Three applications of cosmic-ray probe in hydrology

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Measurements of states, fluxes and properties at field scale

Examples:

1. Soil moisture
2. Rainfall rate
3. Hydraulic conductivity

Focus of this talk

Problem:

Usually done at points
Single point measurements not representative

Solutions:

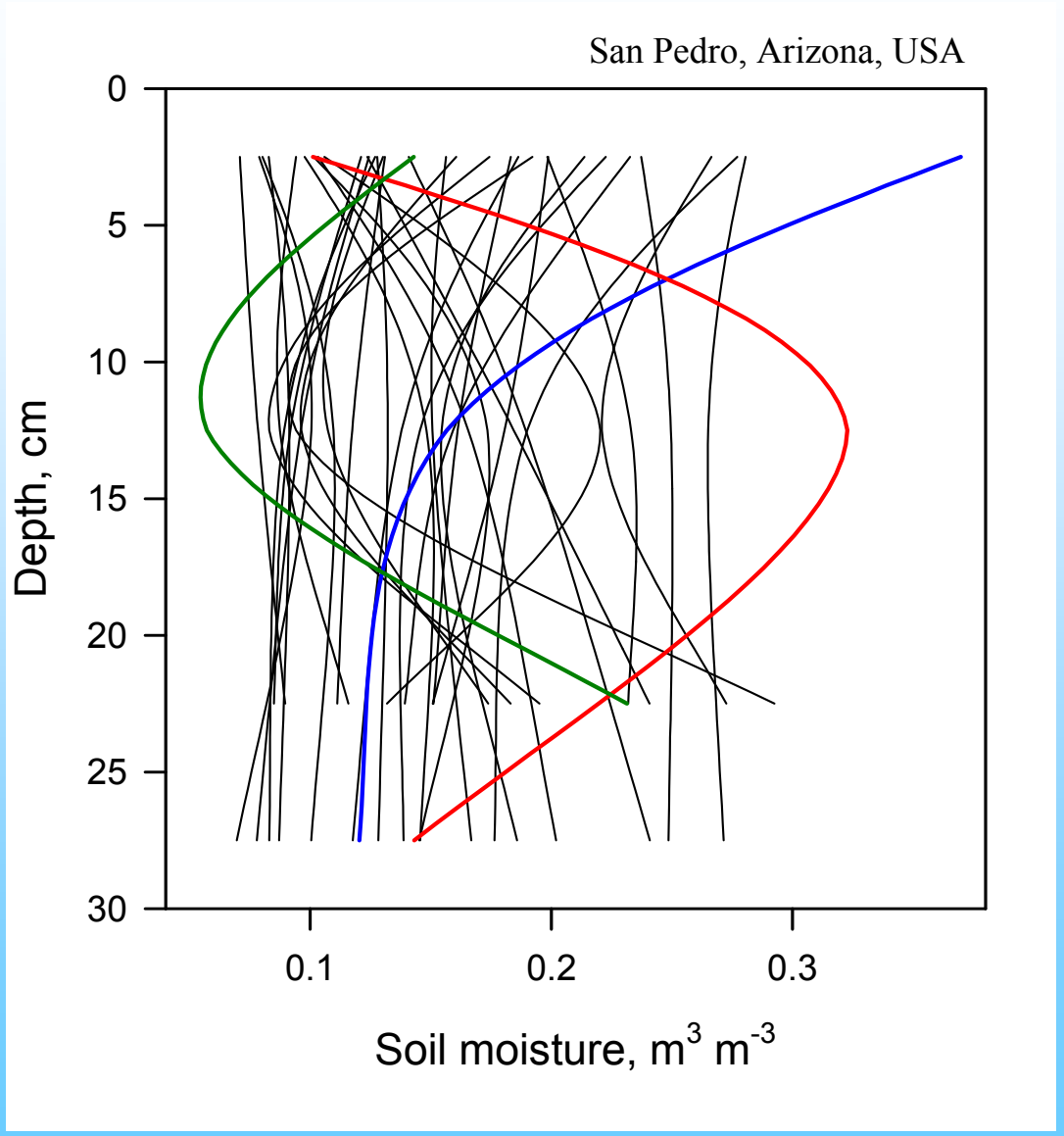
Measurements at many points, followed by aggregating and, if necessary, upscaling

or

Measurements that use **scale-integrating methods**

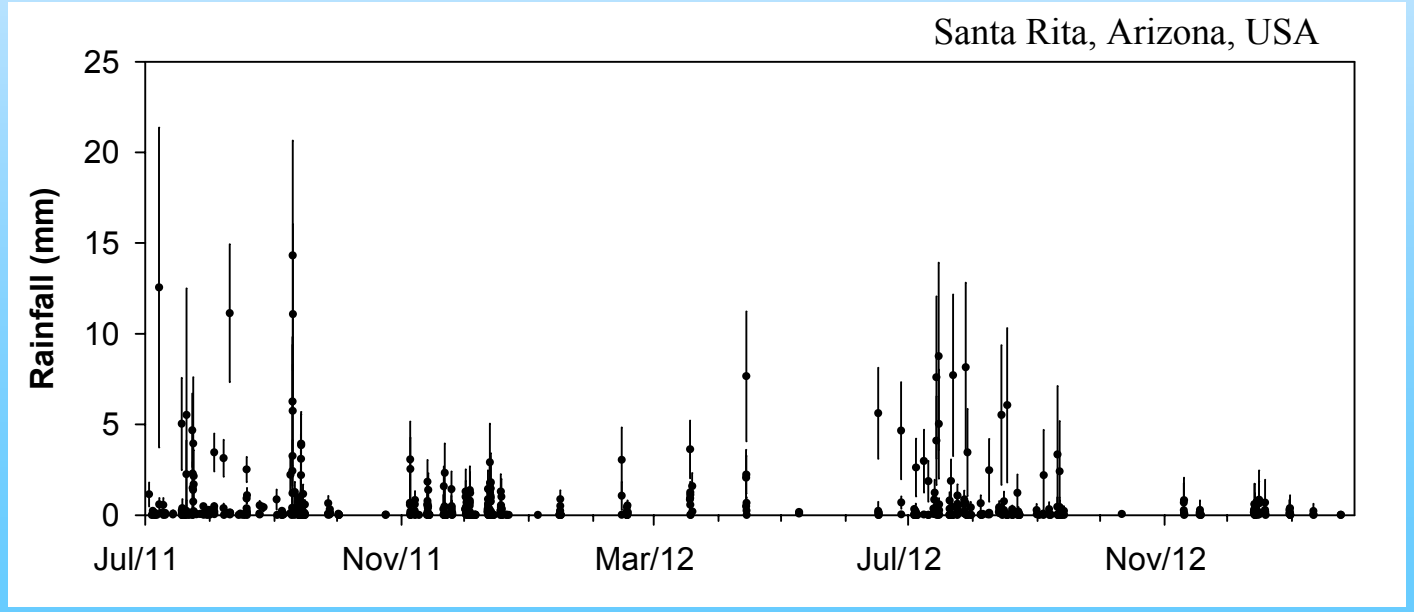
Example 1: Variations in soil moisture, circle, 400 m diameter

