# Update of CTD oxygen data for the cruises MR07-04 and MR07-06

*September 24, 2009*

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## 1. Introduction

The CTD oxygen data were updated after the data book was published by Kawano et al. (2009). In the data book, data from two oxygen optode sensors (Oxygen Optode 3830; Aanderaa Data Instruments AS, Bergen, Norway, and RINKO; JFE Alec Co. Ltd., Kobe, Japan) were combined and used because data quality of the SBE 43 oxygen sensor was relatively bad (Kawano et al., 2009) for the cruise MR07-04. Data from the two oxygen optode sensors were combined because the Optode 3830 had a slow time response without pressure hysteresis and the RINKO had a fast time response with pressure hysteresis. The time-dependent, pressure-induced effect (pressure hysteresis) on the sensing foil of the RINKO was similarly observed in the SBE 43 data. Recently, a correction method of the pressure hysteresis was developed for the SBE 43 (Sea-Bird Electronics, 2009), and the correction method was successfully applied to the RINKO (Murata, 2009). Therefore, the RINKO data were reprocessed, calibrated, and used as the CTD oxygen data for the cruises MR07-04 and MR07-06.

## 2. Data processing

The RINKO data were reprocessed from the raw data. The time-dependent, pressure-induced effect (pressure hysteresis) of the RINKO was corrected for both profile and bottle data by using RINKOCOR (original module, version 1.0) and RINKOCORROS (original module, version 1.0) after the module TCORP. The calibration coefficients, H1 (amplitude of hysteresis correction), H2 (curvature function for hysteresis), and H3 (time constant for hysteresis) were determined empirically as:

H1 = 0.0065 for the RINKO prototype I with the foil A or C

H1 = 0.0055 for the RINKO prototype I with the foil B or prototype II with the foil D

H1 = 0.0060 for the RINKO prototype II with the foil C

H2 = 5000 dbar

H3 = 2000 seconds.

Type of the prototype and foil is listed in Table 1. Data from the RINKO sensors are systematically delayed with respect to depth because of the slow response time compared with the CTD sensors. This delay was compensated by 1 second advancing sensor output (voltage) relative to the CTD temperature data by using the SEASOFT module ALIGNCTD. To remove spikes of the data, the process of the DESPIKE was also performed for the RINKO data. The rest of the data processing was not changed from the data book (Kawano et al., 2009).

**Table 1. Type of the prototype and foil used in the cruises.**

| Cruise | RINKO | Foil | Note |
|---|---|---|---|
| MR07-04 | Prototype I (UV LED) | A | |
| MR07-06_1 | Prototype I | B | |
| MR07-06_2 | Prototype I | C | Stations from P14N_109_2 to P14N_175_1 |
| | Prototype II (Green LED) | D | Stations from P14N_176_1 to P14N_185_1 |
| | Prototype II | C | Stations from P14C_48_1 to P14C_1_1 |

**3. Post-cruise calibration**

The pressure-hysteresis corrected RINKO data was calibrated by the Stern-Volmer equation, basically according to a method by Uchida et al. (2008) with slight modification:

$$[O_2]\ (\mu mol/l) = (V_0 / V - 1) / K_{sv}$$

and

$$K_{sv} = C_0 + C_1 \times T + C_2 \times T^2$$

$$V_0 = 1 + C_3 \times T$$

$$V = C_4 + C_5 \times V_b + C_6 \times t + C_7 \times t \times V_b$$

where $V_b$ is the RINKO output (voltage), $V_0$ is voltage in the absence of oxygen, T is temperature (°C), and t is time (days). The $V_0$ and V are normalized by the phase shift in the absence of oxygen at 0°C, and the time drift of the RINKO output was corrected. The oxygen concentration is calculated by using the in situ calibrated CTD temperature data. The pressure-compensated oxygen concentration $[O_{2c}]$ can be calculated as follows.

$$[O_{2c}] = O_2\ (1 + C_p p / 1000)$$

or

$$[O_{2c}] = O_2\ (1 + C_p p / 1000)^{1/3}$$

where p is CTD pressure (dbar) and $C_p$ is the compensation coefficient. Since the sensing foil of the optode is permeable only to gas and not to water, the optode oxygen must be corrected for salinity. The salinity-compensated oxygen can be calculated by multiplying the factor of the effect of salt on the oxygen solubility (García and Gordon, 1992). García and Gordon (1992) have recommended the use of the solubility coefficients derived from the data of Benson and Krause.

