Geophysical Research Abstracts
Vol. 12, EGU2010-14553, 2010
EGU General Assembly 2010
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Measuring soil moisture content using cosmic-ray fast neutrons emitted from soils: a near-field remote sensing tool

Darin Desilets (1), Marek Zreda (2), Chris Zweck (2), and Ty Ferre (2)

(1) Sandia National Laboratories, Albuquerque, NM 87185, USA (ddesile@sandia.gov), (2) University of Arizona, Hydrology and Water Resources, Tucson, Arizona, United States (marek@hwr.arizona.edu)

Average soil moisture over a footprint of hectometers and a depth of decimeters can be inferred from measurements of cosmic-ray fast neutrons that are generated in air and soil, moderated mainly by hydrogen atoms present in the soil, and emitted back to the atmosphere, where they travel in all directions and form a well-mixed reservoir of neutrons. The intensity of neutrons above the ground surface depends strongly on soil moisture content, and does not depend on soil chemistry and texture. The measurement with a cosmic-ray soil moisture probe placed above the ground takes minutes to hours, permitting high-resolution, long-term monitoring of undisturbed soil moisture. Neutron transport modeling using the MCNPX code shows that the footprint is approximately 600 m at sea level, and the measurement depth from 15 cm for saturated soils to 70 cm for dry soils. The footprint size has been confirmed empirically using field measurements of neutron intensity along water-land transects. The cosmic-ray soil moisture probe is calibrated using a theoretical calibration function in which one parameter is constrained by gravimetric soil moisture determinations on multiple samples collected within the footprint, If local calibration samples are not available, the same theoretical calibration function can be constrained using the knowledge of cosmic-ray variations, providing less accurate but still reasonable soil moisture estimates. The large footprint makes the method ideal for bridging the gap between remote sensing methods (such as SMOS and SMAP) and point or small-scale measurements on the ground.