SOUTHERN ROCKIES
Landscape Conservation Cooperative

DESERT LANDSCAPE
CONSERVATION COOPERATIVE

Grassland Vulnerability to Climate Change in Southwest Deserts

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Grassland Vulnerability to Climate Change in the Southwest Deserts

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Grassland Vulnerability to Climate Change in the Southwest Deserts

TODAY:

Climate change in drylands: an ecohydrological approach

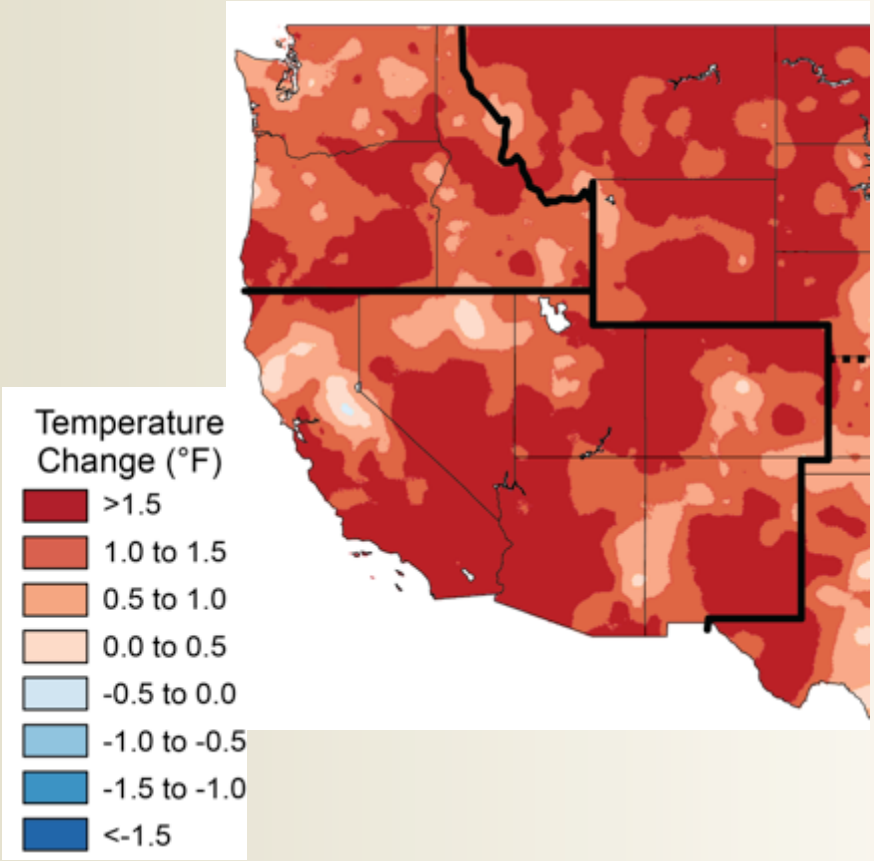
Grasslands in Sonoran, Chihuahuan, & Colorado Plateau

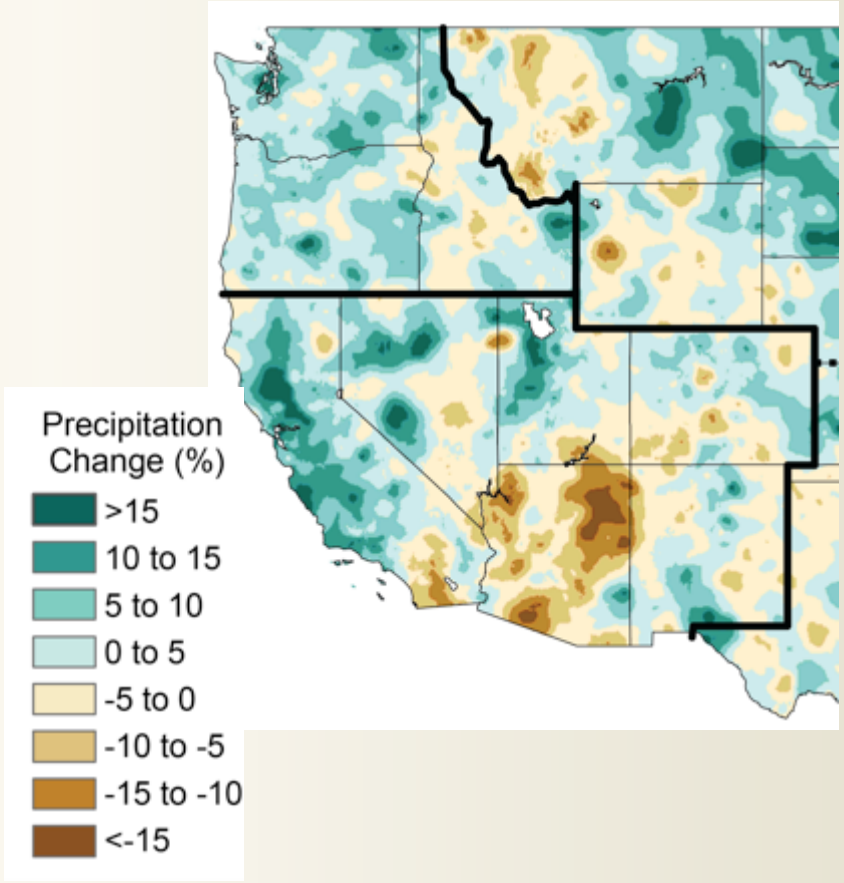
Questions & analysis strategy

Results & Implications

Deserts of the U.S. Southwest

Observed temperature and precipitation changes
1991-2012 vs. 1901-1960





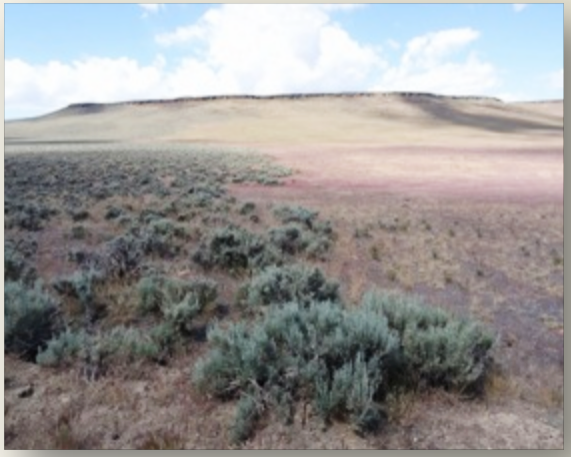
Walsh et al. 2014. *Climate Change Impacts in the United States: The Third National Climate Assessment*.