The pressure-compensation coefficient ($C_p$) and the coefficient for the $V_0$ ($C_3$) were empirically estimated in advance except for the $C_p$ for the cruise MR07-06 leg 1 (Table 2). The $C_p$ for the cruise MR07-06 leg 1 was determined simultaneously with the remaining coefficients. The remaining seven coefficients ($C_0$, $C_1$, $C_2$, $C_4$, $C_5$, $C_6$, and $C_7$) were determined by minimizing the sum of absolute deviation with a weight from the bottle oxygen data. The revised quasi-Newton method (the FORTRAN subroutine DMINF1 from the Scientific Subroutine Library II, Fujitsu Ltd., Kanagawa, Japan) was used to determine the sets. The weight was given as a function of pressure as:

$$\text{Weight} = \min[10, \exp\{\log(10) \times P / PR\}]$$

where PR is threshold of the pressure (950 dbar).

The post-cruise calibrated temperature and salinity data were used for the calibration. The coefficients were determined for some groups of the CTD stations. The calibration coefficients are listed in Table 3. The results of the post-cruise calibration for the RINKO oxygen are summarized in Table 4 and shown in Figs. 1, 2, and 3.

**References**

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**Table 2. Calibration coefficients for the $V_0$ ($C_3$) and for the pressure-compensation equation ($C_p$). The pressure-compensation equation is also shown.**

| Groups | $C_3$ | $C_p$ | Pressure-compensation equation |
|---|---|---|---|
| 01–06 | –0.0022 | 0.109 | $O_2 (1 + C_p p / 1000)^{1/3}$ |
| 07 | –0.0028 | 0.055 | $O_2 (1 + C_p p / 1000)$ |
| 08 | –0.0028 | 0.056 | $O_2 (1 + C_p p / 1000)$ |
| 09 | –0.0028 | 0.057 | $O_2 (1 + C_p p / 1000)$ |
| 10–11 | –0.0028 | 0.055 | $O_2 (1 + C_p p / 1000)$ |
| 12 | –0.0028 | 0.054 | $O_2 (1 + C_p p / 1000)$ |
| 13 | –0.0028 | 0.053 | $O_2 (1 + C_p p / 1000)$ |
| 14–15 | –0.0028 | 0.054 | $O_2 (1 + C_p p / 1000)$ |
| 16 | –0.0028 | 0.053 | $O_2 (1 + C_p p / 1000)$ |
| 17 | –0.0028 | 0.051 | $O_2 (1 + C_p p / 1000)$ |
| 18 | –0.0028 | 0.056 | $O_2 (1 + C_p p / 1000)$ |
| 19 | –0.0028 | 0.055 | $O_2 (1 + C_p p / 1000)$ |
| 20 | –0.0028 | 0.057 | $O_2 (1 + C_p p / 1000)$ |
| 21 | –0.0028 | 0.056 | $O_2 (1 + C_p p / 1000)$ |
| 22 | –0.0028 | 0.058 | $O_2 (1 + C_p p / 1000)$ |
| 23–41 | –0.0021 | 0.100 | $O_2 (1 + C_p p / 1000)^{1/3}$ |
| 42 | –0.0024 | 0.066 | $O_2 (1 + C_p p / 1000)$ |
| 43–45 | –0.0021 | 0.100 | $O_2 (1 + C_p p / 1000)^{1/3}$ |

