Manual for ExtractRINKO

(Version 1.6 Open)

The RINKO EC sensor (model name: ARO-EC-CM) produced by JFE Advantech Co, Ltd is a fast-responding dual oxygen-temperature senor developed for Aquatic Eddy Covariance (AEC) measurements. It is tested and described by Berg et al. (2016). The sensor is designed to “plug-and-play connect” with a standard Nortek Vector acoustic Doppler velocimeter (the workhorse of all AEC measurements to date) through a single cable for power and data transfer. It is the most robust sensor developed for AEC, and it allows eddy fluxes of oxygen and heat to be determined simultaneously. It also allows direct correction of the oxygen signal for temperature sensitivity – a feature that is critically important if used to measure gas exchange right below the air-water interface where heat fluxes, and thus the associated rapid temperature fluctuations, can be substantial and bias the oxygen flux calculation (for details see Berg and Pace; 2017). Due to its large tip size (Ø8 mm), the RINKO EC sensor may disturb the flow recordings if the current flow passes directly over the sensor tip before reaching the velocimeter.

This manual describes how RINKO EC data recorded by the Nortek Vector is processed to obtain accurate AEC measurements corrected for water temperature, salinity, and atmospheric pressure (or altitude above sea level).

1. Input files

ExtractRINKO needs two input files. One is the standard Nortek Vector data file that has been converted from a binary to a text file using the Nortek software that comes with the

Vector. The file has 18 columns and contain the measured x, y, and z velocities (column 3, 4, 5), the water pressure (column 15), the oxygen concentration signal in counts (column 16), and the temperature signal in counts (column 17). For more details, see the Nortek Vector manual.

The second file is referred to as the “definition” file and it defines how measured data are processed. An example of how it is structured is given in Fig. 1. The line numbers in the left margin are not part of the input file. Also, the input file contains some text, which is not used by ExtractRINKO, but serves only as a help for the user. Only the text and values in the red frame are read and used. The input file is a text file and can be created and changed in a program like Office Notepad, for example.

```
 1   Definition file for ExtractRINKOver1.6 (Constants for RINKO nr.0012)                         (this is a text line)
 2   Ur2.dat          Nortek data file with velocities and counts
 3  Ur2a.dat          Output file with velocities and a selection of counts, O2 concentrations, and temperatures
 4    12.0            Time start in output                                                                      [hour]
 5    16.0            Frequency in measured data                                                                  [Hz]
 6     8.0            Frequency in output                                                                         [Hz]
 7    16.0            Offset for pressure sensor to calibrate depth                                             [mbar]
 8    32.0            Salinity                                                                                   [ppt]
 9     0              Flag O2sat calculation: 0: corrected via elevation 1: corrected via actual atm pressure     [-]
10     0              Elevation above sea level                                                                    [m]
11   999.999          Actual atm pressure                                                                       [mbar]
12    -9.0524825      AT, Temperature coefficient                                                                 [-]
13    19.85903        BT, Temperature coefficient                                                                 [-]
14    -2.993419       CT, Temperature coefficient                                                                 [-]
15     0.5387745      DT, Temperature coefficient                                                                 [-]
16   -53.02263        AO2, O2 coefficient                                                                         [-]
17   189.1501         BO2, O2 coefficient                                                                         [-]
18    -0.3655823      CO2, O2 coefficient                                                                         [-]
19     0.01000800     DO2, O2 coefficient                                                                         [-]
20     0.004000000    EO2, O2 coefficient                                                                         [-]
21     0.00001840000  FO2, O2 coefficient                                                                         [-]
22       1.371182     GO2, O2 coefficient                                                                         [-]
23       1.045553     HO2, O2 coefficient                                                                         [-]
24       6            Flag output: 0: counts 1: temp,O2sat 2: temp,pres 3: O2,pres 4: temp,O2 5: O2,temp 6: O2,O2sat   [-]
25       9.9          Time 1 for linear time dependent calibration of O2 concentration                          [hour]
26      99.9          Time 2 for linear time dependent calibration of O2 concentration                          [hour]
27     999.9          Time 3 for linear time dependent calibration of O2 concentration                          [hour]
28       1.0          Factor 1 multiplied to O2 concentration at time 1                                           [-]
29       1.0          Factor 2 multiplied to O2 concentration at time 2                                           [-]
30       1.0          Factor 3 multiplied to O2 concentration at time 3                                           [-]
31     407.4          O2 concentration 1 for linear calibration of O2 concentration                              [myM]
32     225.3          O2 concentration 2 for linear calibration of O2 concentration                              [myM]
33       0.9622       Factor 4 multiplied to O2 concentration at O2 concentration 1                               [-]
34       0.8407       Factor 5 multiplied to O2 concentration at O2 concentration 2                               [-]
```

Figure. 1: The definition file which describes how recorded data are processed by ExtractRINKO.