Coring and oven drying



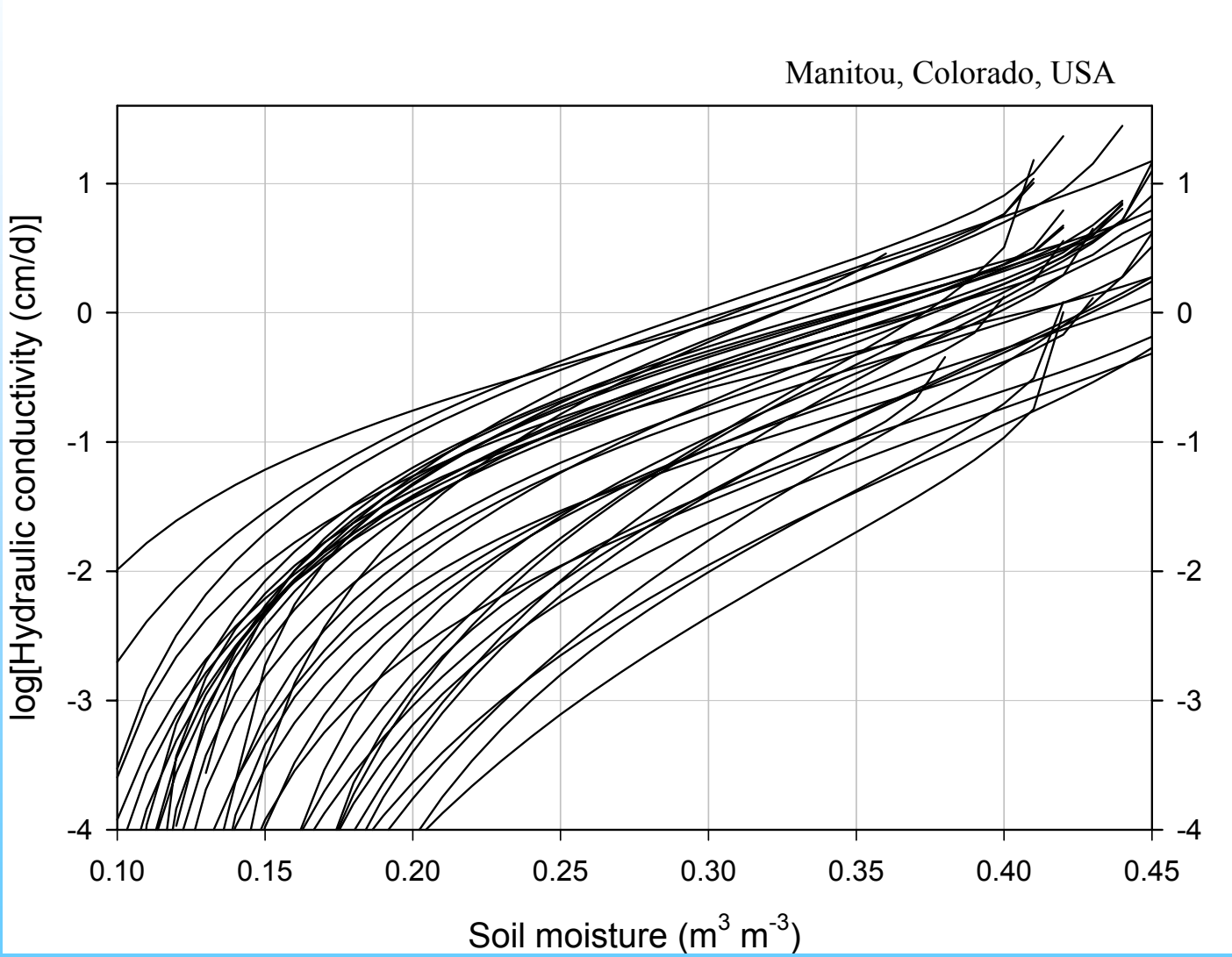
Example 2: Variations in rainfall rate, circle, 400 m diameter

Tipping bucket rain gauge,
Santa Rita, Arizona, USA.



Example 3: Variations in soil hydraulic conductivity, circle, 400 m diameter

HYPROP device



Scale-integrating measurements using cosmic rays

Neutrons are measured at the the horizontal scale of a few hectometers and vertical scale of a few decimeters with the use of cosmic-ray probes (stationary or mobile).

Production and removal of fast neutrons

Space:

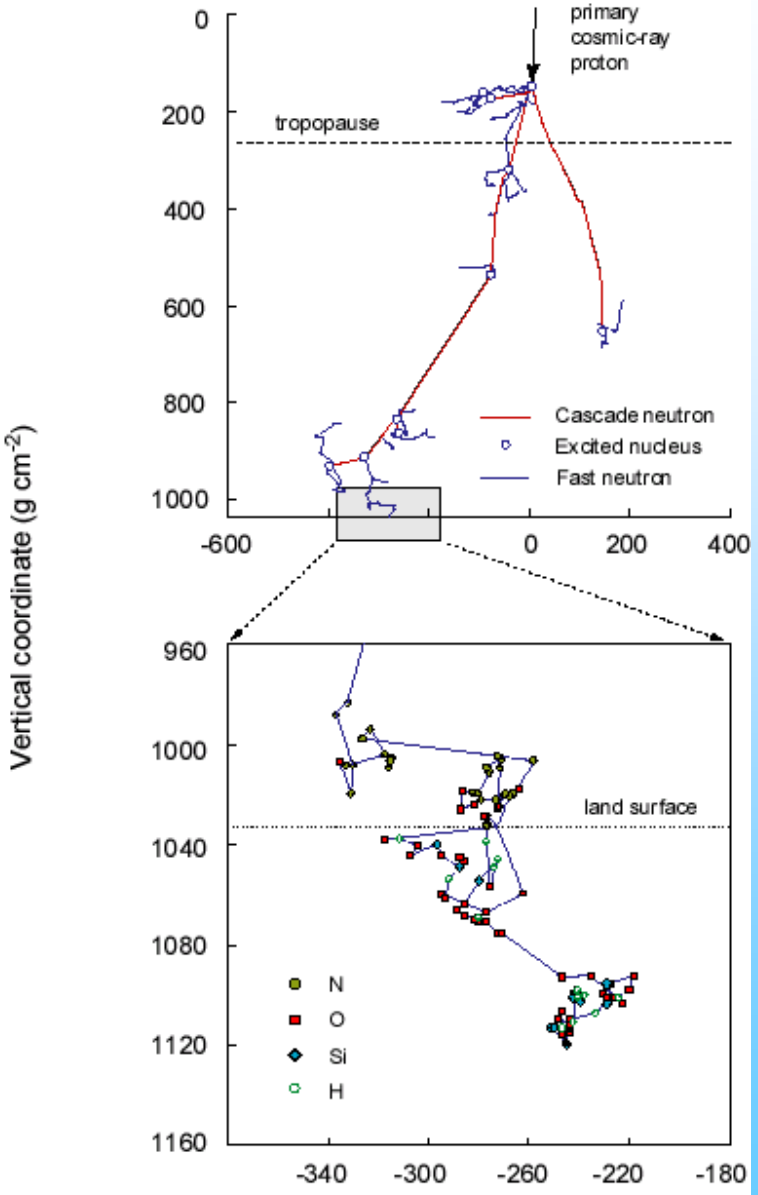
incoming high-energy cosmic-ray protons

Atmosphere:

generation of secondary cosmic rays

Ground:

scattering
thermalization
absorption

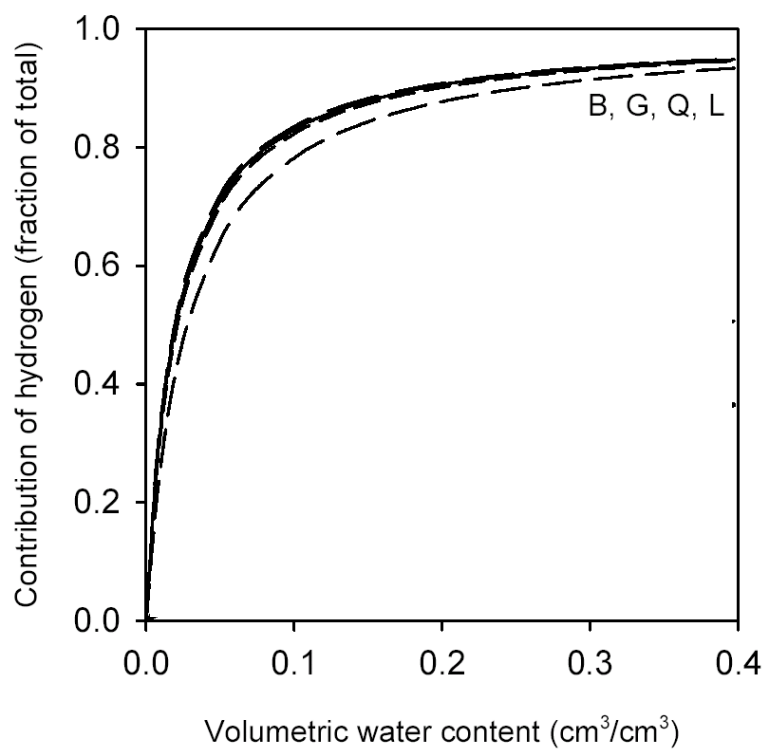


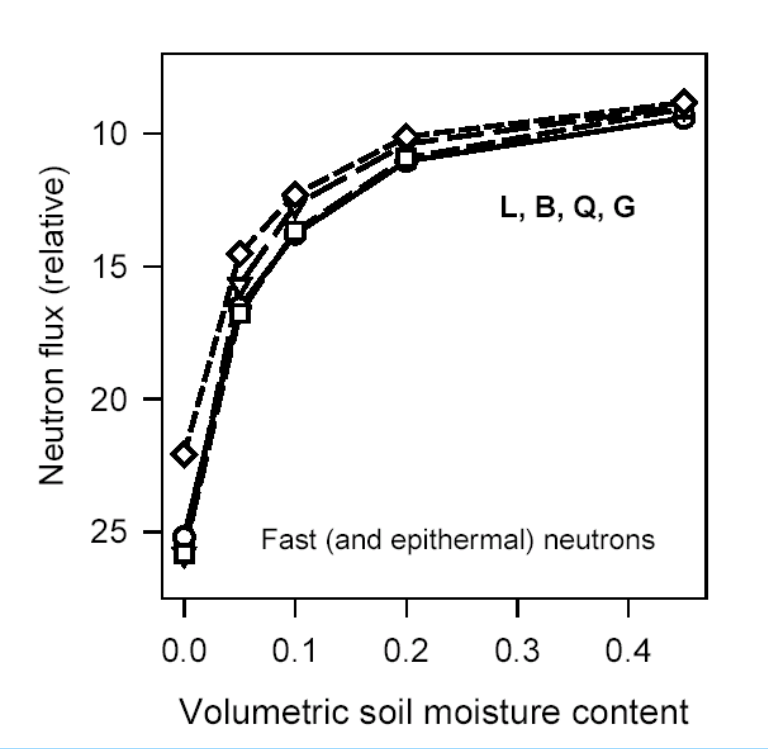
Zreda et al., 2012.

- Primary - mostly protons and alphas
- Interact with magnetic field
  - intensity depends on solar activity and geomagnetic latitude
- Interact with atmospheric nuclei
- Produce secondary particles - cascade
  - intensity depends on barometric pressure
- Produce fast neutrons
- Remove fast neutrons
  - slowing down by elastic collisions
  - leads to thermalization
  - and then absorption

The last three processes depend on the chemical composition of the medium, in particular on its hydrogen content.

Moderating power and neutron intensity





ϕ (E) - flux of neutrons of energy E

Q - strength of source function

N - number of atoms of an element

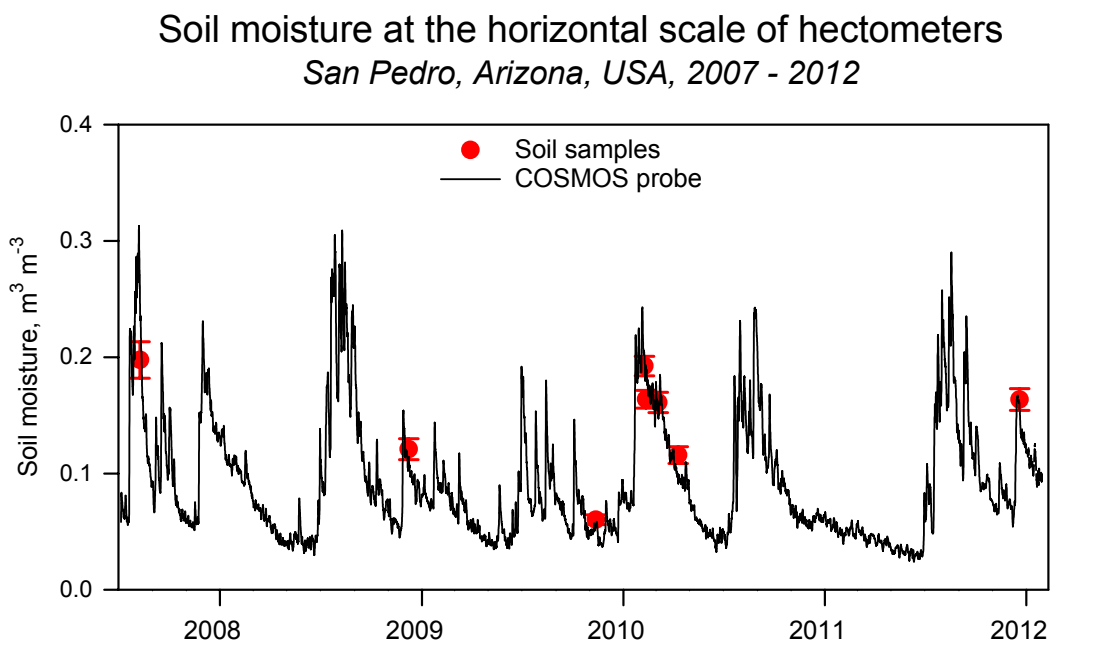
σ_{sc} - scattering cross section for an element

