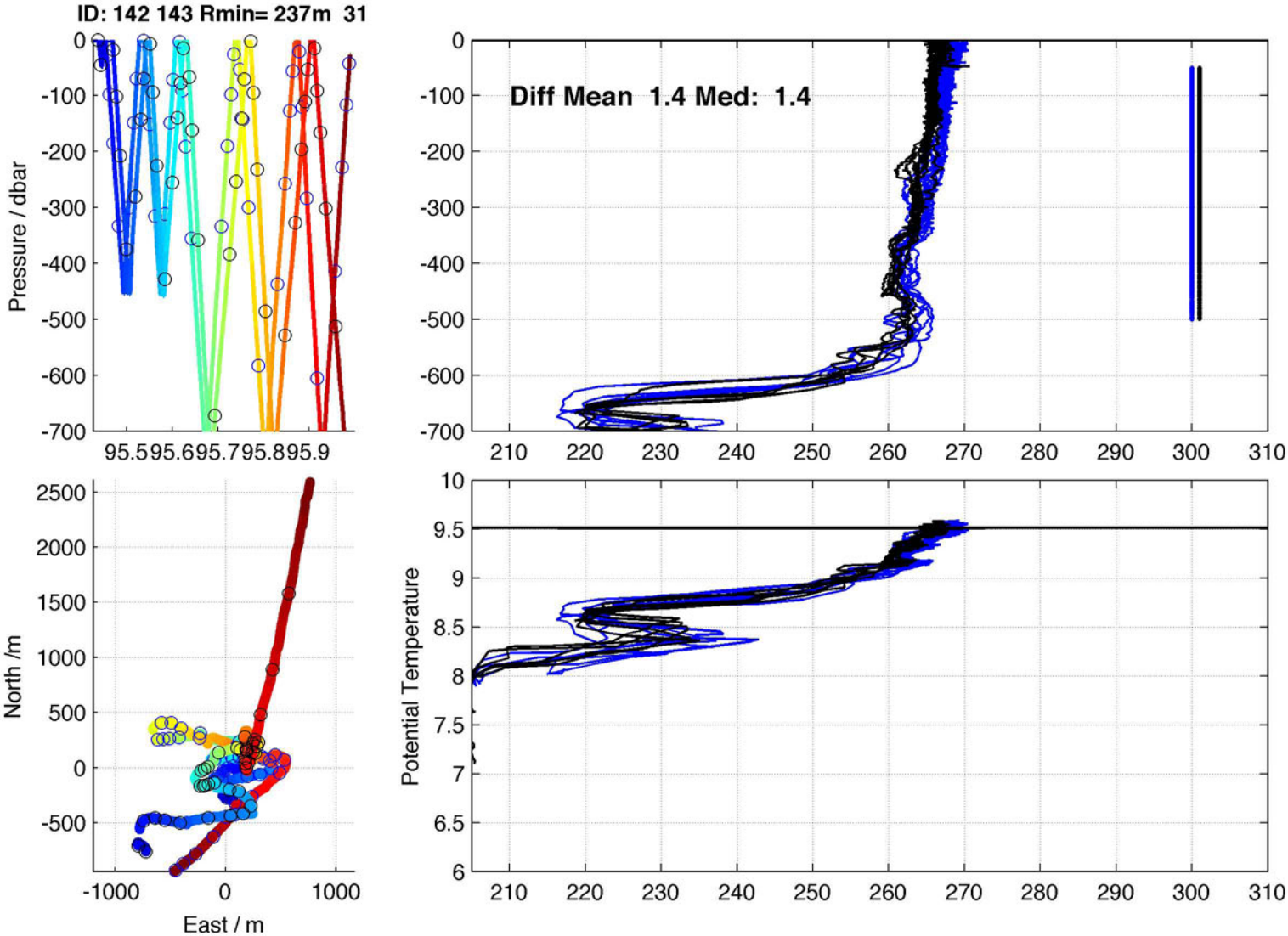

ID: 141 143 Rmin= 323m 26
Pressure / dbar
0
-100
-200
-300
-400
-500
-600
-700
147.1
147.2
147.3
210
220
230
240
250
260
270
280
290
300
310
North /m
2000
1000
0
-1000
-2000
-3000
-4000
-2000
0
2000
East / m
Potential Temperature
10
9.5
9
8.5
8
7.5
7
6.5
6

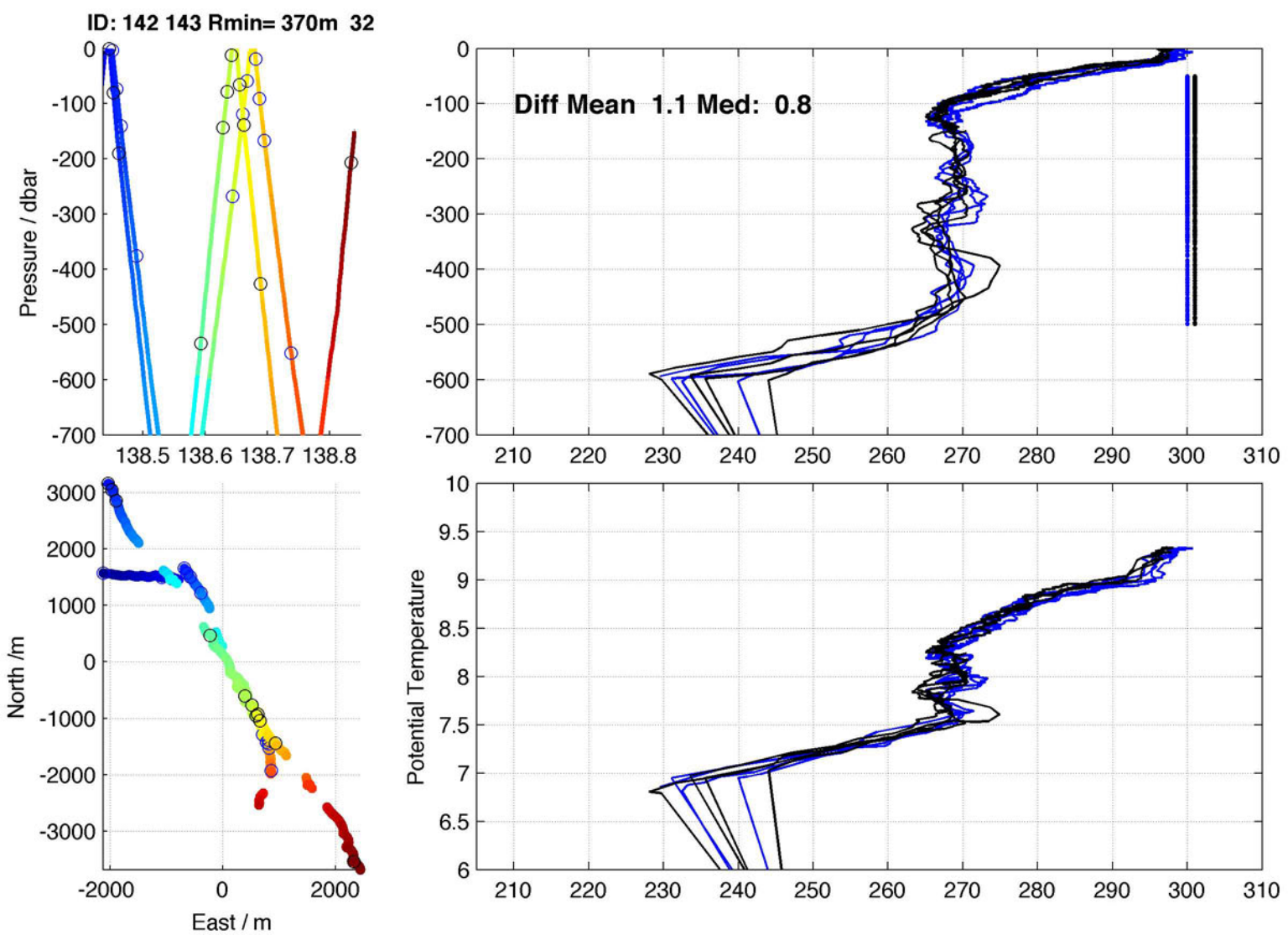

ID: 141 143 Rmin=1935m 27
Pressure / dbar
0
-100
-200
-300
-400
-500
-600
-700
147.25
147.3
147.35
210
220
230
240
250
260
270
280
290
300
310
North /m
500
0
-500
-1000
-1500
East / m
1000
Potential Temperature
10
9.5
9
8.5
8
7.5
7
6.5
6

