Use of cosmic-ray neutron sensors for soil moisture monitoring in forests

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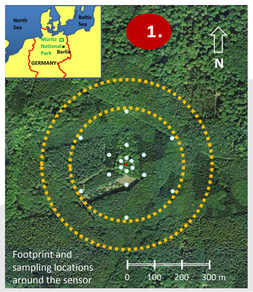
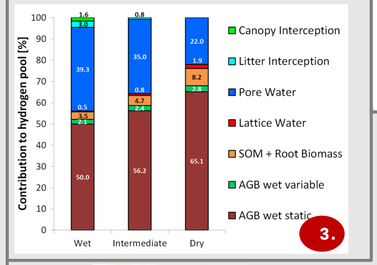
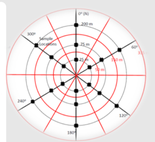
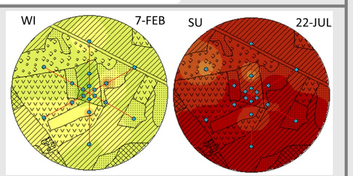
TERENO Terrestrial Environmental Observatories

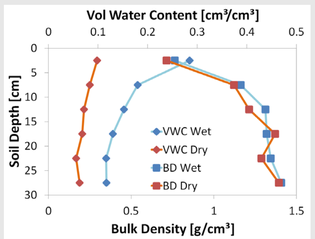
ICLEA Virtual Institute of Integrated Climate and Landscape Evolution Analyses

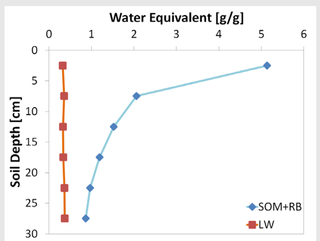












8. $H_p = W_L + SOM + B_R + \theta$

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Our 19 steps to calibrate a CRS

1. Set up the cosmic-ray neutron sensor (CRS) with a weather station close by (homogeneous conditions within a radius of at least 30 m).
2. Choose day with dry or wet soil moisture conditions for first calibration, wait for opposite conditions for second calibration.
3. Choose days without rain or snow for calibrations, litter and canopy should be dry.
4. Take 108 soil samples from 18 locations (six directions, three distances) and six depths (0–30 cm). For equal distance weights choose distances according to Köhli et al. (2015) (~1, 33 and 140 m).
5. Determine volumetric water content (θ) and the bulk density (ρ_{bd}).
6. Determine soil organic matter (SOM) and root biomass (B_R) content.
7. Determine lattice water (W_L) content for each soil depth.
8. Determine water equivalent of average hydrogen content of belowground hydrogen pools (H_p) for each soil depth.
9. Apply a linear weighting function to H_p measurements accounting for change in effective measurement depth z of sensor and retrieve weighted average of H_p within footprint of the CRS.
10. Apply additional distance weighting to depth-weighted H_p contents (equations conveniently provided as a Supplement by Köhli et al. (2015)).
11. Use depth–distance weights to compute weighted values of soil water content (θ), bulk density (ρ_{bd}), lattice water (W_L), soil organic matter and root biomass water equivalent (SOM+B_R).
12. Average raw neutron counts (N_{raw}) over 12 h with moving window.
13. Retrieve data from neutron monitor close to your location to correct for varying intensity of incoming neutrons.
14. Determine average atmospheric pressure (P_o), average incoming neutron intensity (N_{avg}) and average absolute humidity (p_{ref}).
15. Correct raw neutron counts for atmospheric pressure variations (N_p).
16. Correct raw neutron counts for incoming neutron intensity variations (N_{pi}).
17. Correct raw neutron counts for absolute humidity variations (N_{pih}).
18. Plot N_{pih} of both calibrations against gravimetrically measured, distance- and depth-weighted volumetric soil water content (θ). Fit a function through the two calibration points.
19. Use best-fit parameters to convert time series of N_{pih} to volumetric soil water content (θ).

Corrections!

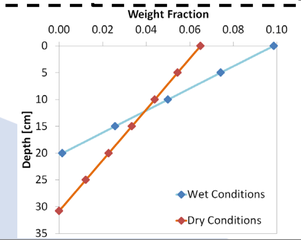
9. Effective depth:

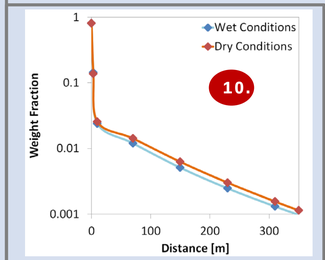
$$z^* = \rho_{bd}^{-1}\left[8.32 + 0.14 * \left(0.97 + e^{\frac{-r}{100}}\right) * \frac{26.42 + H_p}{0.057 + H_p}\right]$$

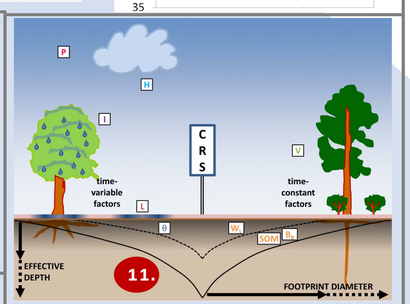
Weight:

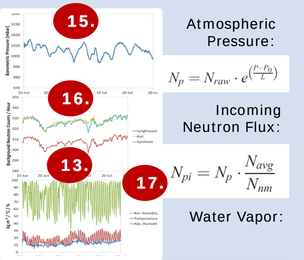
$$wt(z) = a\left[1 - \left(\frac{z}{z^*}\right)^b\right]$$

Layer (cm)	θ (m^3 m^{-3})	W_L (m^3 m^{-3})	SOM+B_R (m^3 m^{-3})	H_p (m^3 m^{-3})	ρ_{bd} (g cm^{-3})
0-5	0.187	0.002	0.034	0.223	0.669
5-10	0.136	0.004	0.024	0.163	1.143
10-15	0.117	0.004	0.019	0.140	1.217
15-20	0.109	0.004	0.015	0.129	1.256
20-25	0.106	0.005	0.013	0.124	1.359
25-30	0.100	0.005	0.012	0.118	1.431









Atmospheric Pressure:

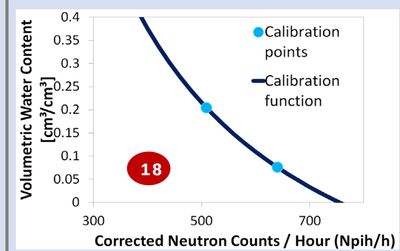
$$N_p = N_{raw} \cdot e^{\left(\frac{P - P_0}{L}\right)}$$

Incoming Neutron Flux:

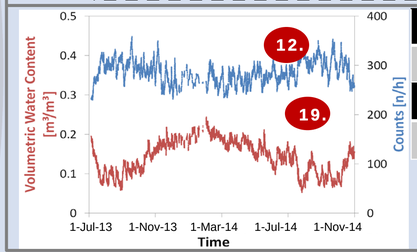
$$N_{pi} = N_p \cdot \frac{N_{avg}}{N_{nm}}$$

Water Vapor:

$$N_{pih} = N_{pi} \cdot \left(1 + 0.0054 \cdot \left(p_{v0} - p_{v0}^{ref}\right)\right)$$



$$\theta(t) = \left\{\left[a_0 * \left(\frac{N_{pih}(t)}{N_0} - a_1\right)^{-1} - a_2\right] * \rho_{bd}\right\} - W_L - (SOM + B_R)$$



N_0	a_0
957.8	0.299
a_1	a_2
0.002	0.355

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