Challenges to understanding plant responses

1. Variability in climate

   Through time and space

   Simple measures may be insufficient



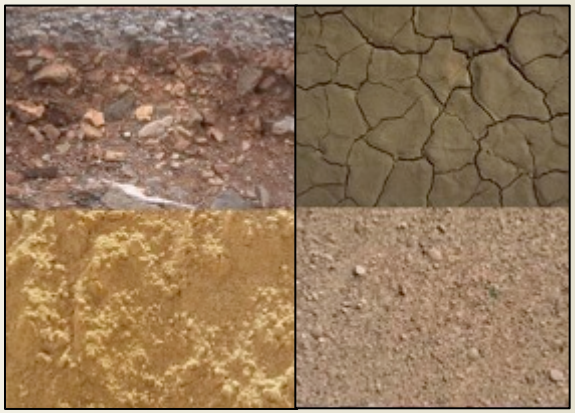
2. Biotic interactions

   Competition, facilitation

3. Variation in soils

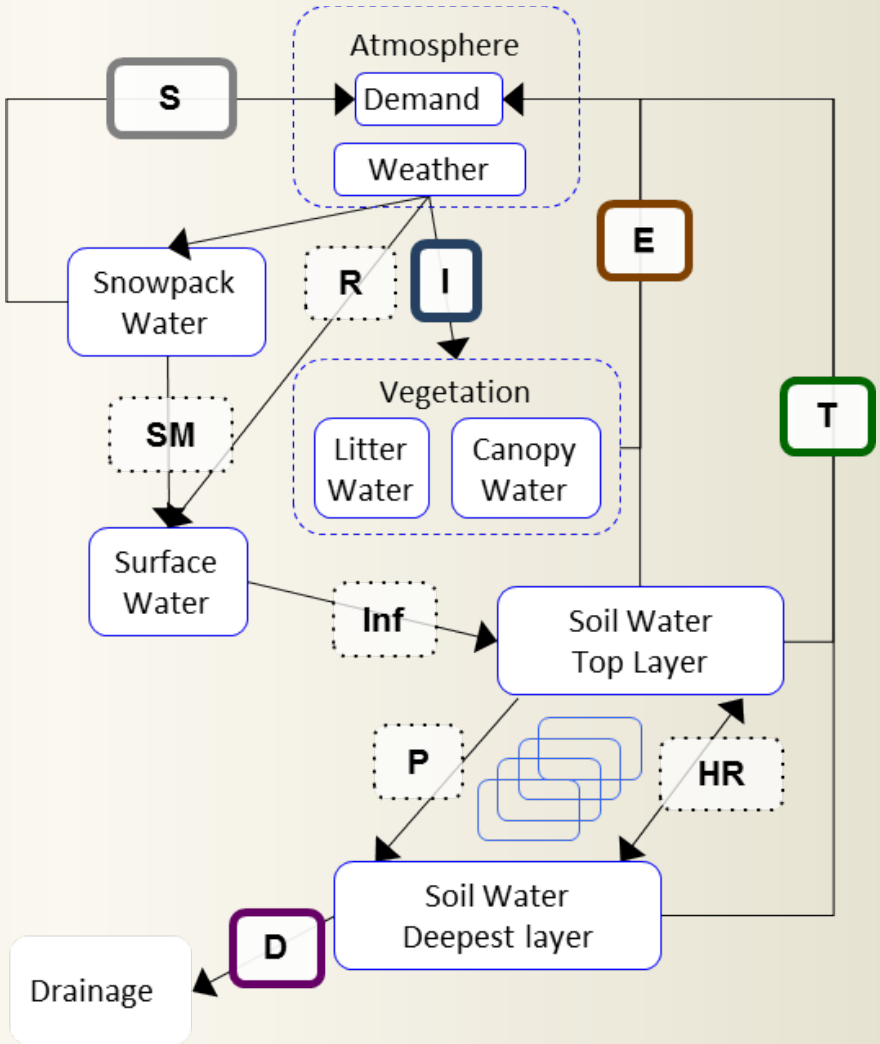
   Texture, depth, development

   Affect water movement, availability, and storage



Ecohydrological modeling: SOILWAT

- Parameterized with:
  - Daily weather
  - Vegetation properties
  - Soil properties
  - Ecosystem processes
- Returns:
  - Daily, monthly, and annual values of each water balance component



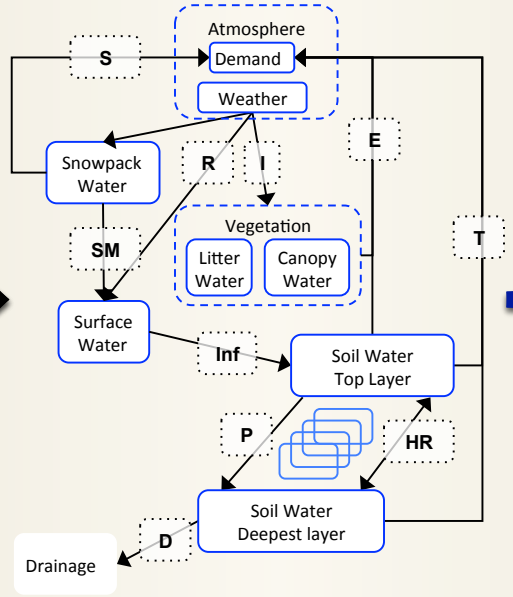
Parton 1978 ➔ Sala et al 1992 ➔ Bradford and Lauenroth 2006 ➔ Lauenroth and Bradford 2006➔ Schlaepfer et al. 2012 ➔ Bradford et al. 2014

