**Stationary CRNS Processing Overview for IAEA Teaching**

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**Goal:** The goal of this document is to familiarize you with the cosmic-ray neutron correction factors and calibration function for converting corrected neutrons into volumetric water content. At the end of this assignment you should be able to perform all necessary computations for processing stationary CRNS data. Please see Tec-Doc 1809, 1845, and Zreda 2012 HESS, Franz 2012 VZJ, Desilets 2010 WRR, Bogena 2013 WRR, Franz 2015 GRL, Kohli 2015 and the COSMOS website for additional information.

**Steps to understand CRNS data processing:**

1. Purchase of a new stationary CRNS will be accompanied by a URL provided by the manufacturer (e.g. HydroInnova LLC). The data will be updated every hour with the neutron counts and atmospheric data (air temperature, relative humidity, air pressure). In addition, information about the high energy incoming cosmic-rays will be added to the data for each time period. This information is needed to make a series of corrections on the moderated neutron counts. An example URL from the FAO/IAEA CRNS at Oman is at <http://nearfld.com/reguser/oman/index.php?timespan72471201=175200>. Click on the URL then the raw data tab to see the hourly data. Note that the most recent value is added to the top of the file.

2. Next open the provided excel spreadsheet (Sample\_CRNS\_Stationary\_Calculations\_Oman.xlsx), the CRNS Calculations Template sheet. Copy the sheet, rename it, and start filling in the header information (Site Name, Latitude, Longitude, and Elevation). To estimate Latitude, Longitude, and Elevation you can use the Google Earth Pro, a handheld GPS or smartphone on site. Next calculate the site’s reference pressure value *P0* (mb) and fast neutron scaling factor (CS/CSF) by plugging in latitude, longitude, and elevation into the online calculator at <http://cosmos.hwr.arizona.edu/Util/calculator.php>.

3. Copy the raw data from the URL and paste in into a clean excel sheet (URL Data Work). Select the data and use the text to columns function with a comma separator to display the data by column. Add an ID column in the first column and fill in from 1, 2, 3, … until the end. Use the sort feature to flip the data upside down so dates go in descending order. Next, copy the Date (UTC), N1 (moderated neutron counts), Air temperature (T7), Air Pressure (P4), Relative Humidity (H7), and high-energy intensity factor (fsol), and paste each column’s value into the yellow area in the CRNS Calculations sheet you just made (Col: C to H). Use the paste special and select value options.

4. The red column (Col: I) will now compute the *CP* factors (pressure corrections) using the *P0* value found in step 2 and the ambient pressure value (P4). You may have to drag the formula boxes to the end of the data column as the number of data records varies and increases over time.

5. The blue columns (Col: J to N) will now compute the *CWV* factors (water vapor corrections, Eq. 2 to 4) for all data rows by using the ambient air pressure (P4), air temperature (T7), and air relative humidity (H7). For reference air temperature use 25oC and for reference relative humidity use 0% (note reference absolute humidity should be 0).

5. Compute the *CI* factors (high-energy intensity) for all data rows. For the stationary CRNS the provided URL has the fsol values already calculated and organized by time (green column, Col: O). Note that CI= 1/fsol in this example using equation (1). The literature has used both historically so be cautions. For correcting the backpack CRNS you will have to pull in fsol/CI data from a stationary probe like the Oman URL listed above or your own CRNS. You will have to match up timestamps and fill in the spreadsheet manually. This can be fairly time consuming in excel.

6. With all of the correction factors by each line, the corrected neutron count rates are calculated using Eq. (1) in the orange column (Col: P).

7. With respect to using the calibration function (5), we will first need estimates of lattice water (g/g), soil organic carbon water equivalent  (g/g), average soil bulk density in the top 30 cm, (g/cm3), a known pore water content (g/g) and associated corrected moderated neutron count (N).

8. Lattice water and soil organic carbon water equivalent are found by chemical sampling and using labs like Actlabs. Using ~1-2 gm from each sampling location and depth a composite sample can be sent in for analysis. The Chemistry\_Results\_Actlabs sheet contains an example of the output for several chemical tests. We are interested in the H20+ (lattice water by % Weight. Note divide by 100 to get g/g) and Total Carbon and C02 columns. Lattice water is directly measured so we can use that column (Col BG). Use eq. (6) to calculate soil organic carbon water equivalent (Col: BH).