*Group of CTD stations* 01: P01_1_1–P01_18_1, 02: P01_19_1–P01_21_1, 03: P01_22_1–P01_26_1, 04: P01_27_1–P01_29_1, 05: P01_40_1–P01_44_1, 06: P01_58_2–P01_115_1, 07: P01_28_2, 08: P01_29_2–P01_30_1, 09: P01_32_1–P01_31_1, 10: P01_33_1–P01_35_1, 11: P01_36_1–P01_37_1, 12: P01_38_1–P01_43_1, 13: P01_44_2–P01_46_1, 14: P01_47_1–P01_55_1, 15: P01_56_1–P01_61_2, 16: P14N_29_1–P14N_16_1, 17: P14N_15_1–P14N_5_1, 18: P14N_1_1–P14N_4_1, 19: P14N_30_1–P14N_49_1, 20: P14N_50_1–P14N_63_1, 21: P14N_64_1–P14N_73_1, 22: P14N_74_1–P14N_109_1, 23: P14N_109_2–P14N_110_1, 24: P14N_111_1–P14N_112_1, 25: P14N_113_1–P14N_115_1, 26: P14N_116_1–P14N_118_1, 27: P14N_119_1–P14N_120_1, 28: P14N_121_1–P14N_122_1, 29: P14N_123_1–P14N_124_1, 30: P14N_125_1–P14N_126_1, 31: P14N_127_1–P14N_130_1, 32: P14N_131_1–P14N_135_1, 33: P14N_136_1–P14N_141_1, 34: P14N_142_1–P14N_144_1, 35: P14N_145_1–P14N_147_1, 36: P14N_148_1–P14N_149_1, 37: P14N_150_1–P14N_154_1, 38: P14N_155_1–P14N_160_1, 39: P14N_161_1–P14N_164_1, 40: P14N_165_1–P14N_170_1, 41: P14N_171_1–P14N_175_1, 42: P14N_176_1–P14N_185_1, 43: P14C_48_1–P14C_49_1, 44: P14C_52_1–P14C_19_1, 45: P14C_18_1–P14C_1_1

**Table 3. Calibration coefficients for the RINKO oxygen sensors. The group of the CTD stations is same as that shown in Table 2.**