SOILWAT:
A translation tool

Daily weather

Soil Conditions

Vegetation Structure



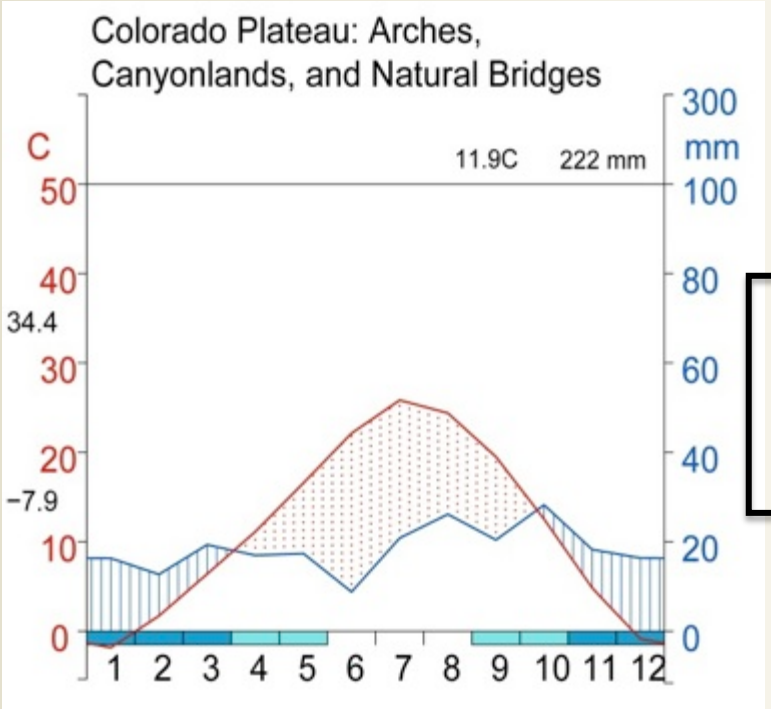
Water balance

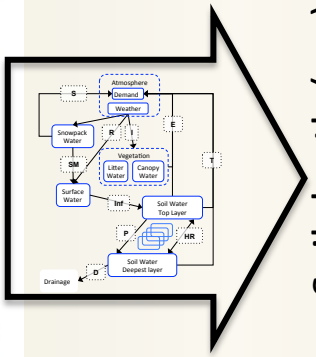
Water availability for plants

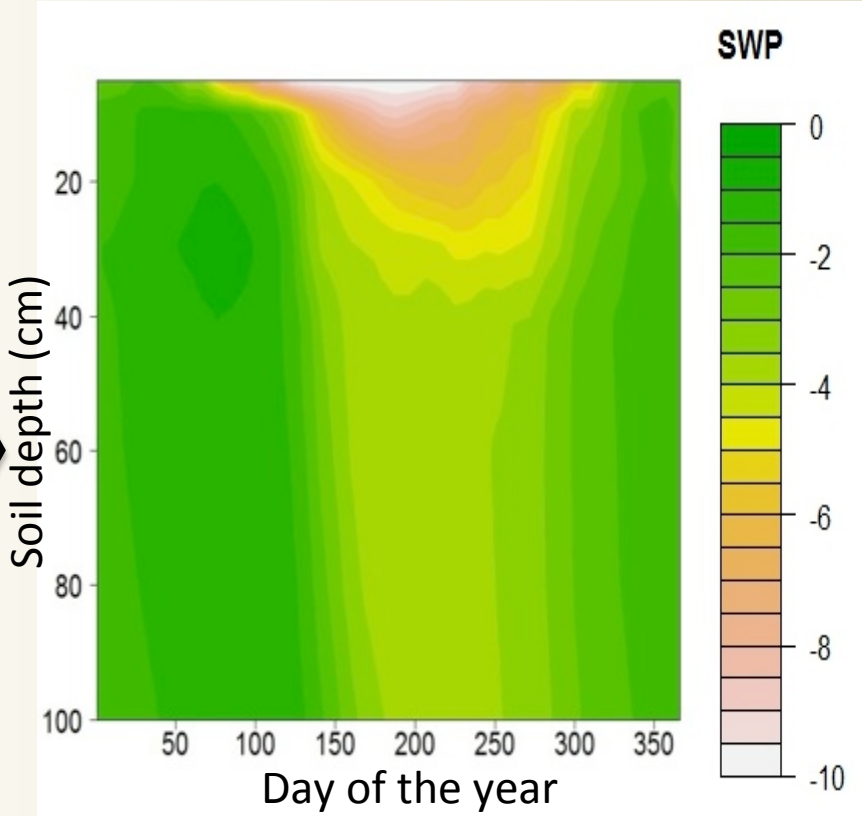
Parton 1978 ➔ Sala et al 1992 ➔ Bradford and Lauenroth 2006 ➔ Lauenroth and Bradford 2006➔ Schlaepfer et al. 2012 Ecohydrology

SOILWAT:

Climate & Soil -> Water availability

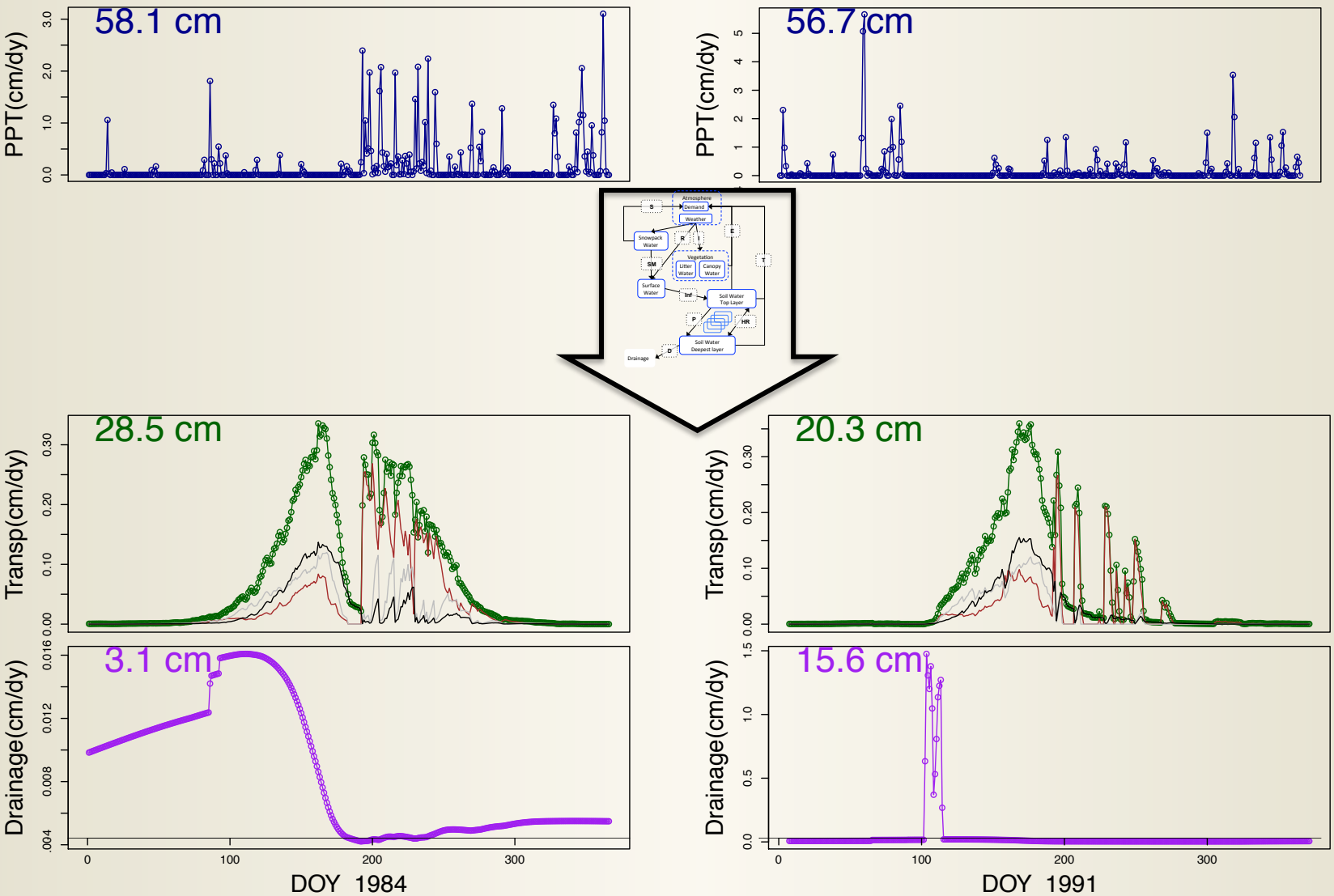






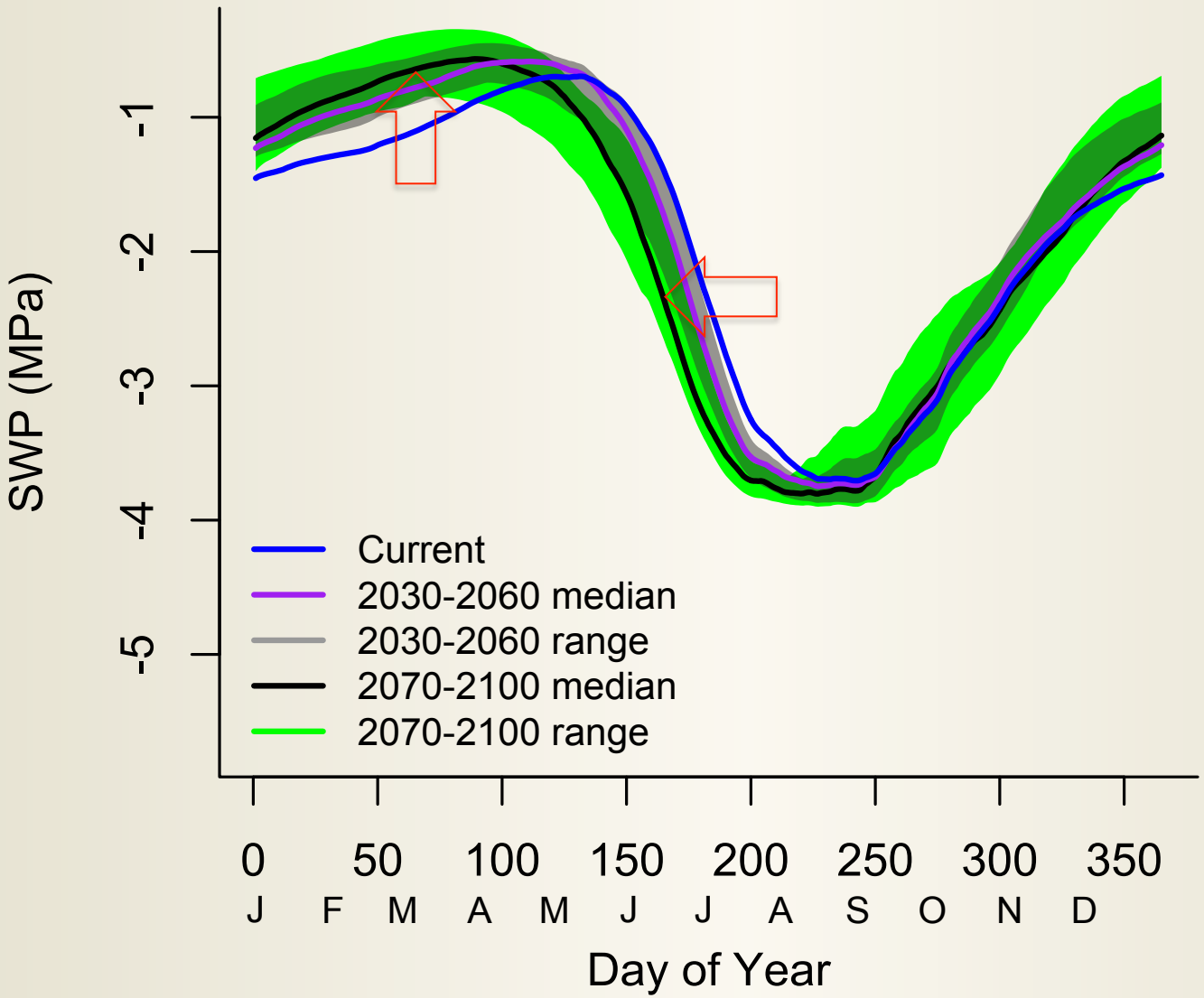
SOILWAT:

Year-to-year comparisons



SOILWAT:

A tool for future projections



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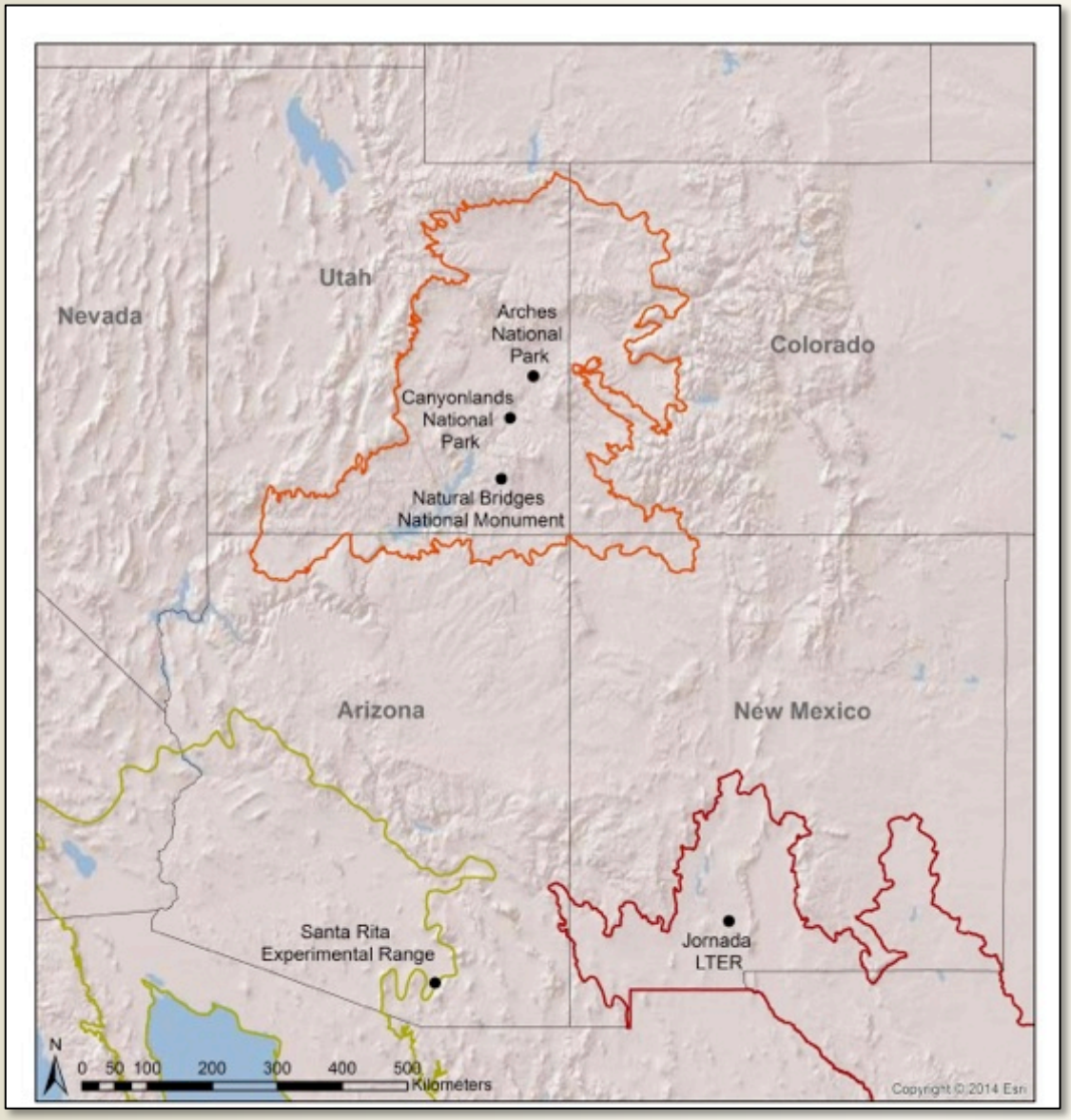
TODAY:

Climate change in drylands: an ecohydrological approach

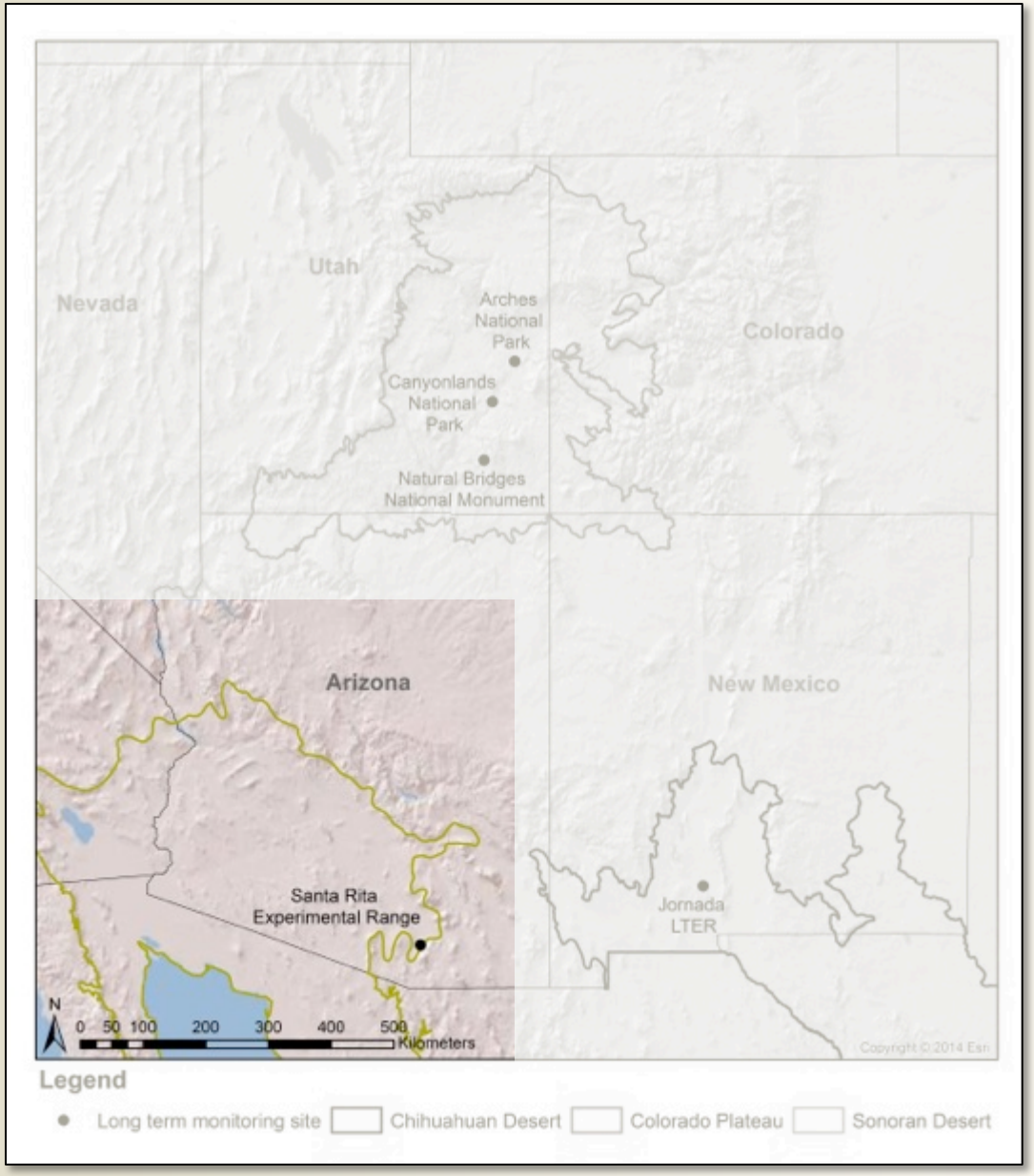
Grasslands in Sonoran, Chihuahuan & Colorado Plateau



3 Southwestern Deserts

- Sonoran
- Chihuahuan
- Colorado Plateau

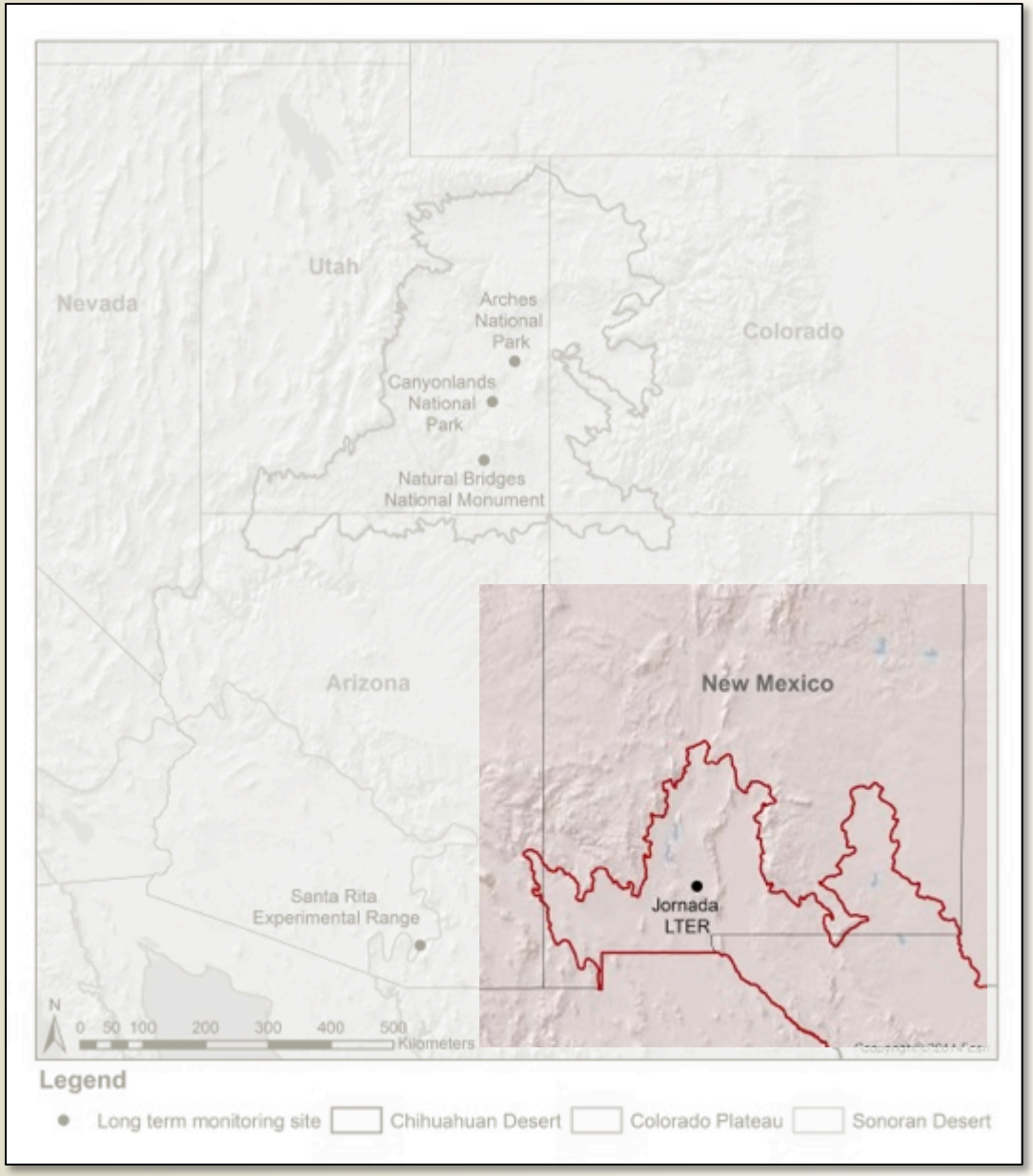
Sonoran Desert



Santa Rita Experimental Range

- Data from 1953-2009
  - 1-4 year intervals
- C_4 grass species
  - Dominants:
    - *Eragrastis lehmanniana*
    - *Digitaria californica*
    - *Muhlenbergia porteri*