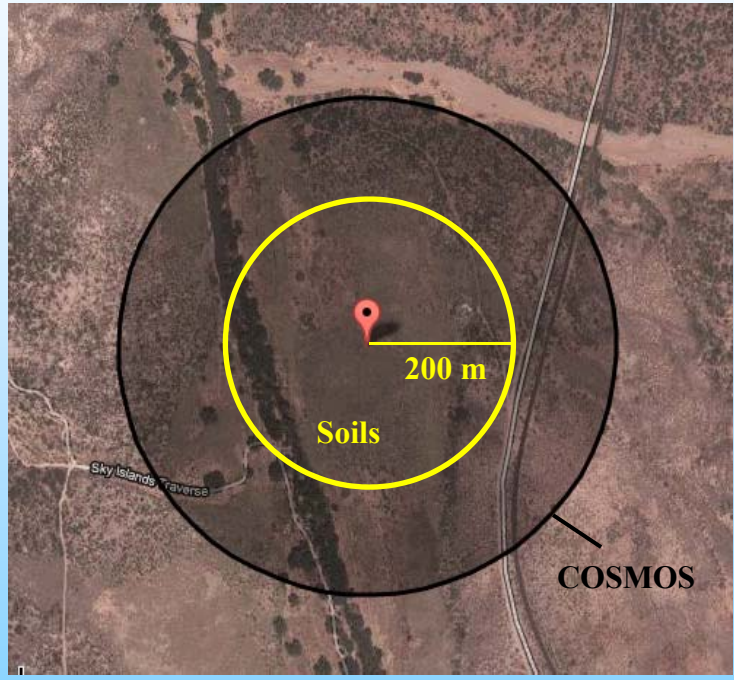
ξ - log decrement of energy per collision

$\sigma \cdot \xi$ - moderating power

$$\phi(\mathrm{E}) = \frac{\mathrm{Q}}{\mathrm{E}\ [N_H \cdot \sigma_H \cdot \xi_H + \Sigma(N \cdot \sigma \cdot \xi)]}$$