| Group | $C_0$ | $C_1$ | $C_2$ | $C_4$ | $C_5$ | $C_6$ | $C_7$ |
|---|---|---|---|---|---|---|---|
| *MR07-04* | | | | | | | |
| 01 | 5.78769e–3 | 1.88171e–4 | 5.21610e–6 | –0.229888 | 0.254955 | –2.43960e–3 | 1.74806e–3 |
| 02 | 5.76112e–3 | 2.05112e–4 | 4.20869e–6 | –0.247620 | 0.261781 | 2.66538e–3 | –1.91261e–4 |
| 03 | 5.58601e–3 | 1.94710e–4 | 3.60579e–6 | –0.212837 | 0.254295 | –2.82424e–3 | 1.37946e–3 |
| 04 | 5.52573e–3 | 2.53171e–4 | –9.45815e–7 | –0.171401 | 0.242433 | –8.92725e–3 | 3.03414e–3 |
| 05 | 5.50404e–3 | 1.54503e–4 | 6.20130e–6 | –0.151539 | 0.241621 | –4.59826e–3 | 1.44984e–3 |
| 06 | 5.33007e–3 | 1.84105e–4 | 3.53496e–6 | –0.211406 | 0.257880 | –9.26535e–4 | 5.21621e–4 |
| *MR07-06 leg 1* | | | | | | | |
| 07 | 6.55224e–3 | 2.12959e–4 | 7.32523e–6 | –0.408829 | 0.281951 | 0.00000 | 0.00000 |
| 08 | 6.45822e–3 | 2.14475e–4 | 6.35186e–6 | –0.417754 | 0.283925 | 1.81734e–2 | –2.32210e–3 |
| 09 | 6.30664e–3 | 1.19267e–4 | 1.02338e–5 | –0.374523 | 0.274294 | –1.66424e–3 | 3.47136e–3 |
| 10 | 6.29642e–3 | 1.30131e–4 | 1.20613e–5 | –0.402078 | 0.283497 | 7.75298e–3 | –8.98322e–5 |
| 11 | 6.40532e–3 | –6.71557e–6 | 2.64522e–5 | –0.367286 | 0.275724 | -4.93850e–3 | 2.98357e–3 |
| 12 | 6.05874e–3 | 9.93107e–5 | 1.32774e–5 | –0.372592 | 0.278740 | 2.17949e–3 | 1.09013e–3 |
| 13 | 6.03637e–3 | 8.01334e–5 | 1.58469e–5 | –0.380144 | 0.285135 | 3.33545e–3 | 9.87750e–5 |
| 14 | 5.94341e–3 | 8.92774e–5 | 1.27029e–5 | –0.354093 | 0.276789 | 6.36922e–4 | 1.12659e–3 |
| 15 | 6.01971e–3 | 1.30065e–4 | 1.09592e–5 | –0.344272 | 0.277559 | –1.21930e–3 | 1.10575e–3 |
| 16 | 5.85814e–3 | 1.51238e–4 | 8.52212e–6 | –0.360336 | 0.280217 | 9.57900e–4 | 7.46866e–4 |
| 17 | 5.76211e–3 | 2.02794e–4 | 7.38395e–6 | –0.366150 | 0.286581 | 5.09066e–4 | 5.41219e–4 |
| 18 | 5.87643e–3 | 1.30110e–4 | 1.47536e–5 | –0.237946 | 0.233457 | –6.75607e–3 | 3.56108e–3 |
| 19 | 5.71949e–3 | 1.68597e–4 | 5.73708e–6 | –0.347475 | 0.284820 | 3.14416e–4 | 4.89874e–4 |
| 20 | 5.70894e–3 | 1.87827e–4 | 4.02373e–6 | –0.366959 | 0.293059 | 1.27735e–3 | 1.13690e–4 |
| 21 | 5.80033e–3 | 1.95761e–4 | 4.35824e–6 | –0.375413 | 0.302121 | 1.28422e–3 | –1.60368e–4 |
| 22 | 5.76787e–3 | 1.80175e–4 | 4.38162e–6 | –0.352233 | 0.298371 | 7.66105e–4 | –8.16506e–5 |