Chihuahuan Desert



Jornada Basin LTER

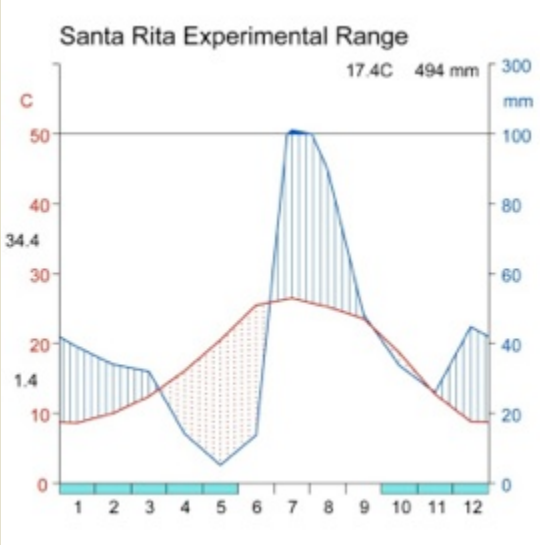
- Data from 1989-2009
- Only grassland sites
- C4 grass species
  - Dominants:
    - *Bouteloua eriopoda*
    - *Muhlenbergia porteri*
    - *Sporobolus flexuosus*

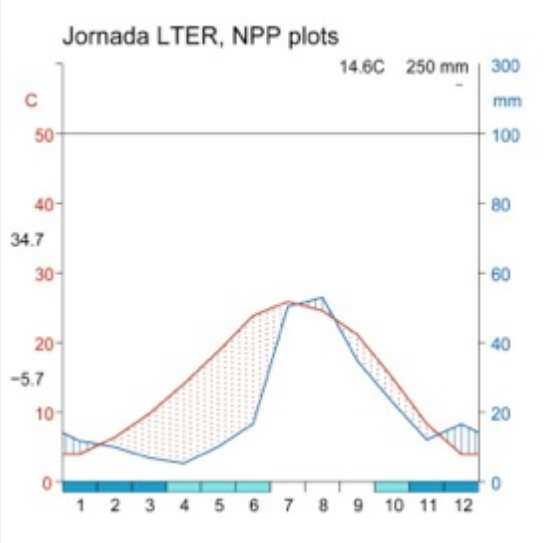
Colorado Plateau

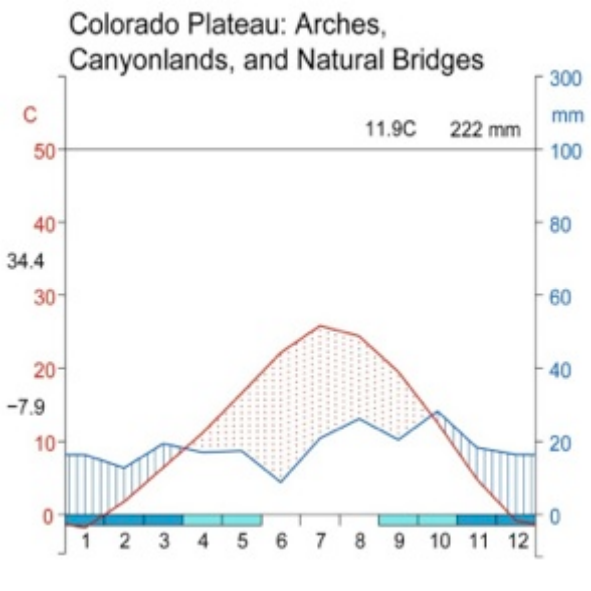
Arches, Canyonlands, & Natural Bridges

- Data from 1989-2009
- Plots chosen by ordination
- Mix of C_3 and C_4 grass species
  - C_3 species (cool season)
    - *Hesperostipa comata*
    - *Achnatherum hymenoides*
  - C_4 species (warm season)
    - *Hilaria jamesii*
    - *Sporobolus airoides*

