Proximal remote sensing enhances a global change experiment & tests assumptions of large-scale approaches

Joel Biederman, Bill Smith, Nathan Pierce, Fangyue Zhang et al.
Motivation: temporal repackaging of rainfall

Since 1974, rainfall has been “repackaged” into fewer, sometimes larger storms with longer dry intervals between

Zhang et al., GRL 2021
Motivation: spatial challenges of dryland remote sensing
RainMan-SR

Rainfall Manipulation in the Santa Rita Experimental Range

5 acre (2 ha) exclosure – room to grow
• Bimodal Sonoran Desert growing season
  • Spring fluxes increasing?
  • priming for summer?
• Fully manipulated rainfall allows altered *timing*
• Proximal Remote Sensing test bed
Proximal Remote Sensing in global change experiments

PRS can improve measurements within local experiments (Shiklomanov, 2019)

- Easier/cheaper/quicker than traditional measures
- Measure different things
- Non-destructive sampling
- Increased coverage spatially & temporally
RainMan Infrastructure

- 60 plots 4 x 5 ft, hydraulically isolated
- Full rainfall exclusion with manual irrigation using captured rainwater
- Soil water content & water potential
- Automated phenocams
Single grassland ecosystem type

- Typical Sonoran Desert grassland
- Annual forbs & grasses
- Perennial forbs & small shrubs
- Transplanted Arizona Cottontop perennial bunchgrass 36/plot
- Mix of rooting depths
Mix of rooting depths from ~10 to 60+ cm

Credit: Sage Grouse Initiative
Experiment 1: temporal repackaging of summer precip: fewer, larger storms, longer dry intervals:

**Design:** 5 blocks (houses) of 12 plots. 4 treatments (n = 15) repeated each summer. Control is manipulated to historical norm (S2 = weekly rainfall)

**Q1:** What plants will be successful? Deep vs. shallow rooting.

**Q2:** What are the consequences for CO2 uptake, water evaporation, surface temperature?

**Q3:** What proximal remote sensing captures ecosystem structure, function, productivity?
Temporal repackaging of summer rainfall

Irrigation Intervals = 3.5, 7, 14, 21 Days

ΣP = 205 mm

Treatments span annual longest dry interval between rainfall events (since 1974)

S2 = historical normal frequency
RainMan Direct and PRS Measurements - Where

- GPP & ET - plot
- Plant Community - plot
- Plant cover - *map
- Aboveground biomass (allometry) - individual
- Water potential - leaf
- Leaf traits (e.g. %N)
- Gas exchange - leaf
- Structural traits - individual/leaf
- Soil water and temp profiles - plot
- Belowground biomass (allometry) - plot
- (?)Soil N species - plot
- Hyperspectral - plot
- LAI - plot
- Aboveground volume (SfM) - *map
- RGB Imagery - *maps hourly (lowres) weekly (high res)
- Thermal *map
- Spectral - leaf
- Root images - plot
- Soil microbial C/N/P & diversity - plot

*Map = collected for whole plot but resolvable at sub-plot scale
RainMan Direct and PRS Measurements - When

- SWC / SMP: HOURLY
- Soil Respiration: HOURLY to WEEKLY
- Phenocam Imagery: BIWEEKLY
- Photogrammetry: BIWEEKLY
- LAI, Root Images: BIWEEKLY
- Nadir & Thermal: WEEKLY + Daily-scale pulse campaign
- Plot-level gas: WEEKLY + Daily-scale pulse campaign
- Leaf: WP, Spec, Gas, trait: WEEKLY + Daily-scale pulse campaign
- Soil Chem/Microbial: BIWEEKLY
- Plant traits: BIWEEKLY
- Plant Community: BIWEEKLY
- Above/Below Biomass: BIWEEKLY

Pulse-chasing

JUL | AUG | SEP | FEB | MAR | APR
Soil water: many/small vs. few/large rainfalls

- S1 Watered 2X Weekly
  - Wet near surface in Jun, Jul
  - Dry-down at all depths
  - Cyclic wetting near surface
  - Increasing moisture at 25 cm

- S4 Watered every 21 Days
  - Wet near surface in Jul, Aug
  - Cyclic wetting near surface
  - Increasing moisture at 25 cm
What do we mean by plant stress?

• Depth, duration, and intensity of soil water potential stress (SWP)
• Paired SWC & SWP Sensors
• Extensive screening for ~steady state
• -100 m water ~ -1MPa = 0.05% SWC
Cumulative days *without* major water stress

Zhang et al., Functional Ecology 2022
Few/large rainfalls *delayed* peak photosynthesis by ~1 month

Zhang et al, *Functional Ecology* 2022
Few/Large rainfalls deepen root production

- No differences in total root area
- Different rooting depths

Average Root Area (mm^2)

- S1
- S2
- S3
- S4

Average Root Area vs. Depth (mm^2)

- S1 many/small rainfall
- S4 few/large rainfall
- Deeper roots

Mid-Rooted Perennial Bunchgrass
Perennial bunchgrass ANPP

- Adjacent destructive sampling plots provide site-specific allometry: \( \text{Ht} \times \text{BD}^2 \)
- Biomass ~ Height * Basal Diameter\(^2\)
- Bigger individuals, no treatment effects at plot scale yet

Pierce et al., in prep
NDVI tracks photosynthesis

- NDVI is a common currency across time and space
Thermal imaging as a common currency
Javadian et al., in prep
Few/Large rainfall plots stayed cooler

Mean Surface Temperature (Aug 17- Sep 22)

- S1: 40.5 °C
- S2: 39.2 °C
- S3: 38.9 °C
- S4: 38.5 °C
RGB cover classification
Thermal results by cover class & rainfall treatment

- 2-3 degrees between cover classes
- Differences grow with dry-down
- In all cover classes, few/large rainfalls=cooler
- Sustained access to root zone moisture
Variety of phenology across temporal repackaging
GCC = Greenness

Wet cycles

Historical norm

Pulse - short lag

Pulse-long lag
Temporal repackaging into fewer/larger rainfalls:

• Increases time of root zone stress in shallow soils, relieves stress deeper
• Promotes deeper roots (and fewer shallow roots), no change in total root area
• Cools land surface by 1-2 degrees at midday
• Favors perennial plants with greater access to moisture (thermal)
• Delays peak productivity up to 30 days, no change in peak magnitude
• Bigger bunchgrass individuals, no change in ANPP
• Increases challenges with phenology models
• Increases importance of high-frequency measurements
Future Directions

• Temporal: Develop pulse-driven phenology models appropriate for drylands
• Quantify the impacts of temporal resolution with intensifying rainfall packaging
• Spatial: Link plot-scale heterogeneity in greenness & thermal to satellite RS
• Greenness ~ photosynthetic capacity
• Thermal ~ access to moisture/plant stress
• Hyperspectral ~ Functional traits