| *MR07-06 leg 2* | | | | | | | |
| 23 | 5.44937e–3 | 1.65251e–4 | 2.76961e–6 | –0.199505 | 0.239278 | 3.09346e–3 | 4.15719e–3 |
| 24 | 5.54177e–3 | 1.61531e–4 | 3.18336e–6 | –0.228340 | 0.249132 | 1.83265e–2 | –2.15387e–3 |
| 25 | 5.42048e–3 | 1.83287e–4 | 2.07555e–6 | –0.192462 | 0.241038 | –4.07720e–4 | 2.49626e–3 |
| 26 | 5.45889e–3 | 1.64536e–4 | 2.88640e–6 | –0.192265 | 0.243283 | –1.88936e–3 | 2.06094e–3 |
| 27 | 5.35393e–3 | 1.60876e–4 | 2.80193e–6 | –0.138462 | 0.225840 | –1.67471e–2 | 7.32406e–3 |
| 28 | 5.38960e–3 | 1.85479e–4 | 2.07045e–6 | –0.213034 | 0.253068 | 4.39692e–3 | –6.93024e–4 |
| 29 | 4.91234e–3 | 1.69346e–4 | 1.34107e–6 | –0.138257 | 0.236248 | –7.47363e–3 | 3.11840e–3 |
| 30 | 5.29710e–3 | 1.86796e–4 | 1.85766e–6 | –0.190758 | 0.248364 | –7.30369e–4 | 7.20446e–4 |
| 31 | 5.29129e–3 | 1.84807e–4 | 2.06747e–6 | –0.197598 | 0.249238 | –1.06270e–4 | 8.01728e–4 |
| 32 | 5.35606e–3 | 1.85394e–4 | 2.29483e–6 | –0.188360 | 0.247306 | –2.34961e–3 | 1.19205e–3 |
| 33 | 5.23672e–3 | 1.76559e–4 | 2.52414e–6 | –0.195684 | 0.252713 | –1.02750e–3 | 5.84364e–4 |
| 34 | 5.36437e–3 | 1.71687e–4 | 3.34220e–6 | –0.287883 | 0.282532 | 7.97539e–3 | –2.50022e–3 |
| 35 | 5.07284e–3 | 1.80971e–4 | 2.12433e–6 | –0.238973 | 0.284333 | 3.72564e–3 | –2.43784e–3 |
| 36 | 5.16377e–3 | 1.77869e–4 | 2.70794e–6 | –0.209220 | 0.246022 | 1.93576e–4 | 1.20839e–3 |
| 37 | 5.18307e–3 | 1.78043e–4 | 2.97573e–6 | –0.238163 | 0.274864 | 2.18383e–3 | –1.17744e–3 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 38 | 5.18550e–3 | 1.72648e–4 | 3.33928e–6 | –0.224989 | 0.271406 | 6.54311e–4 | –6.88668e–4 |
| 39 | 4.73947e–3 | 1.70534e–4 | 2.09447e–6 | –0.237428 | 0.284716 | 3.34250e–3 | –1.69718e–3 |
| 40 | 4.53781e–3 | 1.65093e–4 | 1.75764e–6 | –0.113741 | 0.233677 | –4.24469e–3 | 1.73284e–3 |
| 41 | 4.60581e–3 | 1.62495e–4 | 2.23853e–6 | –0.179177 | 0.254948 | –5.72044e–4 | 4.97947e–4 |
| 42 | 3.51665e–3 | 1.16255e–4 | 2.37582e–6 | –0.413749 | 0.300233 | –3.24861e–3 | 1.34826e–3 |
| 43 | 4.24252e–3 | 1.22672e–4 | 3.09423e–6 | 0.122545 | 0.051831 | –3.05446e–2 | 1.20623e–2 |
| 44 | 3.77773e–3 | 1.20741e–4 | 2.44550e–6 | –0.507127 | 0.309672 | 4.31407e–4 | –1.68904e–4 |
| 45 | 3.40682e–3 | 1.16962e–4 | 1.79879e–6 | –0.529886 | 0.325479 | 1.74046e–3 | –6.22456e–4 |