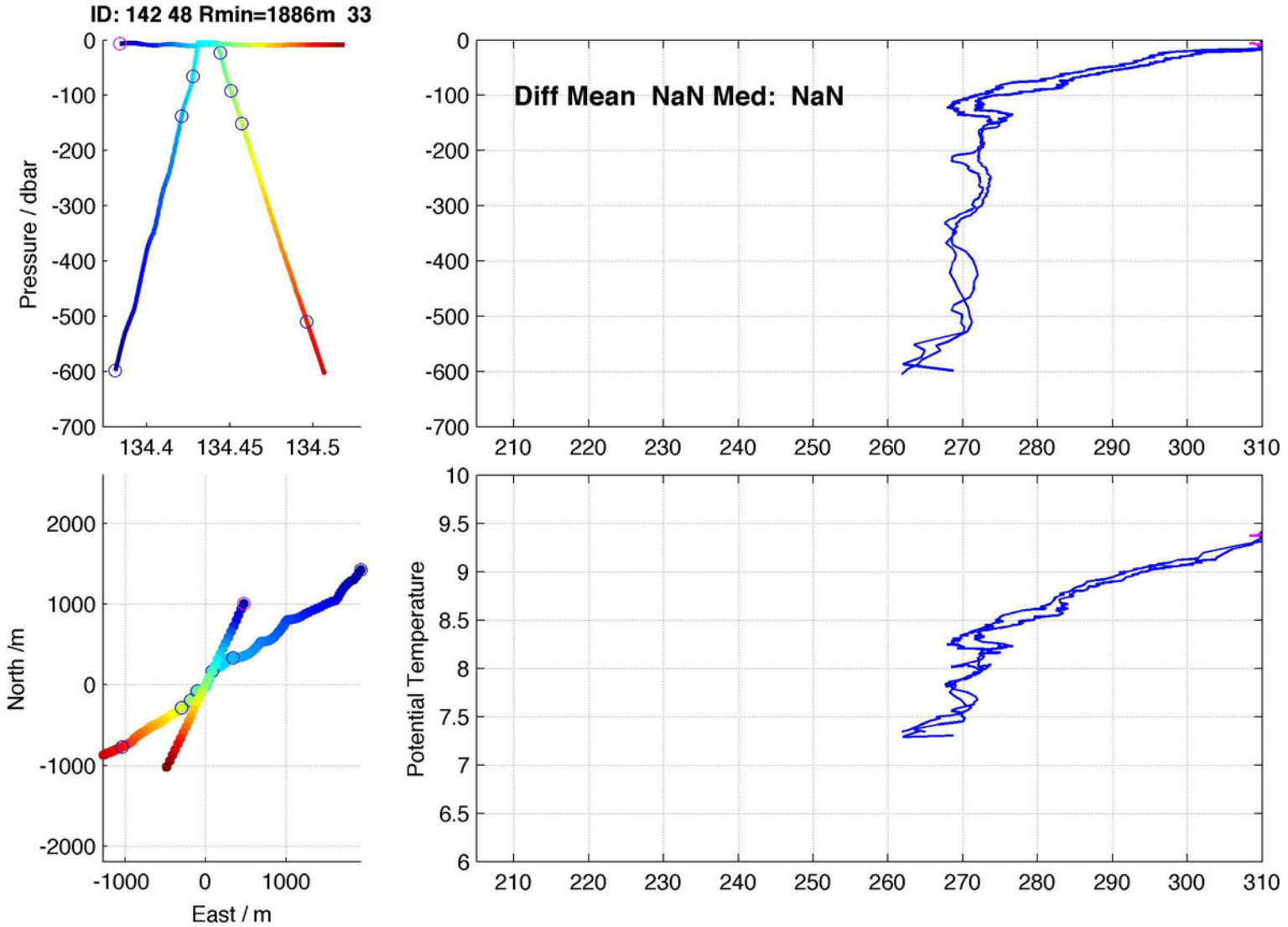

ID: 141 48 Rmin=1721m 28
Pressure / dbar
Diff Mean -1.9 Med: -1.0
North /m
East / m
Potential Temperature

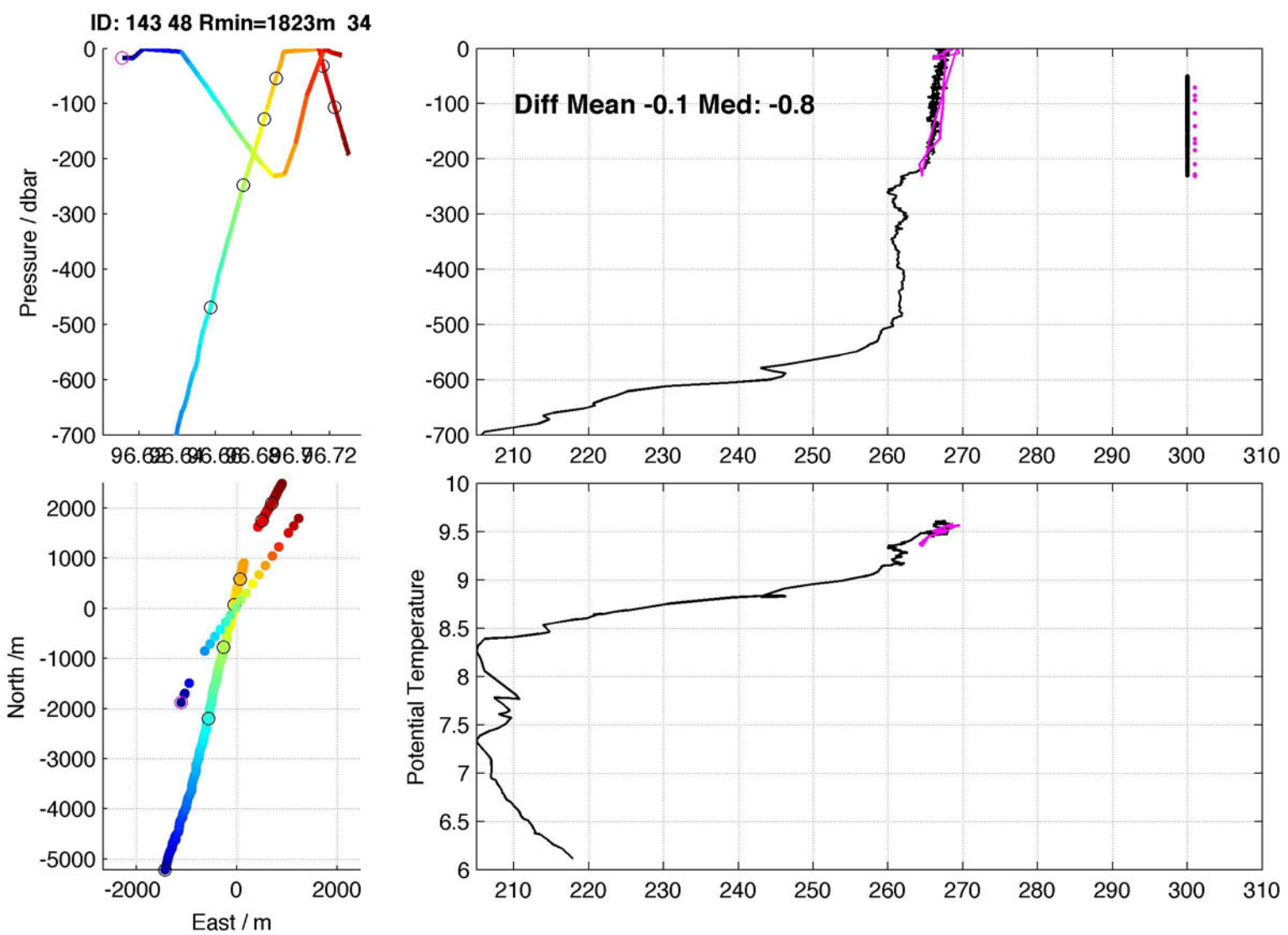

ID: 141 48 Rmin= 697m 29
Pressure / dbar
0
-100
-200
-300
-400
-500
-600
-700
134.2
134.3
134.4
Diff Mean NaN Med: NaN
210
220
230
240
250
260
270
280
290
300
310
North /m
5000
0
-5000
-4000
-2000
0
2000
East / m
Potential Temperature
10
9.5
9
8.5
8
7.5
7
6.5
6