Example 1: Soil moisture: cosmic-ray soil moisture probe

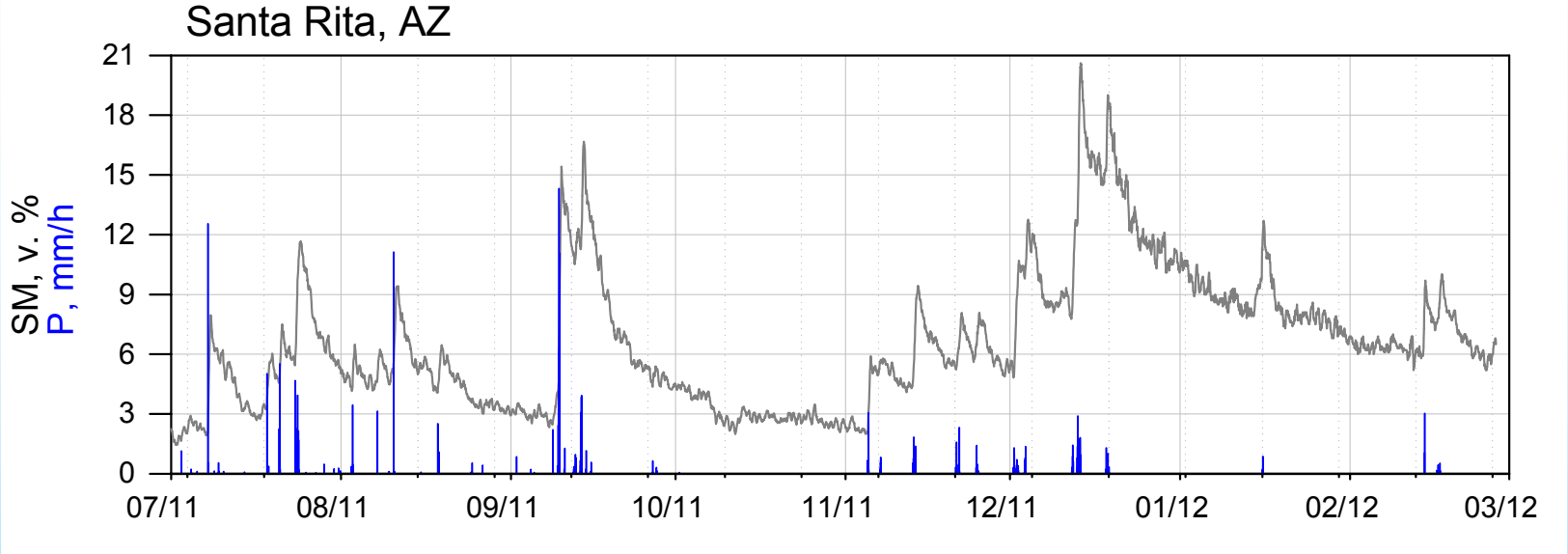


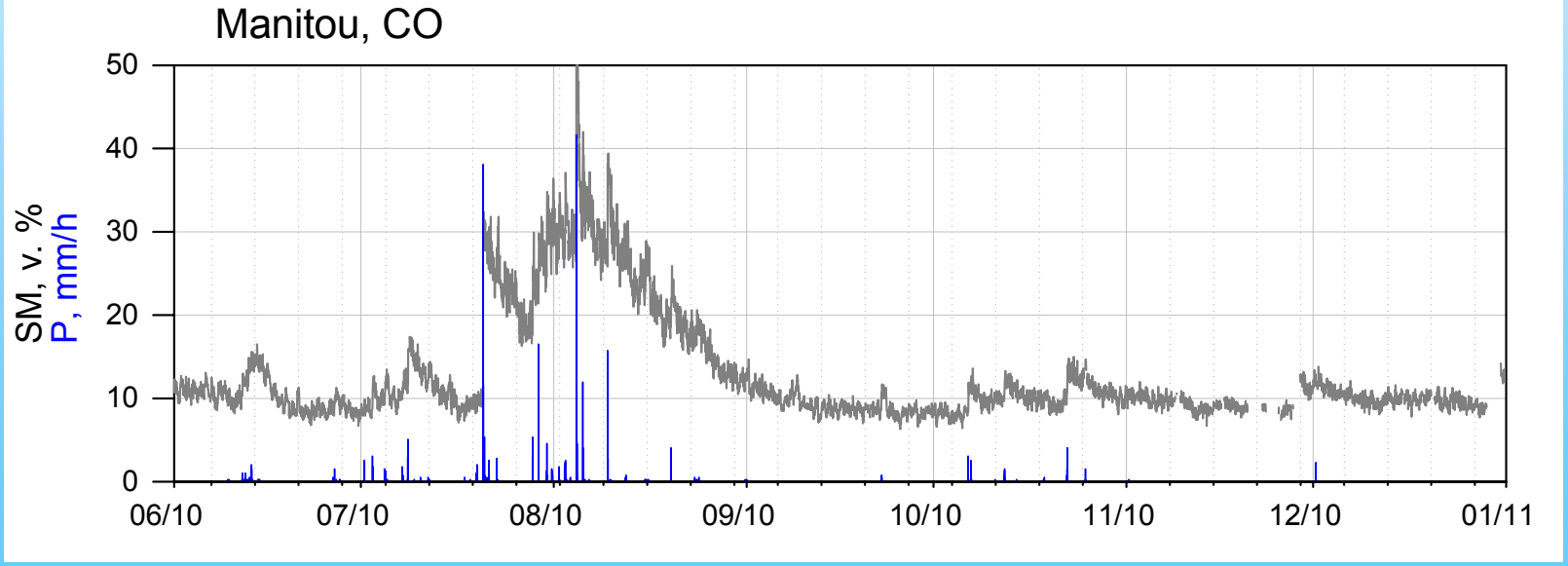


Example 2: Rainfall: cosmic-ray rain gauge

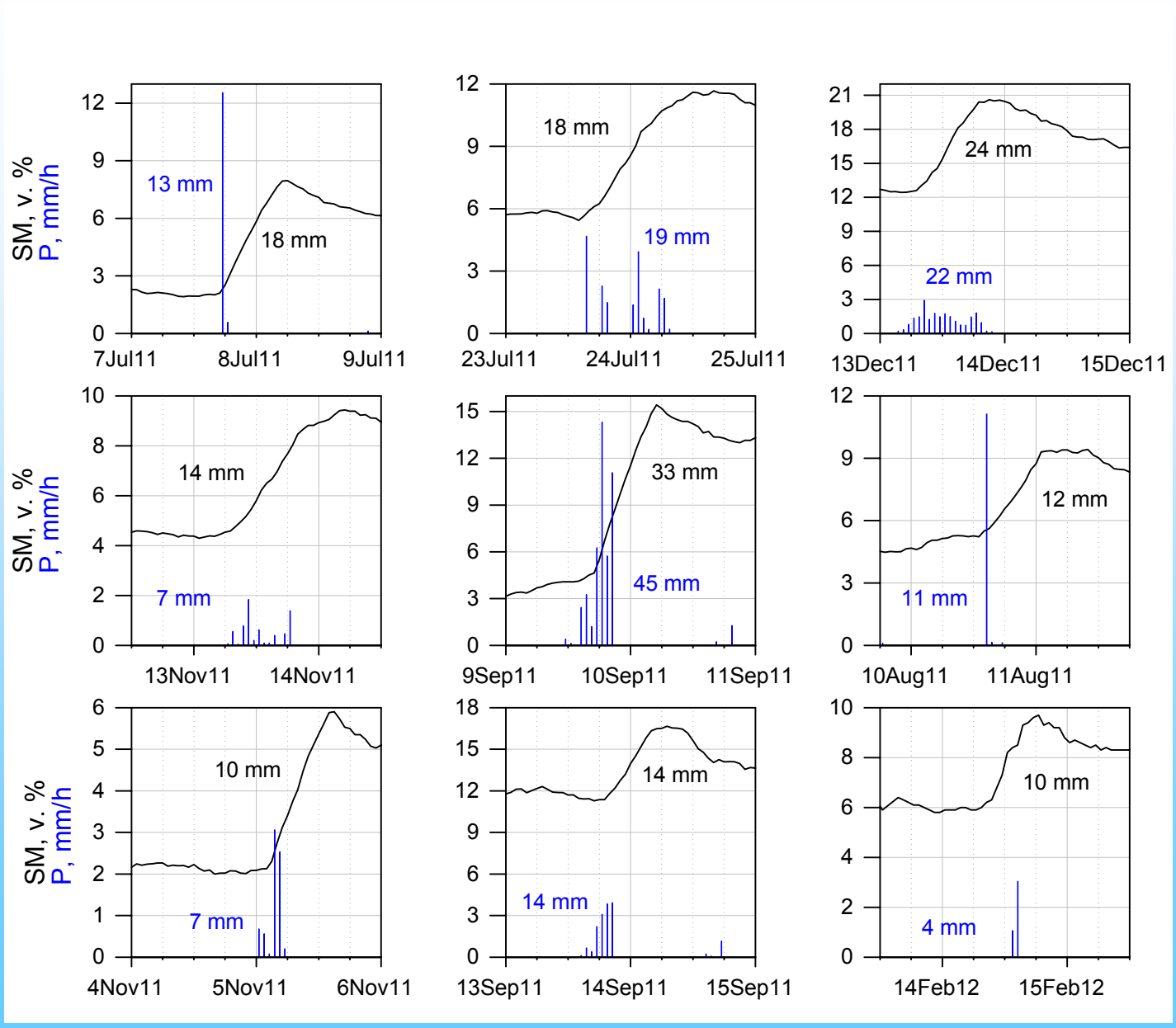
Santa Rita COSMOS probe, Arizona, USA.

