Currently only 1 site is used to represent snow depth and snow water equivalent. The gap between expanding hydrologic model resolution and conventional Fast neutrons most strongly related to changes in hydrogen in soil water. Water storage on/in vegetation canopies is poorly understood primarily due to lack of quality observations.

**1. Introduction**
- The gap between expanding hydrologic model resolution and conventional point-scale observations continues to widen.
- Up-scaling of point measurements to larger scales in order to validate and calibrate hydrologic models continues to be a challenge.
- Feedback between land surface and atmospheric energy and water fluxes is poorly understood primarily due to lack of quality observations.

**The Cosmic-ray Soil Moisture Observing System (COSMOS)**
- Phase I, 2009-2013: NSF funded national network of 50 cosmic-ray neutron sensors to provide real-time soil moisture data, proof of concept stage
- Phase II, 2013-?: Expansion to 500 sensors
- Cosmic-ray sensor measures relative number of fast and thermal neutrons in sensor support volume
- Fast neutrons most strongly related to changes in hydrogen in soil water
- Thermal neutrons thought to be affected by changes in hydrogen from other pools, like snow and canopy water

**COSMOS Science priorities**
1. Soil moisture controls on weather and climate models, ecological processes, and hydrologic flow processes
2. Water storage on/in vegetation canopies
3. Frozen precipitation
4. Remote sensing of soil moisture

**4. Observations**

The cosmic-ray neutron probe was installed at TWDEF on August 13, 2011. Here we present the average hourly neutron counts over the day for fast and thermal, daily rainfall, daily snow depth, and daily snow water equivalent from a Snotel site located 300 m from the cosmic-ray sensor. Finally we report the average soil moisture and temperature from 108 TDF sensors distributed around the cosmic-ray footprint in various land types.

**5. Particle Transport Modeling**

Using a general purpose Monte Carlo particle transport code (MCNPx, Pelowitz, 2005) we simulated different snow pack conditions overlapping different soil moisture conditions. For the simulations we setup a sensor 5-6 m above the surface and changed the height and density of the snow. All simulations were performed using vertical homogeneous layers of snow and soil moisture and each simulation was normalized to an infinite layer of liquid water with density 1.

- Simulations confirm observations of relative neutron sensitivity of ~23 cm SWE for thermal neutrons and ~10 cm SWE for fast neutrons
- Simulations indicate a dependence of water density on shape of sensitivity function, however, this is not consistent with current understanding, as neutrons are thought to respond to only total mass.
- We are currently investigating this inconsistency, but these types of sensitivity functions could ultimately be used to partition soil water, SWE, and snow depth.

**6. Summary and Conclusions**
- A cosmic-ray neutron probe was installed in August 2011 at TWDEF, which is part of the COSMOS national network that provides intermediate scale measurements of hydrogen.
- Fast and thermal neutron observations from TWDEF illustrate sensitivity to changes in both soil moisture and snow that form distinct clusters of points.
- Numerical modeling of particles illustrates theoretical relationships that may be used to partition two pools of hydrogen with simultaneous measurements of thermal and fast neutrons, but more work is needed to validate numerical sensitivity functions.

**7. Future Work**
- Currently only 1 site is used to represent snow depth and snow water equivalent.
- Additional snow data should be used to identify average conditions over the footprint, in particular during highly heterogeneous melting periods.
- The discrepancy in neutron modeling and observations may be due to changes in canopy storage, which is less understood in both neutron modeling and observations at the site.

**9. Acknowledgments**

COSMOS project is funded by the Atmospheric Science, Hydrology, and Ecology Programs of the US National Science Foundation (grant ATM-0858491). T. Franz and M. Zreda would like to thank D. Dofflemyer of Sandia National Laboratories for his contributions to this work.