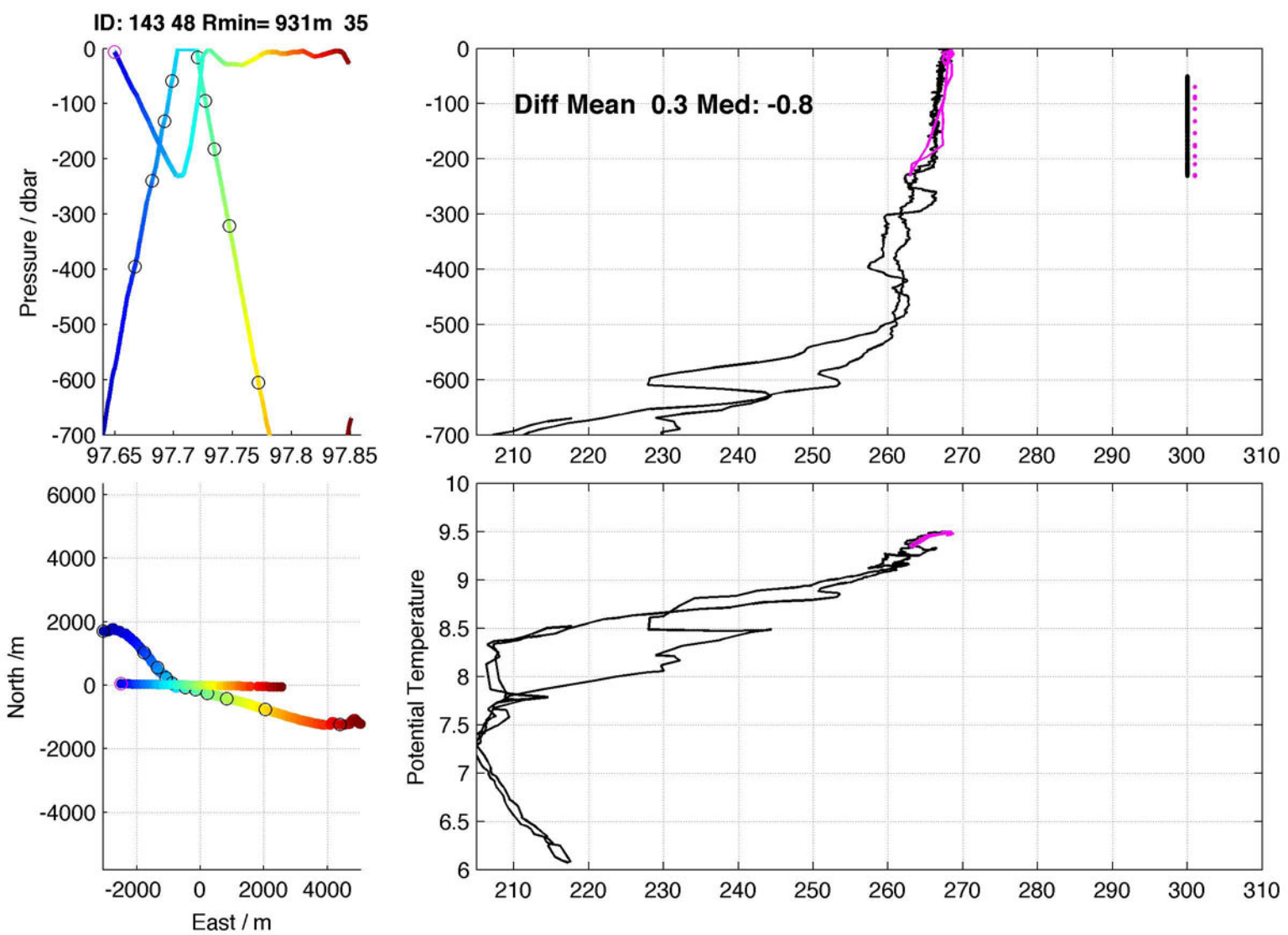

ID: 141 48 Rmin= 773m 30
Pressure / dbar
0
-100
-200
-300
-400
-500
-600
-700
146.05
146.1
146.15
146.2
Diff Mean NaN Med: NaN
210
220
230
240
250
260
270
280
290
300
310
North /m
2000
1000
0
-1000
-2000
East / m
-1000
0
1000
2000
Potential Temperature
10
9.5
9
8.5
8
7.5
7
6.5
6