The lines in the input file specify the following information:

Line1: Not used by ExtractRINKO but serves as a description of the data in the input file. A user can freely use this for helpful notes. As a minimum, a blank line must be given.

Line 2: Name of the standard Vector file after conversion with data to be processed.

Line 3: Name of the output file from ExtractRINKO. See details on its format below (Line 24).

Line 4: Start time (in hours) of the recorded data. This will be the first time point in the output file from ExtractRINKO.

Line 5: Frequency of the continuously measured input data (in Hz).

Line 6: Frequency of data written to the ExtractRINKO output file (in Hz).

Line 7: Correction (offset) of the pressure sensor reading. The given value (in mbar) is subtracted from the Vector's pressure reading.

Line 8: Water salinity (in ppt).

Line 9: Flag equal to 0 or 1.

a) Flag = 0: Oxygen saturation concentration is calculated from a given site elevation above sea level (Line 10)
b) Flag = 1: Oxygen saturation concentration is calculated from a known atm pressure on site (in mbar).

Line 10: Elevation above sea level (in m). Only used if flag above is 0.

Line 11: Actual atm pressure (in mbar) Only used if flag above is 1.

Line 12-15: Constants used to calculate the temperature. These constants are specific for each RINKO EC sensor and are provided by the manufacture.

Line 16-23: Constants used to calculate the oxygen concentration. These constants are specific for each RINKO EC sensor and type of foil disc mounted on the sensor tip. These constants, or ways to determine them, are provided by the manufacture.

Line24: Flag equal to 0, 2, 3, 4, 5 or 6. The output file from ExtractRINKO contains six columns. The first four are not affected by this flag. Column 1 is the time (in hours), and columns 2, 3, and 4 are the x, y, and z velocity (in cm s^{-1}). Columns 5 and 6 contain the following data depending on the flag:

a) Flag = 0: The oxygen concentration signal in counts and the temperature signal in counts, both averaged to the output frequency (line 6).
b) Flag = 1: The temperature (in °C) and the oxygen saturation concentration (in µmol L^{-1}) at the measured temperature, and the given salinity (Line 8), elevation above sea level (Line 10), or atm pressure (Line 11).
c) Flag = 2: The temperature (in °C) and the pressure (in mbar).
d) Flag = 3: The oxygen concentration (in µmol L^{-1}) and the pressure (in mbar).
e) Flag = 4: The temperature (in °C) and the oxygen concentration (in µmol L^{-1}).
f) Flag = 5: The oxygen concentration (in µmol L^{-1}) and the temperature (in °C).
g) Flag = 6: The oxygen concentration (in µmol L^{-1}) and the oxygen saturation concentration (in µmol L^{-1}) at the measured temperature, given salinity (Line 8), and elevation above sea level (Line 10), or atm pressure (Line 11).

Line25-30: The calculated oxygen concentration can be calibrated against auxiliary data, for example measured with a slow-responding stable sensor using a calibration factor that is multiplied with the oxygen concentration. The factor can vary through time as determined using two line segments (see figure below). The line segments are defined by three points in time (Line 25-27) and values of the factor at these times (Line 28-30). For times outside the first and last points in time (Line 25, 27), the factor equal the values specified for these times (Line 28, 30). See details below.

Line31-34: The oxygen concentration can also be calibrated using a calibration factor that varies with the oxygen concentration (see figure below). In this case, two oxygen concentrations are given (Line 31, 32) as are the values of the factor for these concentrations (Line 33, 34). The factor varies linearly between and beyond these given values. See details below.

2. The calculation

The data processing by ExtractRINKO is done in several steps, which are outline below. After the definition file and the converted Nortek Vector file are read, an air pressure correction factor is calculated based on the values given in Line 9-11:

$$\text{Flag} = 0: \quad factor = \frac{1013.25 - z\ 0.11568}{1013.25} \tag{1}$$

or

$$\text{Flag} = 1: \quad factor = \frac{p}{1013.25} \tag{2}$$

where z is the elevation above sea level and p is the actual atm pressure.

A timeline is calculated based on the information given in Line 4-5:

$$hour_i = hour_{start} + \frac{i}{3600\ Hz} \tag{3}$$

where i is a counter (1, 2, 3,…, and equal to the line number in the converted Nortek Vector data file). $hour_{start}$ is the start time of the recorded data (Line 4) and Hz is the frequency of the input data (Line 5).

The unit of velocities are converted to cm s^{-1}. The unit of the Vector's pressure reading is converted to mbar and correct with the specified offset (Line 7).

The oxygen concentration and temperature signals, both in counts, are converted to a voltage between 0 and 5 Volt:

$$volt_{1i} = \frac{5\ p_i}{65535} \tag{4}$$

and

$$volt_{2i} = \frac{5\, q_i}{65535} \quad (5)$$

where p_i and q_i are the counts of the oxygen concentration and temperature reading by the RINKO EC.