Neutron-derived soil moisture vs. rainfall

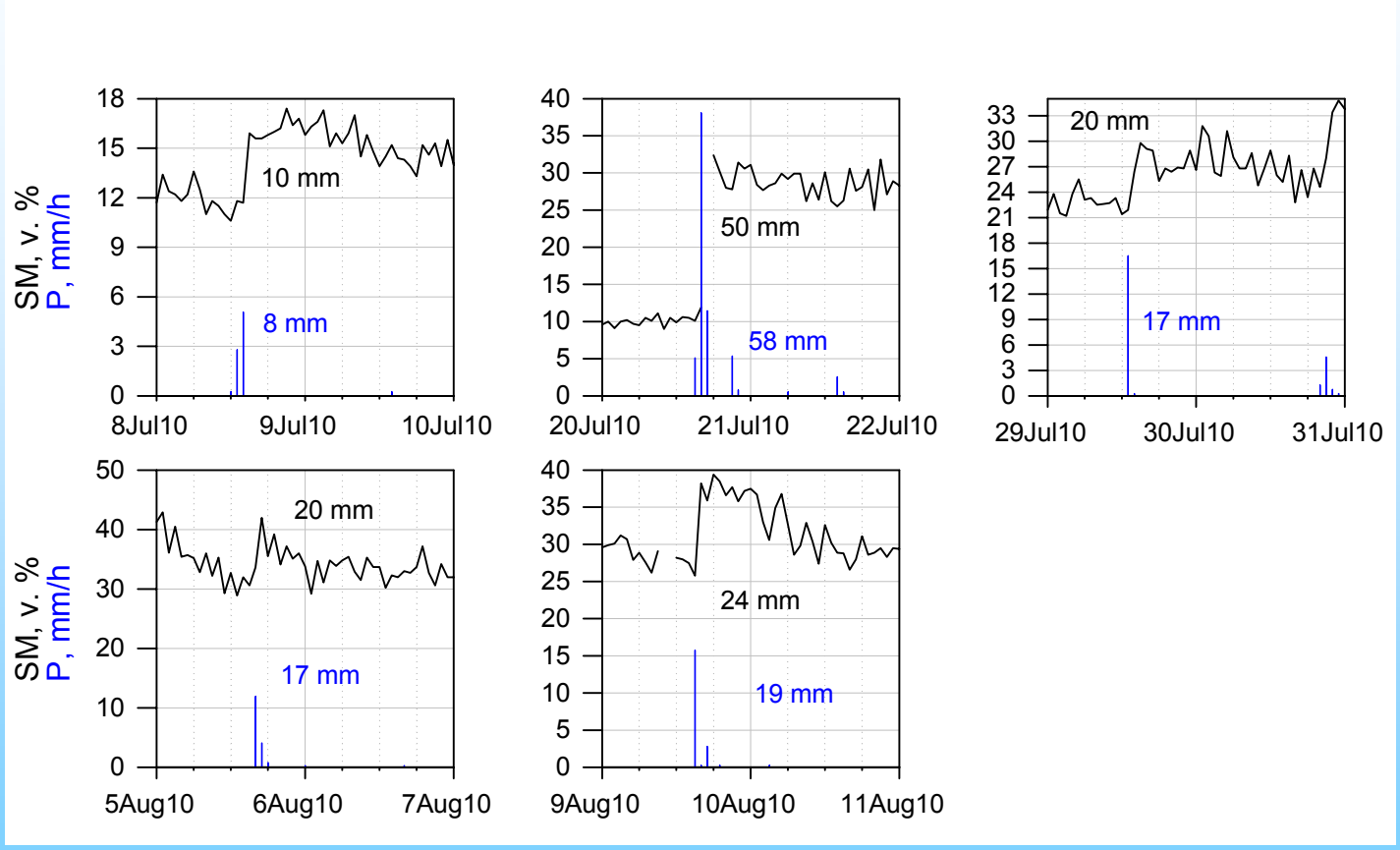




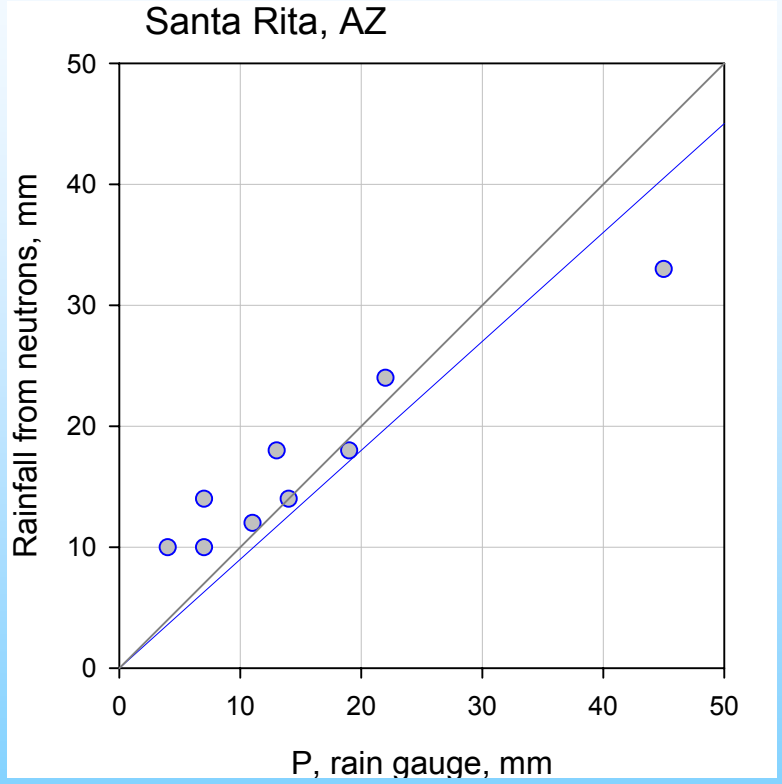
Neutron-derived rainfall amounts, Santa Rita