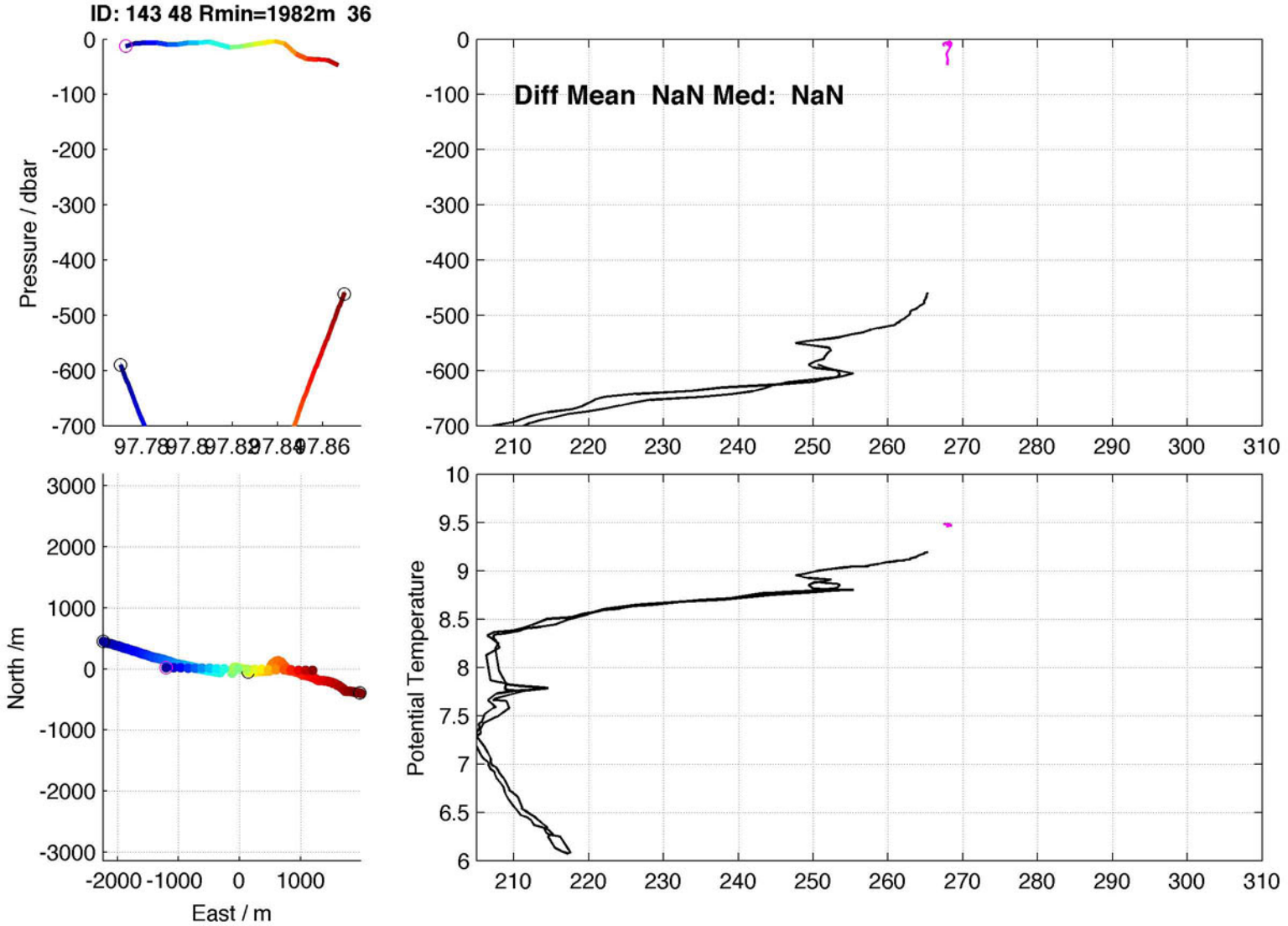

ID: 142 143 Rmin= 237m 31
Pressure / dbar
0
-100
-200
-300
-400
-500
-600
-700
95.5
95.6
95.7
95.8
95.9
Diff Mean 1.4 Med: 1.4
210
220
230
240
250
260
270
280
290
300
310
North /m
2500
2000
1500
1000
500
0
-500
-1000
1000
East / m
Potential Temperature
10
9.5
9
8.5
8
7.5
7
6.5
6

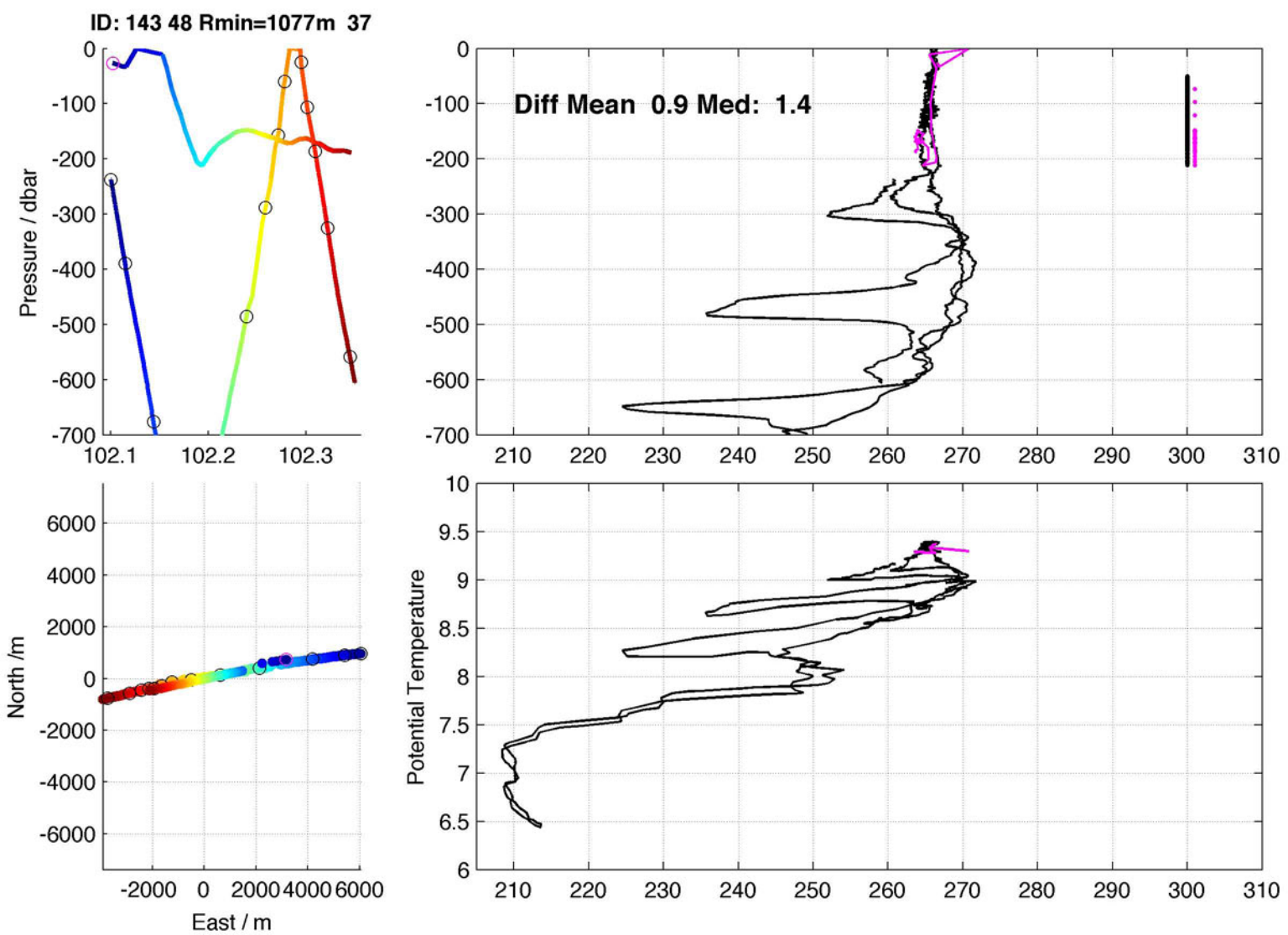

ID: 142 143 Rmin= 370m 32
Pressure / dbar
Diff Mean 1.1 Med: 0.8
North /m
East / m
Potential Temperature