9. Once a CRNS is running, a calibration can be performed. Typically, we collect samples at 18 locations (transects every 60 degrees and distances of 10, 50, 125 m, note this used to be 25, 75, 200 m but has been updated). At each location we take 6 gravimetric samples every 5 cm down to 30 cm. The samples are stored in soil cans and weighed wet and then dried for 24-48 hours at 105 degrees C and then reweighed. In addition bulk density samples are collected at each depth and at 3-6 locations as sampling is labor intensive. We are interested in an average estimate of gravimetric water content and soil bulk density from 0-30 cm and averaged across the entire CRNS footprint. The Soil Sampling Ex. From USA spreadsheet contains summary data. We will use the average gravimetric soil water (cell I9) and soil bulk density (cell U14) for use in the calibration function.

10. From the data in steps 8 and 9 and a known corrected moderated neutron count during the calibration sampling, we can solve for N0 using eq. (5). The CRNS Calculations Ex. Oman sheet shows a summary table of the calibration data and calculation of N0 (cell B23). This N0 can now be used back in eq. (5) to calculate pore water content (g/g). Multiply by soil bulk density to obtain volumetric water content (cm3/cm3). This is shown in the orange column (Col: Q).

11. Lastly a 12 hour moving average filter can be applied to smooth the soil water content time series if desired (aqua columns, Col: R to S).

**Neutron correction factors**:

 (1)

Where *N* is the corrected neutron counts per hour (cph), *N’* is the raw moderated neutron counts (cph), *CP* is the pressure correction factor, *CWV* is the water vapor correction factor, *CI* is the high-energy intensity correction factor, and *CS* is the scaling factor for geomagnetic latitude. In *CS*, *x*, *y*, *z*, is location and elevation, and *t* is time.

In *CP*, *Pi* is the current ambient pressure (mb), *P0* is the reference pressure (mb), and 130 is the attenuation length of neutrons (g/cm2) in Nebraska. In *CI*,  is the current high-energy neutron intensity,  is the reference level high-energy neutron intensity (1 May 2011 is the reference date for the COSMOS website). In *CWV*,  is the absolute humidity of the air (g/m3),  is the reference absolute humidity of the air (g/m3), *T* is air temperature in (oC), *P* is pressure (mb), and *RH* is relative humidity (%).

**Absolute Water Vapor Calculations:**

 (2)

Where *es0* is the saturated vapor pressure at surface (Pa), *T* is air temperature (oC). Note: 1 mb = 1 hPa =100 Pa, and T(K)=T(oC)+273.15.

 (3)

Where e0 is actual vapor pressure at surface (Pa) and *RH* is the relative humidity (%).



(4)

Where  is the absolute humidity of air (g/m3),  is the gas constant for water vapor (J/K/kg), *R* is universal gas constant ( = 8.31432 J/mol/K), *Mvap* is the molar mass of water vapor ( = 18.01528 g/mol = 0.01801528 kg/mol ), and *T* is air temperature (oC).

**Calibration Function:**

 (5)

Where is pore water content (g/g),  (cm3/cm3) = ,  is lattice water content (g/g),  is soil organic carbon water content (g/g),  is dry soil bulk density (g/cm3), is the density of water = 1 (g/cm3), is the corrected neutron counts per hour (cph), and is an instrument specific calibrated parameter that represents the count rate over dry silica soils (cph). The 3 coefficients were determined by Desilets 2010 WRR from a semi-analytical solution of a neutron diffusion equation.

(6)

Where *TC* is the soil total carbon (g/g), *CO2* is the soil *CO2* (g/g), 12/44 is the stoichiometric ratio of carbon to *CO2*, and 0.494 is the stoichiometric ratio of H2O to organic carbon (assuming organic carbon is cellulose C6H10O5).

**Biomass Correction Factor (not used here)**

We correct for variations between instruments and for changes in *BWE* by scaling the fixed probe observations against the rover:

 (7)

Where  is the fixed probe estimate of  with no standing biomass,  is the rover estimate of  with no standing biomass, and  is the slope of the relationship between  and *BWE* from the rover surveys and calibration datasets. The *BWE* was found from the calibration sampling as:

 (8)

Where  is the standing wet biomass per unit area (kg/m2 ~ mm of water/m2) and *SDB* is the standing dry biomass per unit area (kg/m2 ~ mm of water/m2) found by oven drying samples at 70oC for 5 days. Note *fwe* is = 0.494 like above. From the available calibration datasets we found the rover had a statistically significant linear relationship yielding the coefficients of cpm and  with an R2 = 0.515 and p value = 0.03.