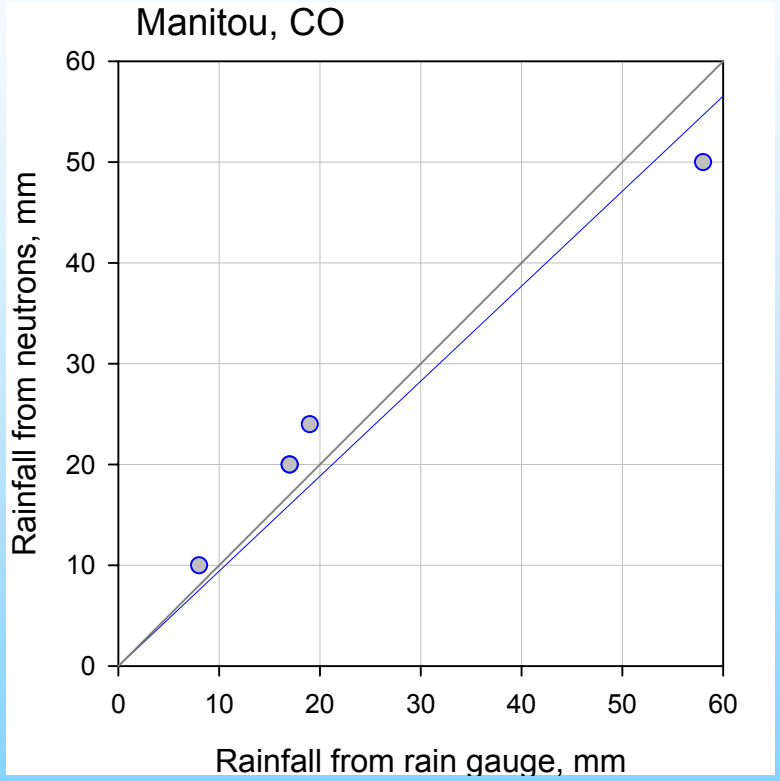


Neutron-derived rainfall amounts, Manitou

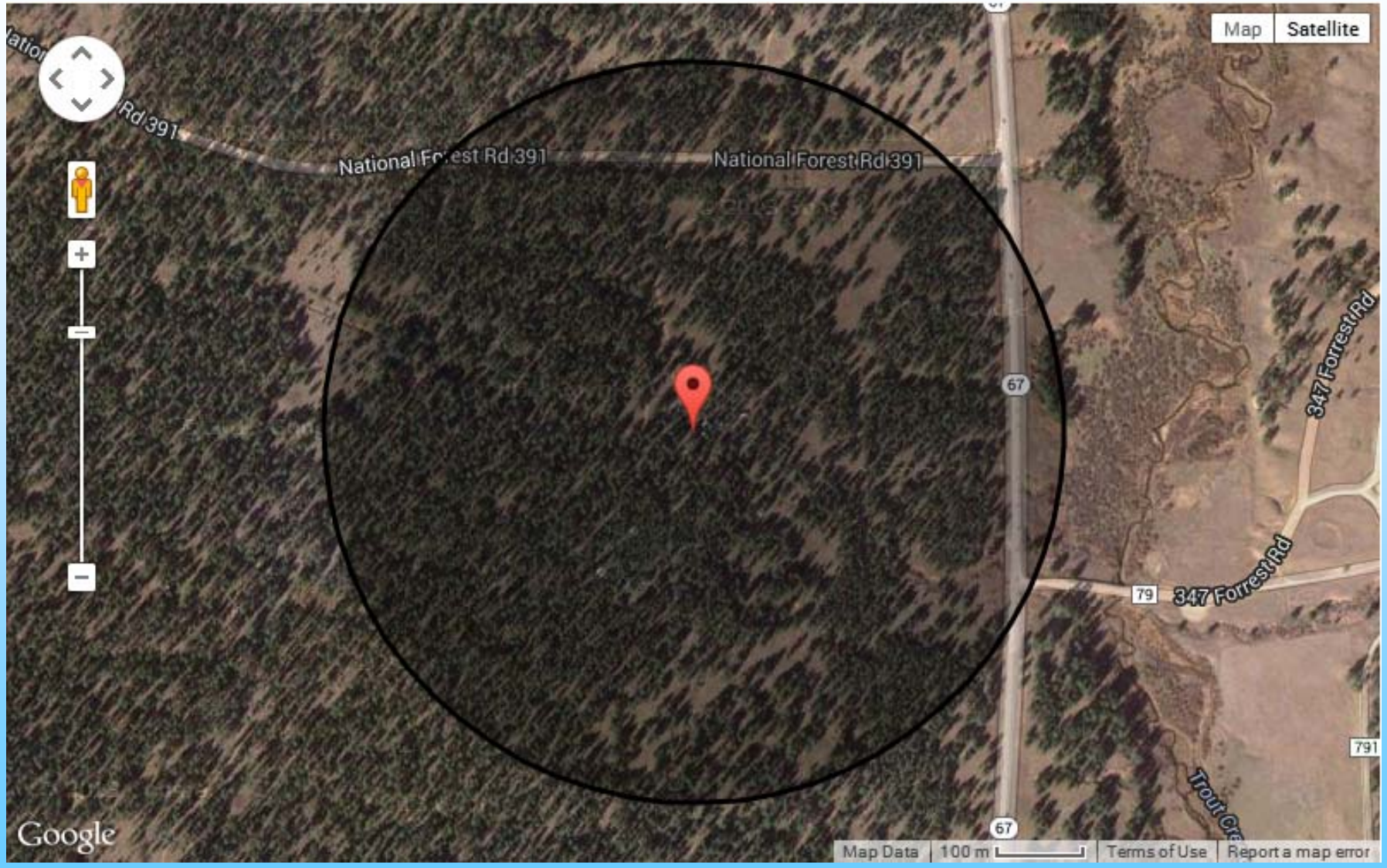


Rainfall: cosmic-ray vs. rain gauge



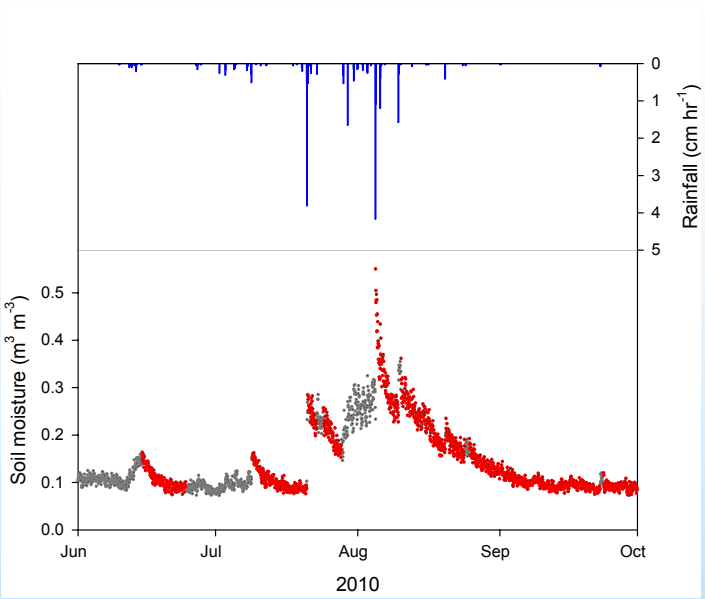


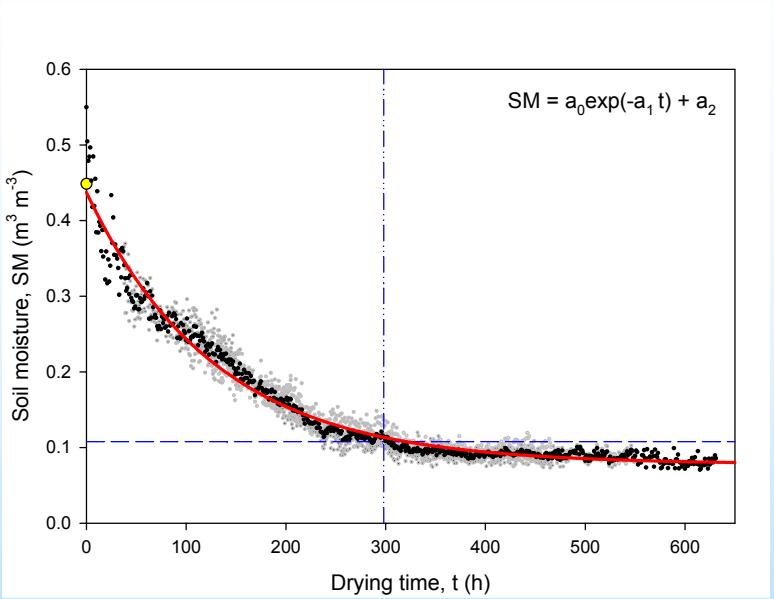
Example 3: Unsaturated hydraulic conductivity: cosmic-ray hydraulic conductivity meter