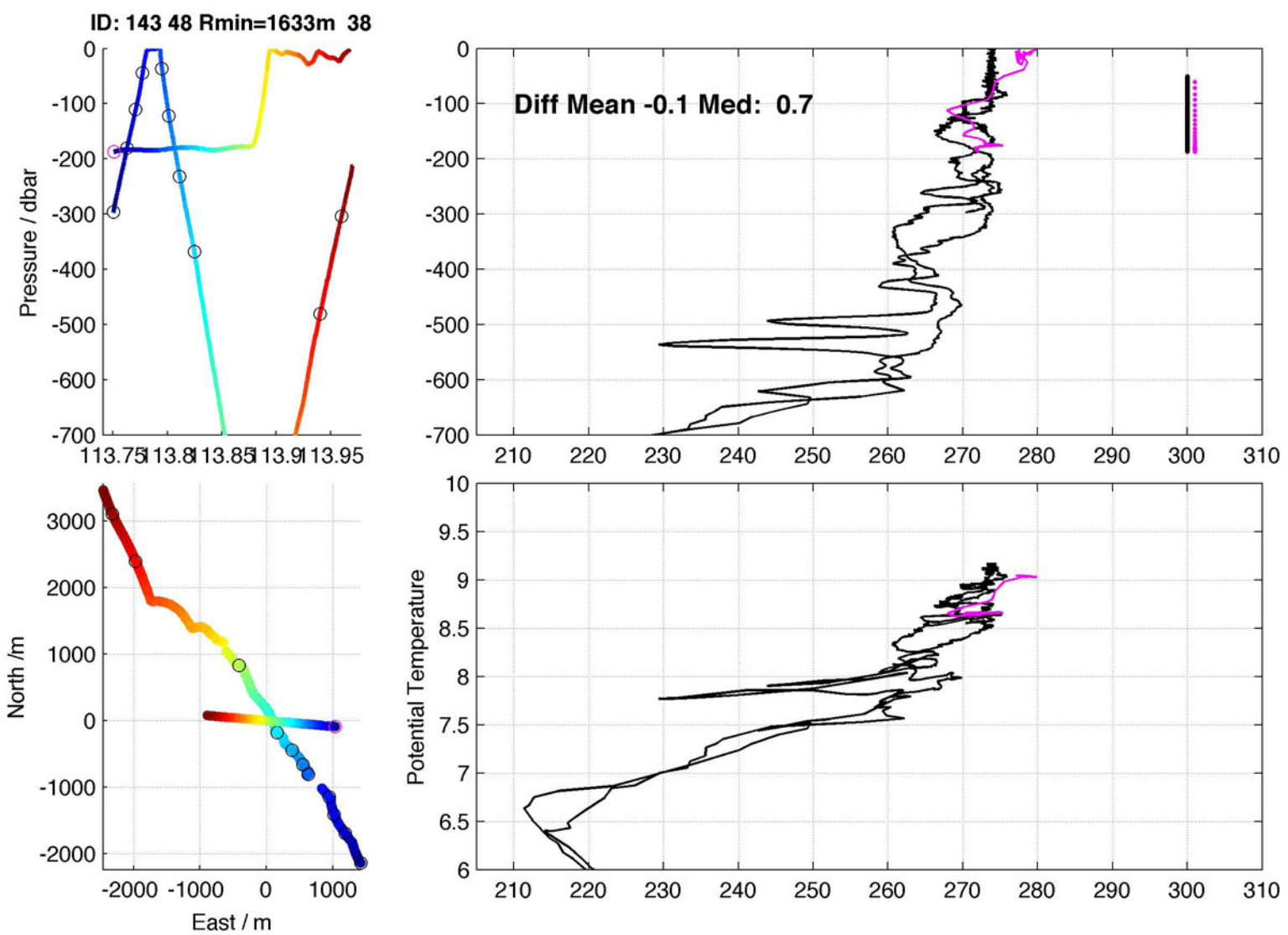

ID: 142 48 Rmin=1886m 33
Pressure / dbar
0
-100
-200
-300
-400
-500
-600
-700
134.4
134.45
134.5
Diff Mean NaN Med: NaN
210
220
230
240
250
260
270
280
290
300
310
North /m
2000
1000
0
-1000
-2000
-1000
0
1000
East / m
Potential Temperature
10
9.5
9
8.5
8
7.5
7
6.5
6

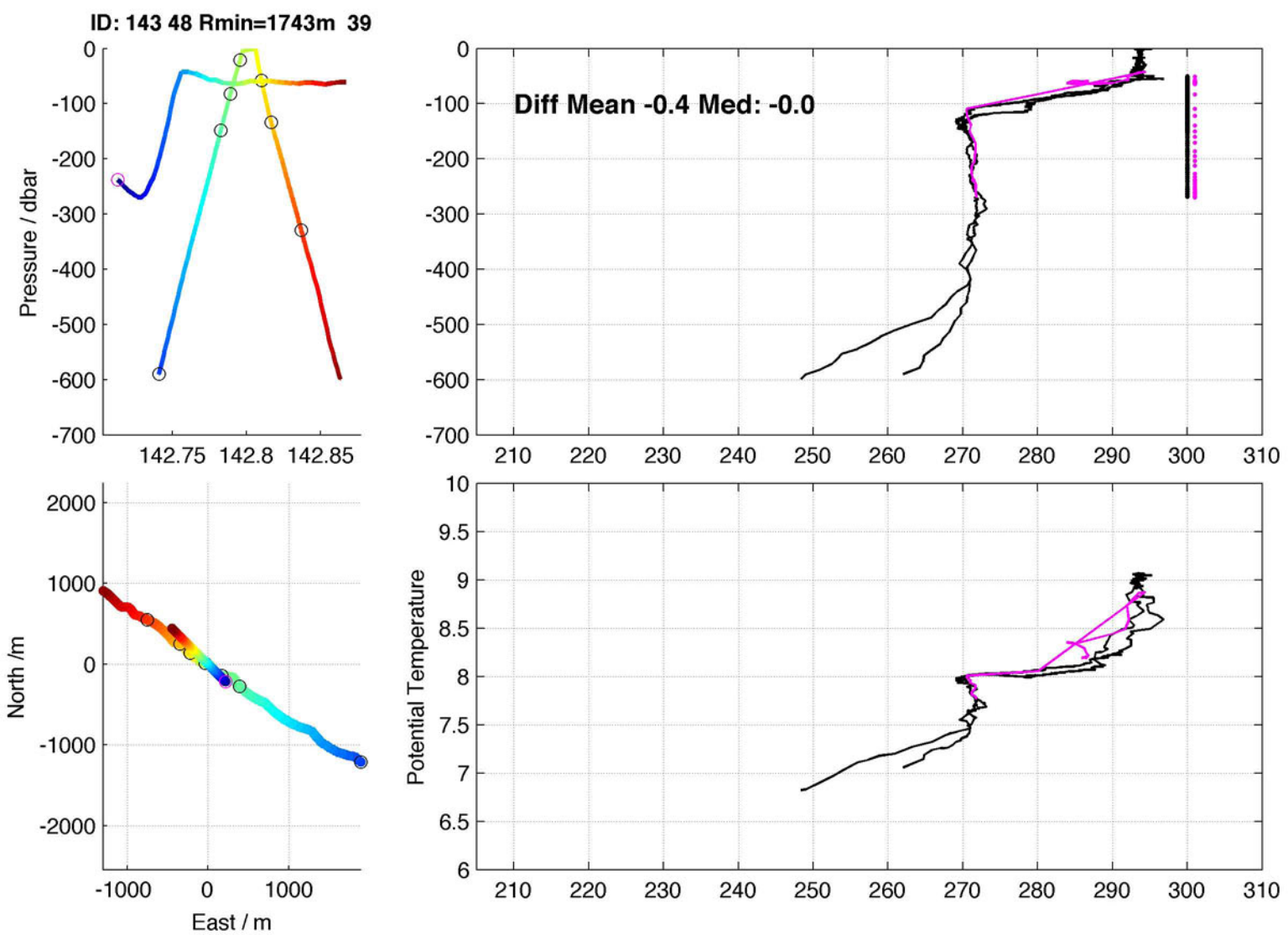

ID: 143 48 Rmin=1823m 34
Pressure / dbar
Diff Mean -0.1 Med: -0.8
North /m
East / m
Potential Temperature

