Importance of Deep Soil Moisture in Dryland Land Surface – Atmosphere Interactions

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Deep Soil Moisture ≠ Groundwater

Depth to the water table often exceeds 100 ft / 30 m in drylands.

This very deep unsaturated zone means dryland plants are not accessing groundwater.

Dryland plants depend on soil moisture provided by precipitation.
Therefore, compared to other areas which receiver greater annual precipitation, drylands are highly sensitive to precipitation inputs.

While U.S. annual average precipitation has increased about 5 percent over the past 50 years, there have been important regional differences as shown above.
Annual precipitation has been decreasing at the SRER-SRC over the past ~ 30 years

"Long-Term Precipitation Trends of Two Uniquely Water-Limited Ecosystems: Implications for Future Soil Moisture Dynamics" – Wehr and Papuga in prep
Precipitation at SRER-SRC is bimodal

Surface soil moisture responds to all storms, but deep soil moisture only available after large storms.
Most storms are small, with larger storms mostly occurring in the summer.
Surface moisture is lost quickly, whereas deep moisture remains available in the soil for longer.
Climate Change: *Precipitation*

Less small storms, more large storms

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Percentage Change

Percentile

Higher emissions scenario

Lower emissions scenario

Lightest

Moderate

Heaviest

CCSP SAP 3.3

www.globalchange.gov
Predicting the response of our ecosystems to changes in climate is one of today’s greatest challenges.

Predicting how changes in our ecosystems affect the climate system is another of our greatest challenges.
Work from my research group has shown:

• Transpiration in dryland ecosystems (grassland and shrubland) is triggered by deep soil moisture
  [Kurc and Small 2007, Cavanaugh et al 2011]

• Carbon uptake in dryland ecosystems (grassland and shrubland) is triggered by deep soil moisture
  [Kurc and Small 2007, Kurc and Benton 2010]
Walter’s Two-Layer Hypothesis

A root-based niche-partitioning hypothesis of tree-grass coexistence positing that shallow rooted grasses exploit soil moisture in shallow layers while deep rooted trees have exclusive access to soil moisture in deep layers.

http://gerrymarten.com/human-ecology/chapter06.html
Hydrologically-Defined Two-Layer Framework
Stable Water Isotopes In Two-Layer Framework

We hypothesized that the shallow and deep soil layers are isotopically distinct – through precipitation and evaporation.

Small storms are heavier in $\delta^{18}O$ and $\delta^2H$.

Large storms are more depleted in $\delta^{18}O$ and $\delta^2H$.

Evaporation further enriches $\delta_{\text{water}}$ values in the shallow layer.
Stable Water Isotopes In Two-Layer Framework

We further hypothesized that we could identify the source water for plants because the layers were isotopically distinct.
Methods

• **Micrometeorological and Eddy Measurements**
  – Evapotranspiration, Precipitation

• **Soil Moisture Measurements**
  – Multiple Depths Averaged to Shallow and Deep

• **Sap Flow System**
  – Transpiration

• **Isotopic Field Campaign (2014&2015)**
  – Soil, Plant, and Precipitation Samples
  – Lab Analyzed with Picarro Induction Module
Stable Water Isotopes In Two-Layer Framework

Are shallow and deep soil layers are isotopically distinct?

Shallow soil is more enriched in $\delta^2$H

Except after storms depleted in $\delta^2$H
Stable Water Isotopes In Two-Layer Framework

Are trends in shallow or deep moisture expressed in the plants?

We can see water from these isotopically light storms moving through the soil and being taken up by plants.
Stable Water Isotopes In Two-Layer Framework

Are trends in shallow or deep moisture expressed in the plants?

Stems fall along the deep soil regression line: plants are isotopically more similar to deep moisture!
Predicting the response of our ecosystems to changes in climate is one of today's greatest challenges. Desert shrublands depend on rainfall events capable of wetting the deep soil layers suggesting they can handle less overall precipitation as long as there are still big events. Predicting how changes in our ecosystems affect the climate system is another of our greatest challenges.
Albedo in Two-Layer Framework

Lighter, More Reflective

Darker, Less Reflective
Moisture decreases the albedo of the ecosystem.

Deep moisture influences albedo regardless if moisture is present at the surface.
Albedo in Two-Layer Framework

- PBL height lowest under wet conditions when albedo is also lowest
- Deep moisture influences PBL height regardless if there is moisture at the surface

Boundary layer height from Tucson airport radiosonde data

Deep moisture influence on albedo

- shrub “greenness” controlled by deep soil moisture
- wet “green” canopies are darker and less reflective

Deep moisture influence on albedo

Surface moisture not enough to support plants

Deep moisture enough to support plants

Deep moisture influence on albedo

- Canopy albedo is always lower than bare albedo
- A “wet” surface, whether soil or vegetation, always has the lowest albedo

Now we ask...

Can we use empirical relationships between soil moisture, albedo, and planetary boundary layer height to evaluate consequences of future precipitation changes?
So we propose…

A simple modeling approach:

- Daily Precipitation is generated using a stochastic process.
- Shallow soil moisture is calculated using a two-layer bucket model.
- Deep soil moisture is calculated using a two-layer bucket model.
- Albedo is calculated from a linear relationship with shallow soil moisture.
- $PBL_h$ is calculated from shallow soil moisture, deep soil moisture, and albedo using polynomial relationships.

Sanchez-Mejia, Z.M. and S.A. Papuga in prep for Journal of Hydrometeorology
Results from our empirical model:

Current regime: Rains ~ every 3 days in summer, 6 days in winter

Annual values:
- 358 mm
- 0.114 m$^3$ m$^{-3}$
- 0.104 m$^3$ m$^{-3}$
- 18.1%
- 2118 m

Sanchez-Mejia, Z.M. and S.A. Papuga in prep for Journal of Hydrometeorology
Results from our empirical model:

Example New regime: Decrease in Overall Precip, Increase in Frequency

Annual values:
- 286 mm
- 0.098 m$^3$ m$^{-3}$
- 0.101 m$^3$ m$^{-3}$
- 18.52 %
- 2217 m

Sanchez-Mejia, Z.M. and S.A. Papuga in prep for Journal of Hydrometeorology
Predicting the response of our ecosystems to changes in climate is one of today’s greatest challenges.

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Greening in shrublands leads to decreased albedo and lower boundary layer potentially generating better conditions for rainfall.

[Sanchez-Mejia and Papuga 2014; Sanchez –Mejia et al. 2014]
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THANK YOU!

Questions?

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