The high temporal resolution water temperature is calculated as specified by the RINKO EC manufacture as:

$$temp_i = AT + BT\ volt_{2i} + CT\ volt_{2i}^2 + DT\ volt_{2i}^3 \quad (6)$$

where the coefficients *AT*, *BT*, *CT*, and *DT* are given in the definition file (Line 12-15).

The calculation of the high temporal resolution oxygen concentration is done in several steps. First the oxygen saturation concentration is calculated as a function of the water temperature (Eq. 6), salinity (Line 8), and the air pressure correction factor (Eqs. 1, 2):

$$\mathrm{O}_{2\ sat\ den\ i} = \mathrm{O}_{2\ sat\ i}\ density\ factor \quad (7)$$

where $\mathrm{O}_{2\ sat\ i}$ is calculated as outlined by Garcia and Gordon (1992). The variable $density$ serves as a unit conversion factor to give $\mathrm{O}_{2\ sat\ den\ i}$ the unit µmol L^{-1} and is calculated as described in “Standard Methods for the Examination of Water and Wastewater” (1999):
https://beta-static.fishersci.com/content/dam/fishersci/en_US/documents/programs/scientific/technical-documents/white-papers/apha-water-testing-standard-methods-introduction-white-paper.pdf

Then the actual oxygen concentration in percent is calculated as:

$$\mathrm{O}_{2\ \mathrm{pct}\ i} = GO2 + HO2\left(\frac{AO2}{1+DO2(temp_i-25)+FO2(temp_i-25)^2} + \frac{BO2}{volt_{1i}(1+DO2(temp_i-25)+FO2(temp_i-25)^2)+CO2}\right) \quad (8)$$

where the coefficients *AO2*, *BO2*, *CO2*, *DO2, FO2, GO2,* and *HO2* are given in the definition file (Line 16-23). The RINKO EC manual describes an additional correction associated with the water pressure at deployment depth. However, because the current version of the standard RINKO EC sensor can only be deployed to a water depth of 50 m this correction is negatable (<0.02%). Thus, the coefficient *EO2* given in the definition file (Line 20) is not used by ExtractRINKO.

Finally, the high temporal resolution oxygen concentration is calculated as

$$\mathrm{O}_{2i} = \frac{\mathrm{O}_{2\ \mathrm{pct}\ i}\ \mathrm{O}_{2\ sat\ den\ i}}{100} \quad (9)$$

The optional time-dependent calibration of the calculated oxygen concentration outlined above is defined by the six variables (Line 25-30): *Time 1*, *Time 2*, *Time 3*, *Factor 1*, *Factor 2*, and *Factor 3*. Their values are illustrated in Fig. 2. If no correction is needed, *Factor 1*, *Factor 2*, and *Factor 3* are given the value 1.

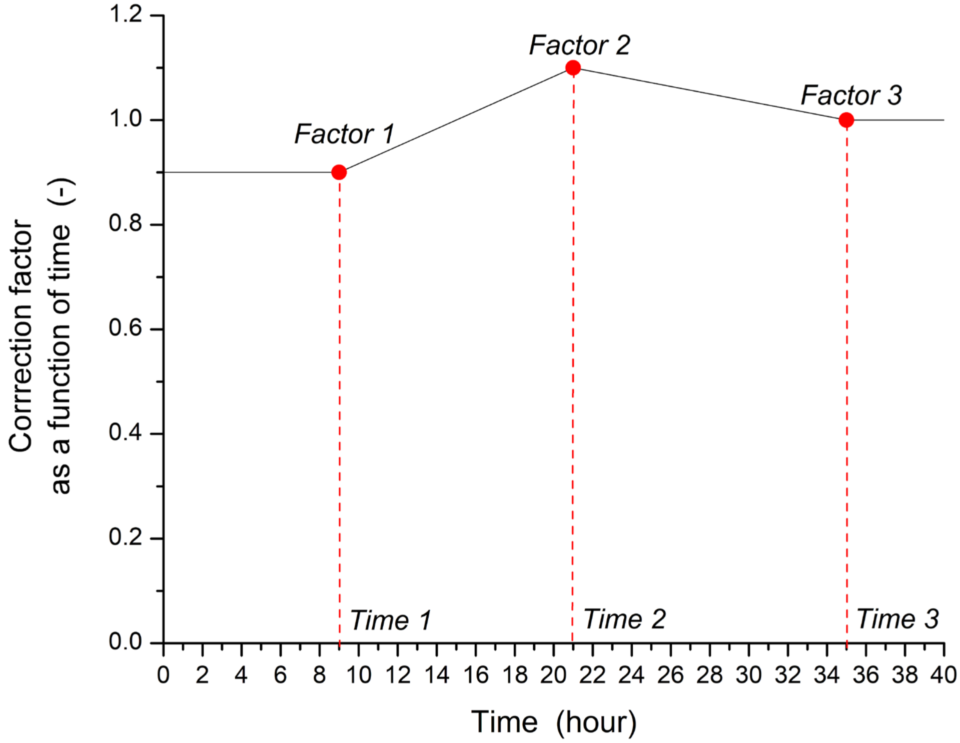

Figure 2: Optional correction factor as a function of time. For times < *Time 1*, the correction factor equals *Factor 1*. For times > *Time 3*, the correction factor equals *Factor 3*.