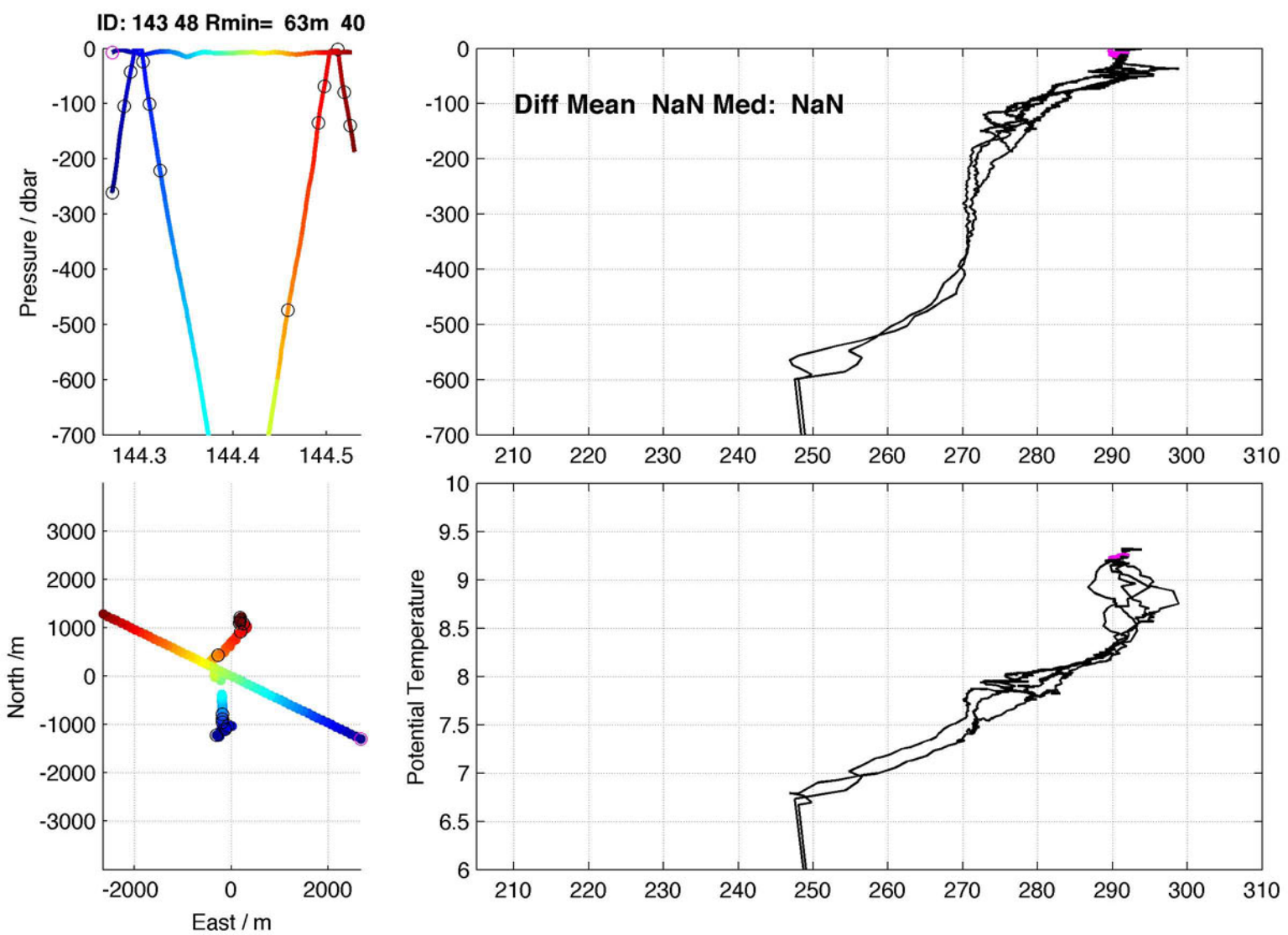

ID: 143 48 Rmin= 931m 35
Pressure / dbar
Diff Mean 0.3 Med: -0.8
North /m
East / m
Potential Temperature

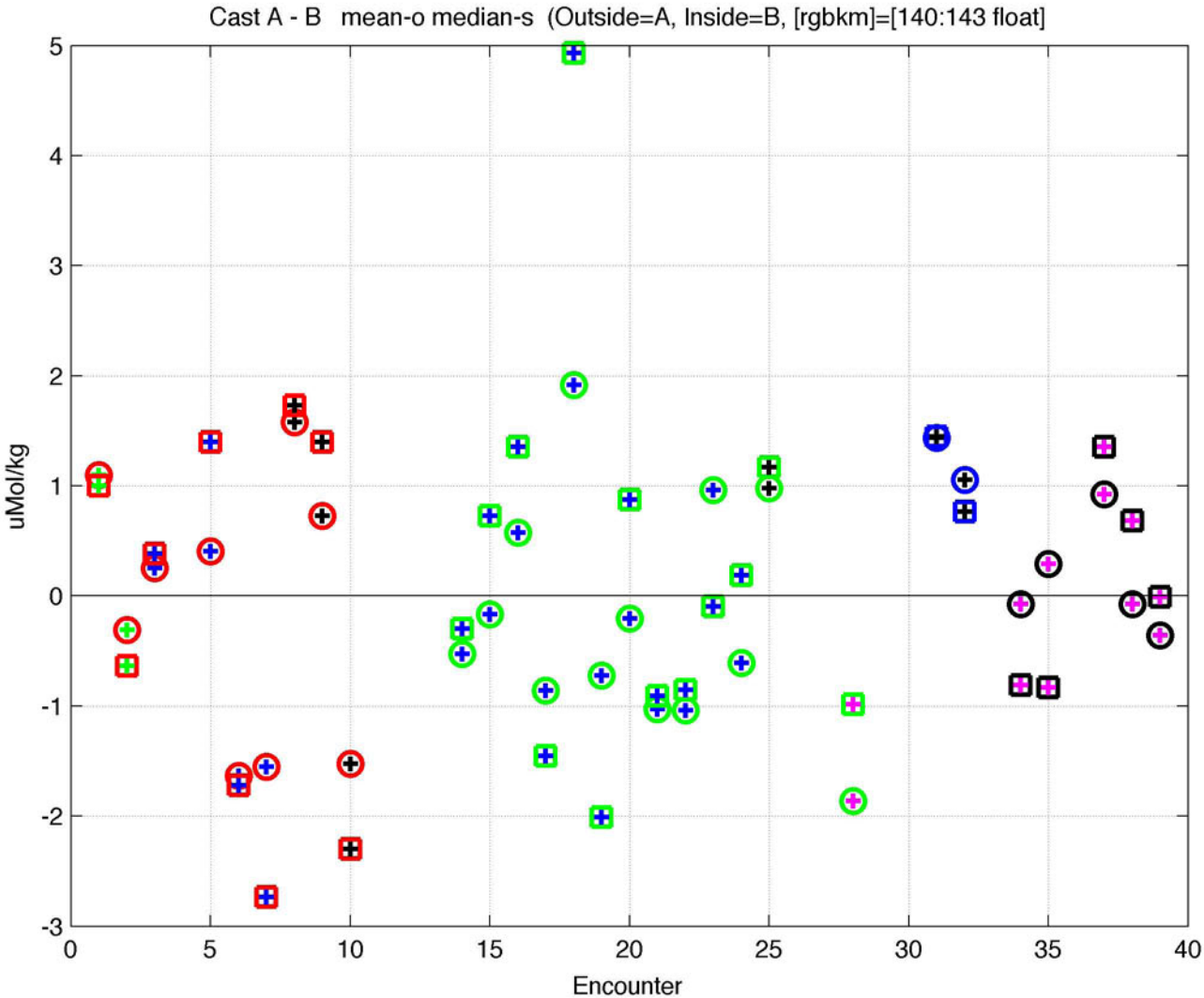

ID: 143 48 Rmin=1982m 36
Pressure / dbar
0
-100
-200
-300
-400
-500
-600
-700
97.78
97.8
97.82
97.84
97.86
Diff Mean NaN Med: NaN
210
220
230
240
250
260
270
280
290
300
310
North /m
3000
2000
1000
0
-1000
-2000
-3000
-2000
-1000
0
1000
East / m
Potential Temperature
10
9.5
9
8.5
8
7.5
7
6.5
6


ID: 143 48 Rmin=1077m 37
Pressure / dbar
Diff Mean 0.9 Med: 1.4
North /m
East / m
Potential Temperature