**Table 4. Difference between the RINKO oxygen and the bottle oxygen after the post-cruise calibration. Mean and standard deviation (Sdev) are calculated for the data below and above 950 dbar. Number of data used is also shown.**

| Cruise | Pressure ≥ 950 dbar | | | Pressure < 950 dbar | | |
|---|---|---|---|---|---|---|
| | Number | Mean (μmol/kg) | Sdev (μmol/kg) | Number | Mean (μmol/kg) | Sdev (μmol/kg) |
| MR07-04 | 1510 | –0.01 | 0.22 | 1118 | 0.25 | 2.70 |
| MR07-06_1 | 2698 | –0.01 | 0.18 | 1876 | –0.07 | 1.31 |
| MR07-06_2 | 2095 | –0.00 | 0.24 | 1642 | –0.01 | 1.03 |

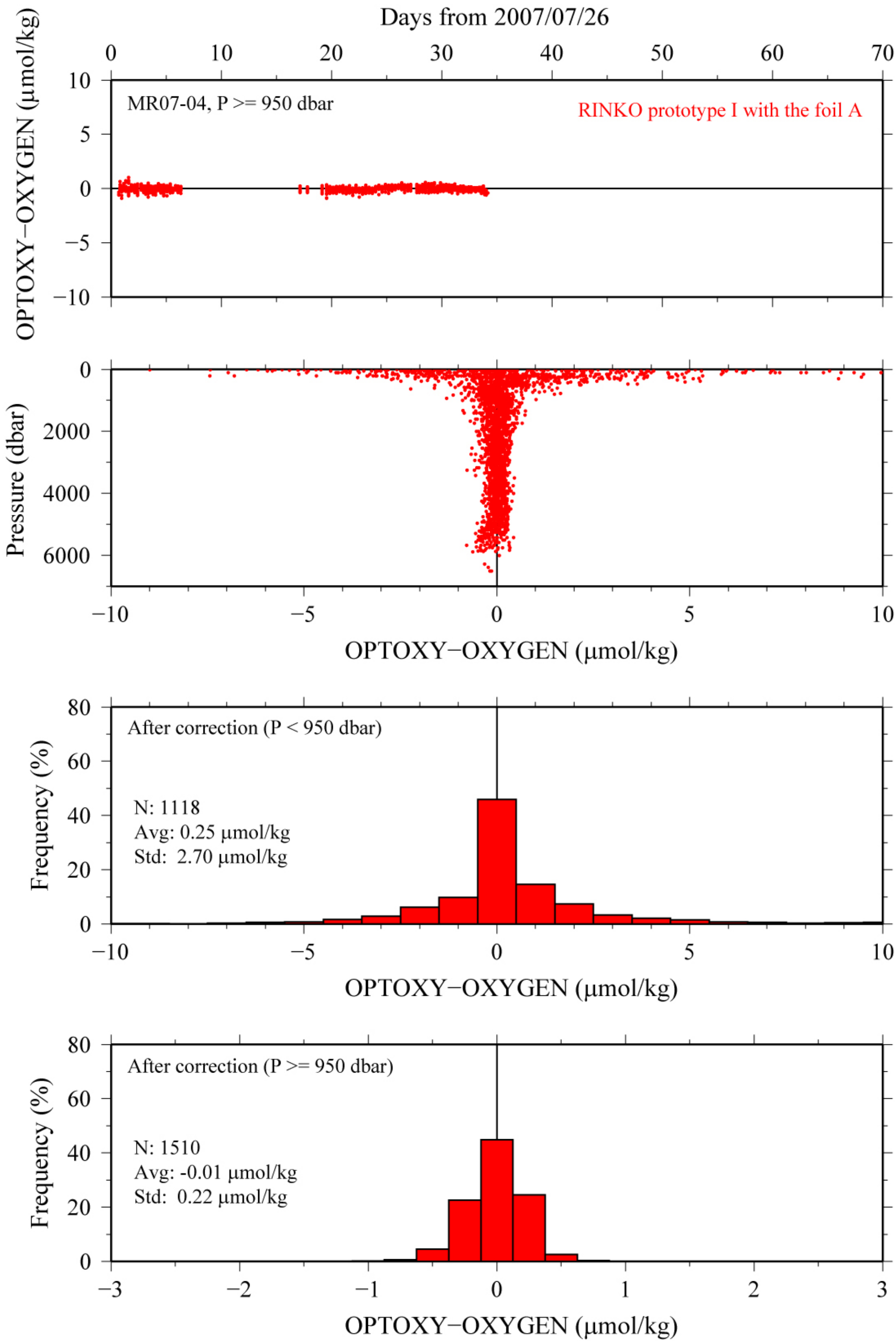


**Figure 1. Difference between the RINKO oxygen and the bottle oxygen after the post-cruise calibration for the cruise MR07-04. Lower two panels show histogram of the difference.**