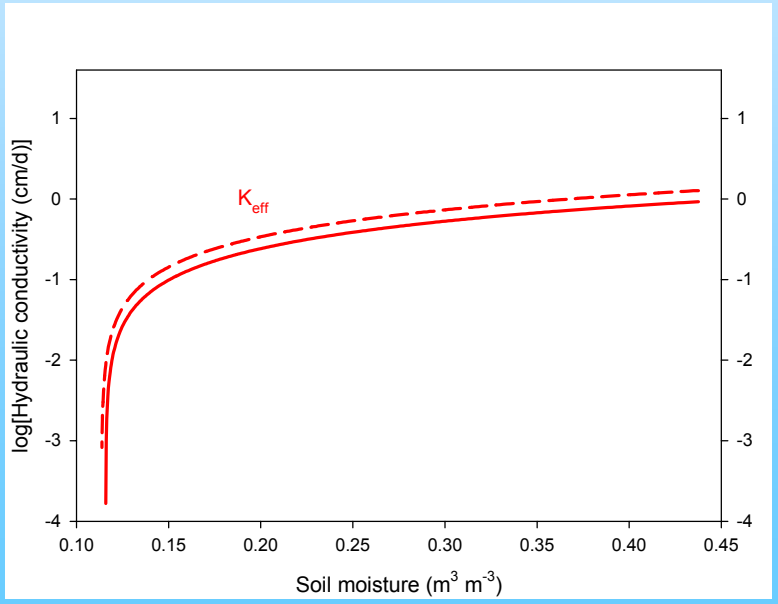


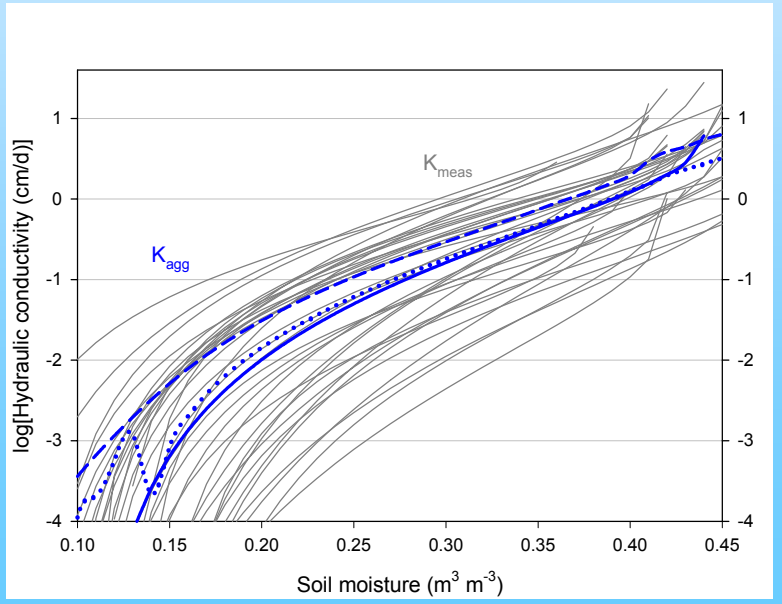
Manitou COSMOS probe, Colorado, USA.

Measuring soil hydraulic conductivity

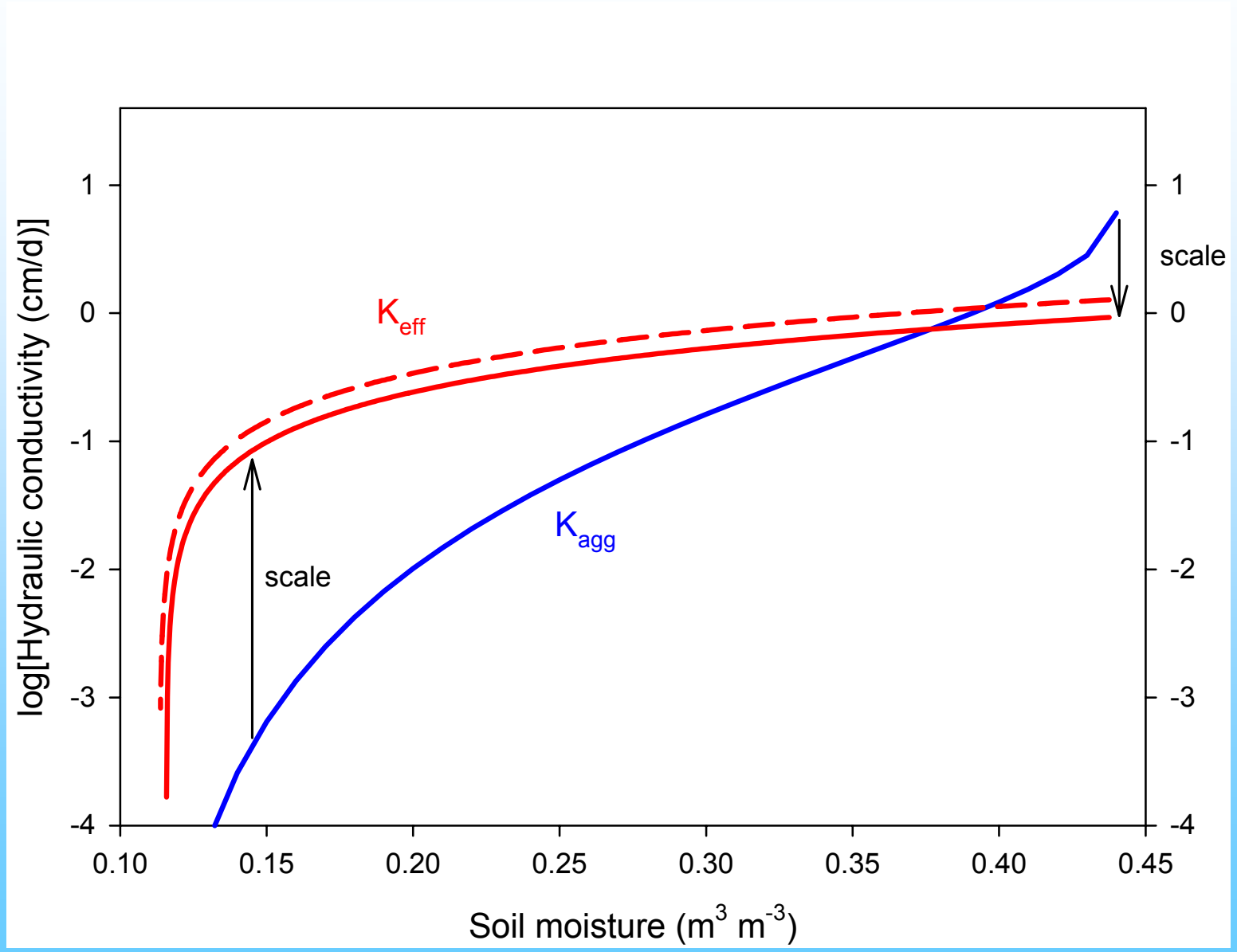








Hydraulic conductivity: cosmic-ray vs. HYPROP



Giant HYPROP device?