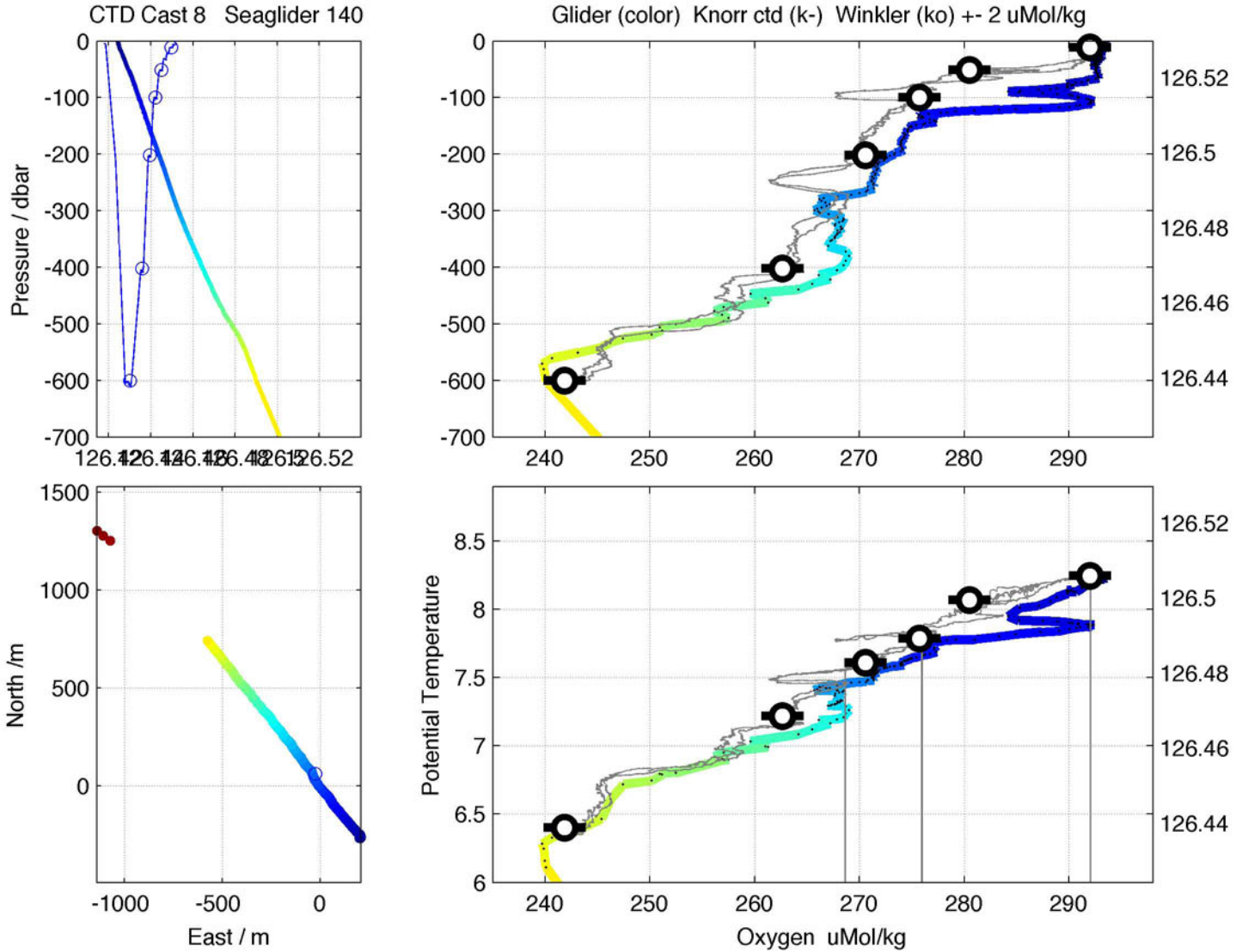

ID: 143 48 Rmin=1633m 38
Pressure / dbar
Diff Mean -0.1 Med: 0.7
North /m
East / m
Potential Temperature

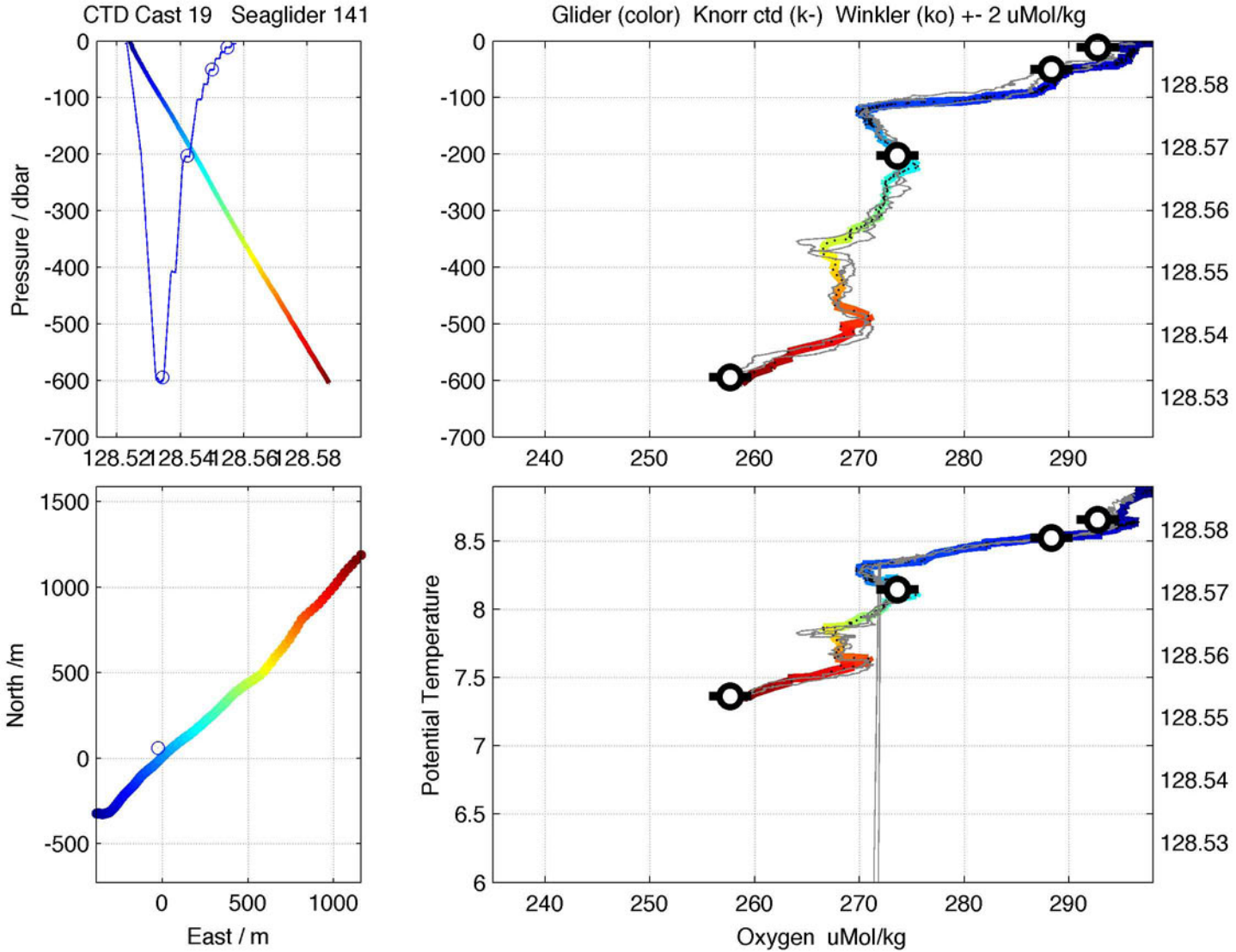

ID: 143 48 Rmin=1743m 39
Pressure / dbar
0
-100
-200
-300
-400
-500
-600
-700
142.75
142.8
142.85
Diff Mean -0.4 Med: -0.0
210
220
230
240
250
260
270
280
290
300
310
North /m
2000
1000
0
-1000
-2000
East / m
-1000
0
1000
Potential Temperature
10
9.5
9
8.5
8
7.5
7
6.5
6