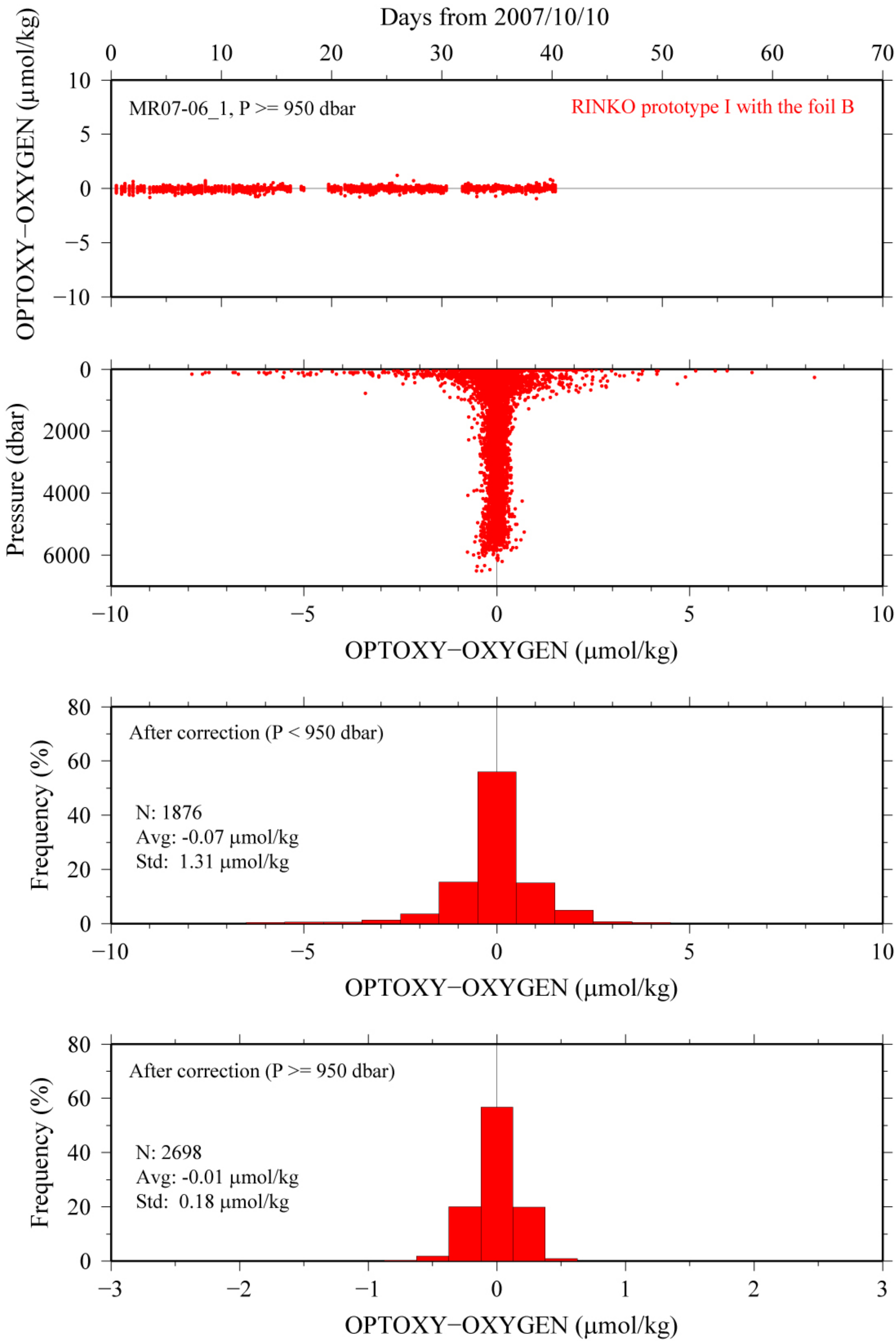


**Figure 2. Same as Fig. 1, except for the cruise MR07-06 leg 1.