The optional concentration-dependent calibration of the oxygen concentration is defined by the four variables (Line 31-34): *Oxygen conc. 1*, *Oxygen conc. 2*. *Factor 4*, and *Factor 5*. Their values are illustrated in Fig. 3. If no correction is needed, *Factor 4* and *Factor 5* are given the value 1.

After these calculations are done, the results are averaged down to the specified output frequency (Line 6) and written to the specified output file (Line 3).

3. Source and executable code

ExtractRINKO is programmed in Fortran (**source code freely available for download**). Almost all of the code satisfies the Fortran 90 standard. One exception is that 132 characters per line are used, but most compilers will allow this as an option. The source code file is named: ExtractRINKOver1.6open.for.

The compiled code (**also freely available for download**) can be executed on any PC based computer and will perform all calculations in double pressions (~16 significant digits). The code must be located in the same directory as the two input files, and is run by double-clicking on it. The executable file is named: ExtractRINKOver1.6open.exe.

This manual, the source and executable code files, and an example definition file can be downloaded from:

1) https://berg.evsc.virginia.edu/

or

2) https://www.vcrlter.virginia.edu/

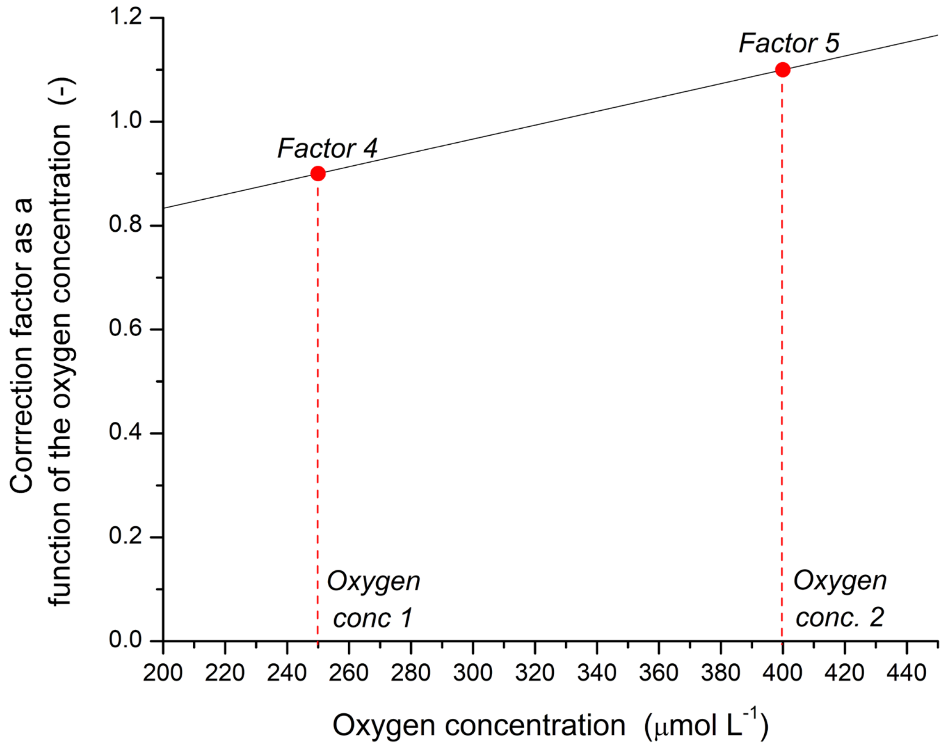

Figure 3: Optional linear concentration-dependent correction factor as a function of the oxygen concentration. A linear extrapolation of the factor is used below *Oxygen conc. 1* and above *Oxygen conc. 2*.

4. References:

Berg, P., D. Koopmans, M. Huettel, H. Li, K. Mori, and A. Wüest. 2016. A new robust dual oxygen-temperature sensor for aquatic eddy covariance measurements. Limnol. Oceanogr.: Methods **14:** 151–167.

Berg, P., and M. L. Pace. 2017. Continuous measurement of air–water gas exchange by underwater eddy covariance. Biogeosciences **14:** 5595-5606.

Garcia, H. E., and L. I. Gordon. 1992. Oxygen solubility in seawater: Better fitting equations. Limnology and Oceanography **37:** 1307-1312.