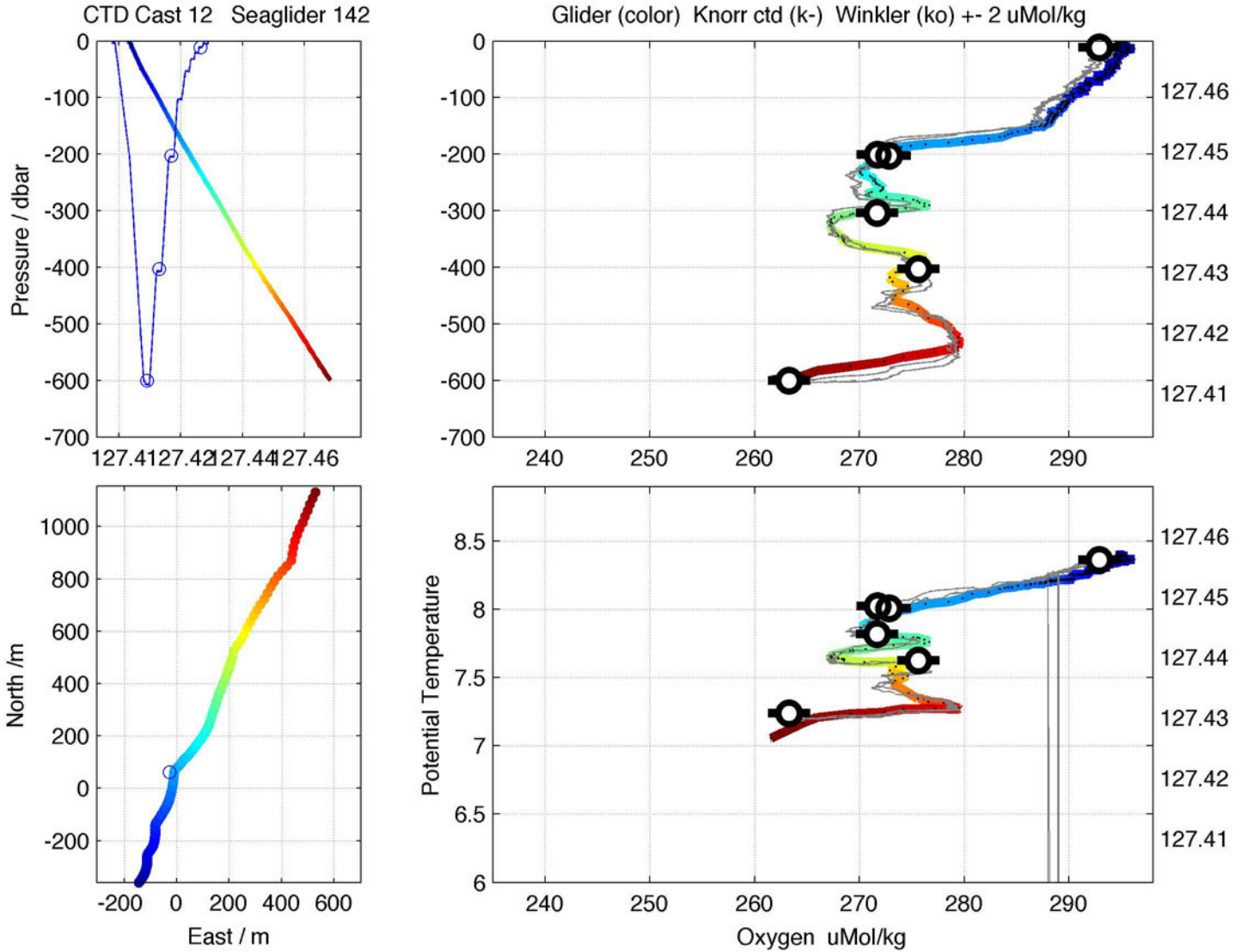

ID: 143 48 Rmin= 63m 40
Pressure / dbar
0
-100
-200
-300
-400
-500
-600
-700
144.3
144.4
144.5
Diff Mean NaN Med: NaN
210
220
230
240
250
260
270
280
290
300
310
North /m
3000
2000
1000
0
-1000
-2000
-3000
-2000
0
2000
East / m
Potential Temperature
10
9.5
9
8.5
8
7.5
7
6.5
6

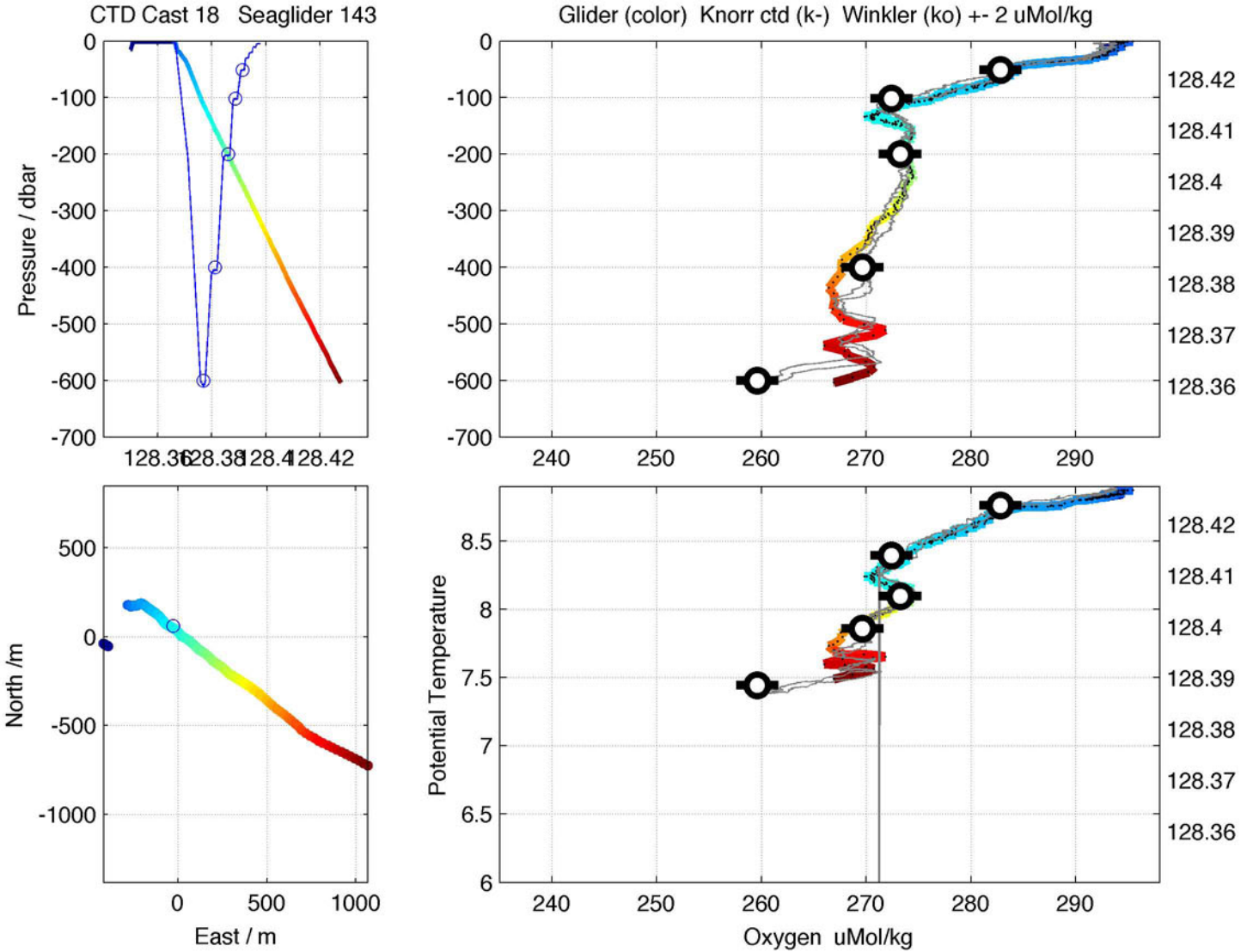

Cast A - B mean-o median-s (Outside=A, Inside=B, [rgbkm]=[140:143 float]
uMol/kg
Encounter
5
4
3
2
1
0
-1
-2
-3
0
5
10
15
20
25
30
35
40

Appendix 3 – Glider-Winkler Comparisons


CTD Cast 8 Seaglider 140
Pressure / dbar
Glider (color) Knorr ctd (k-) Winkler (ko) +- 2 uMol/kg
North /m
East / m
Potential Temperature
Oxygen uMol/kg


CTD Cast 19 Seaglider 141
Pressure / dbar
0
-100
-200
-300
-400
-500
-600
-700
128.52
128.54
128.56
128.58
Glider (color) Knorr ctd (k-) Winkler (ko) +- 2 uMol/kg
240
250
260
270
280
290
128.58
128.57
128.56
128.55
128.54
128.53
North /m
1500
1000
500
0
-500
East / m
Potential Temperature
8.5
8
7.5
7
6.5
6
Oxygen uMol/kg


CTD Cast 12 Seaglider 142
Pressure / dbar
0
-100
-200
-300
-400
-500
-600
-700
127.41
127.42
127.44
127.46
Glider (color) Knorr ctd (k-) Winkler (ko) +- 2 uMol/kg
240
250
260
270
280
290
North /m
1000
800
600
400
200
0
-200
-200
0
200
400
600
East / m
Potential Temperature
8.5
8
7.5
7
6.5
6
Oxygen uMol/kg


CTD Cast 18 Seaglider 143
Pressure / dbar
0
-100
-200
-300
-400
-500
-600
-700
128.36
128.38
128.4
128.42
Glider (color) Knorr ctd (k-) Winkler (ko) +- 2 uMol/kg
240
250
260
270
280
290
128.42
128.41
128.4
128.39
128.38
128.37
128.36
North /m
500
0
-500
-1000
East / m
1000
Potential Temperature
8.5
8
7.5
7
6.5
6
Oxygen uMol/kg