**

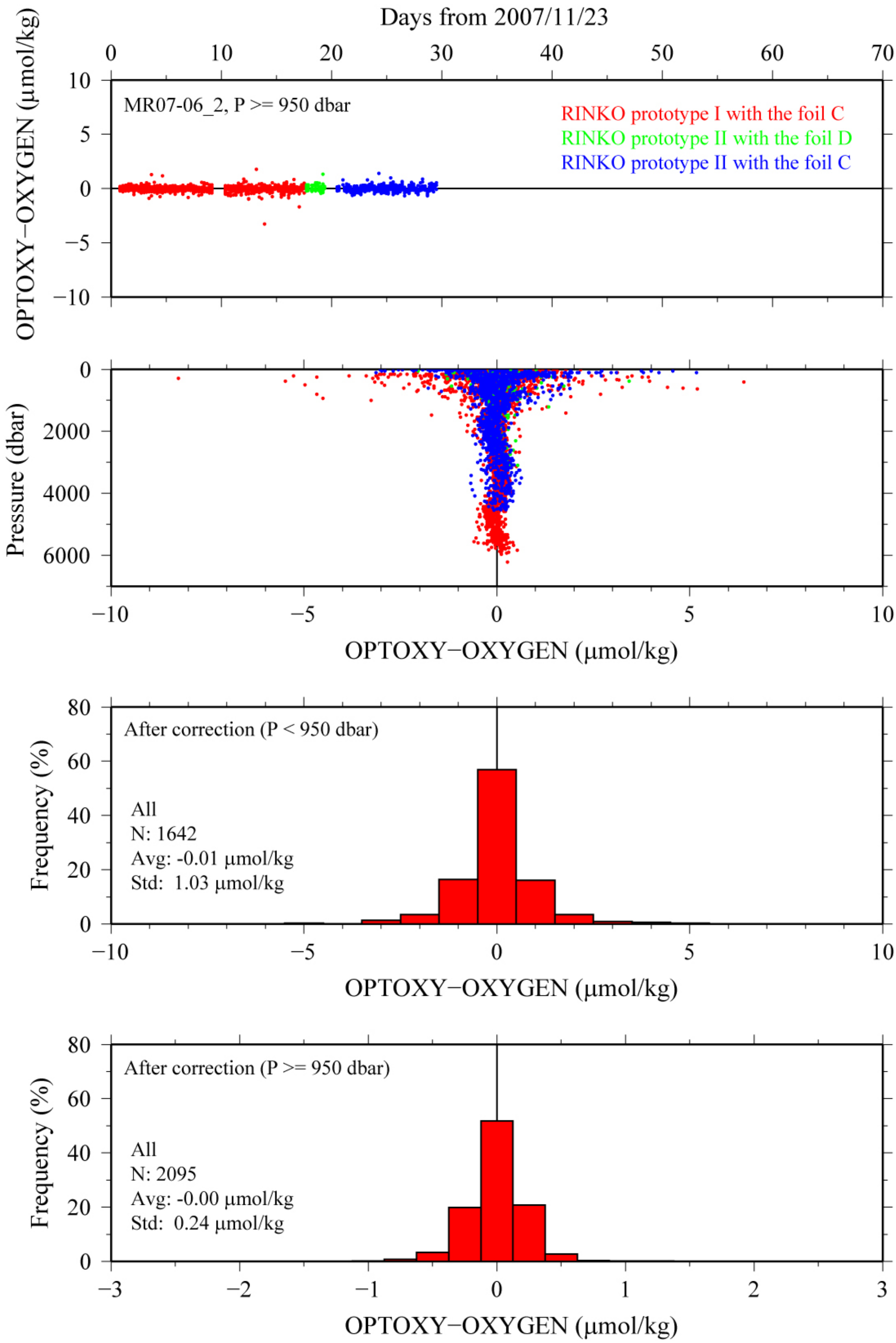


**Figure 3. Same as Fig. 1, except for the cruise MR07-06 leg 2.**