Sites differ in climate and soil water dynamics







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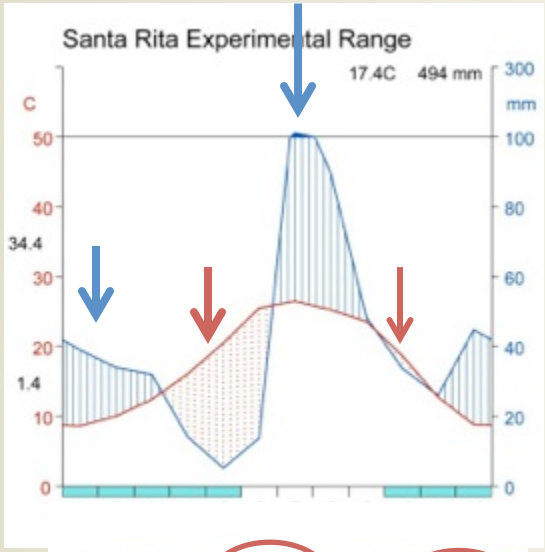
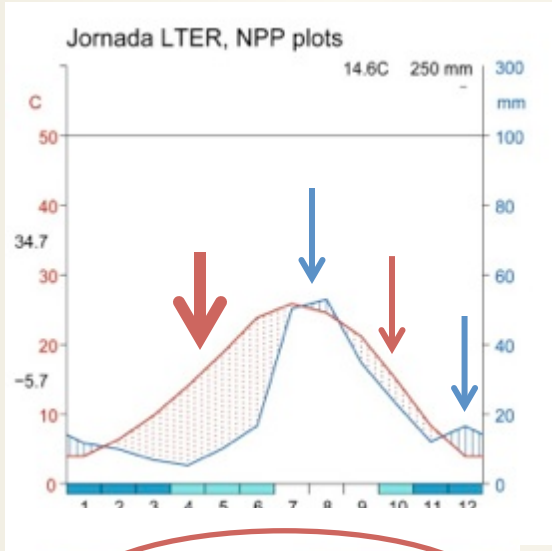
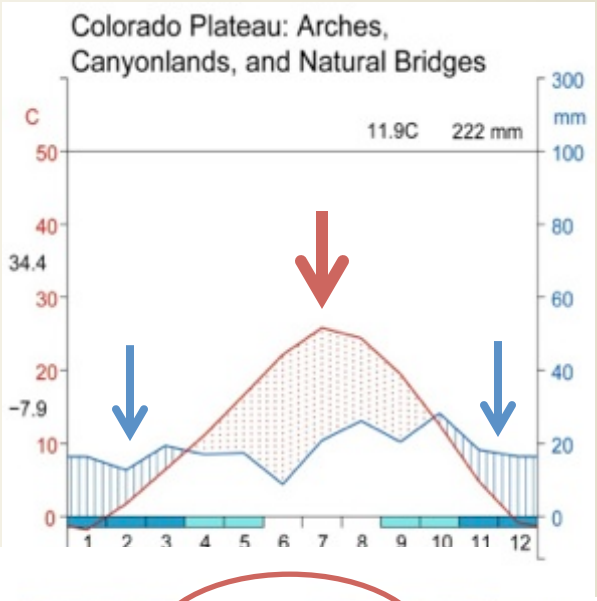
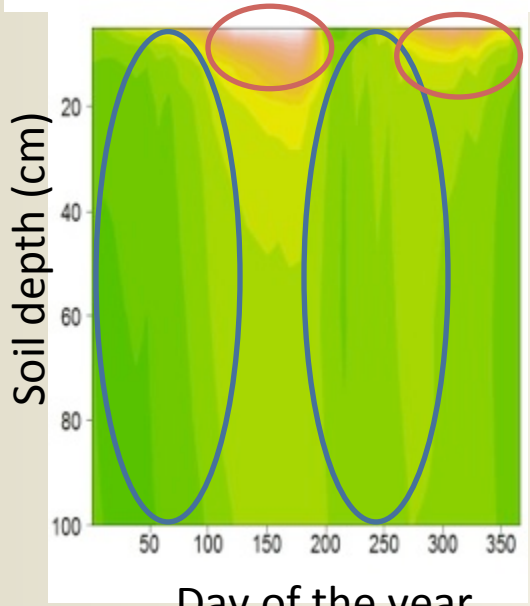
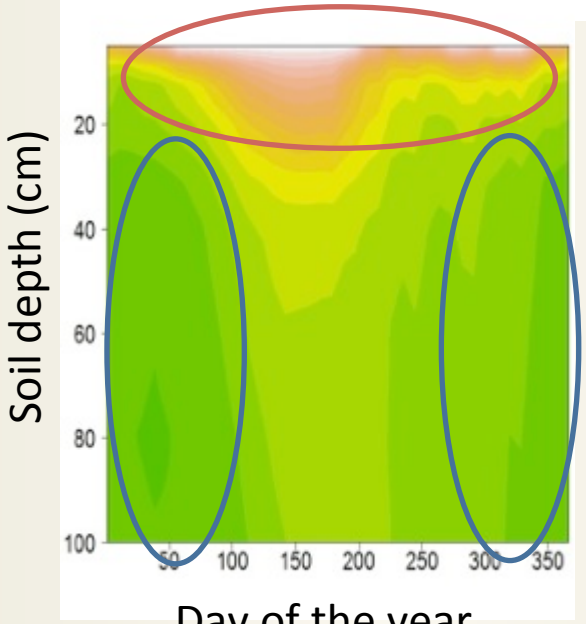
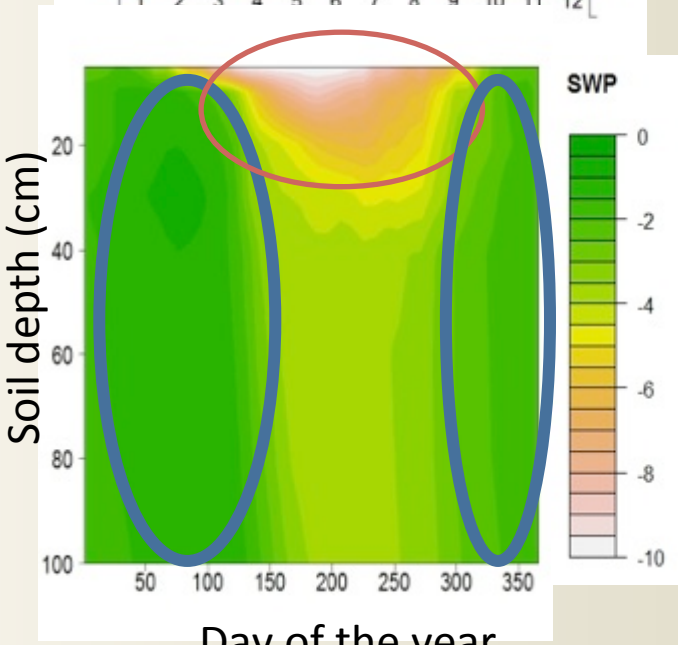












Grassland Vulnerability to Climate Change in the Southwest Deserts

TODAY:

Climate change in drylands: an ecohydrological approach

Grasslands in Sonoran, Chihuahuan, & Colorado Plateau

Questions & analysis strategy

Questions

- What aspects of climate and soil water explain past grassland dynamics?
- Does incorporating soil water dynamics enhance our ability to understand responses?
- What do forecasts of climate & soil moisture imply about grassland vulnerability to climate change?

Long-term vegetation monitoring

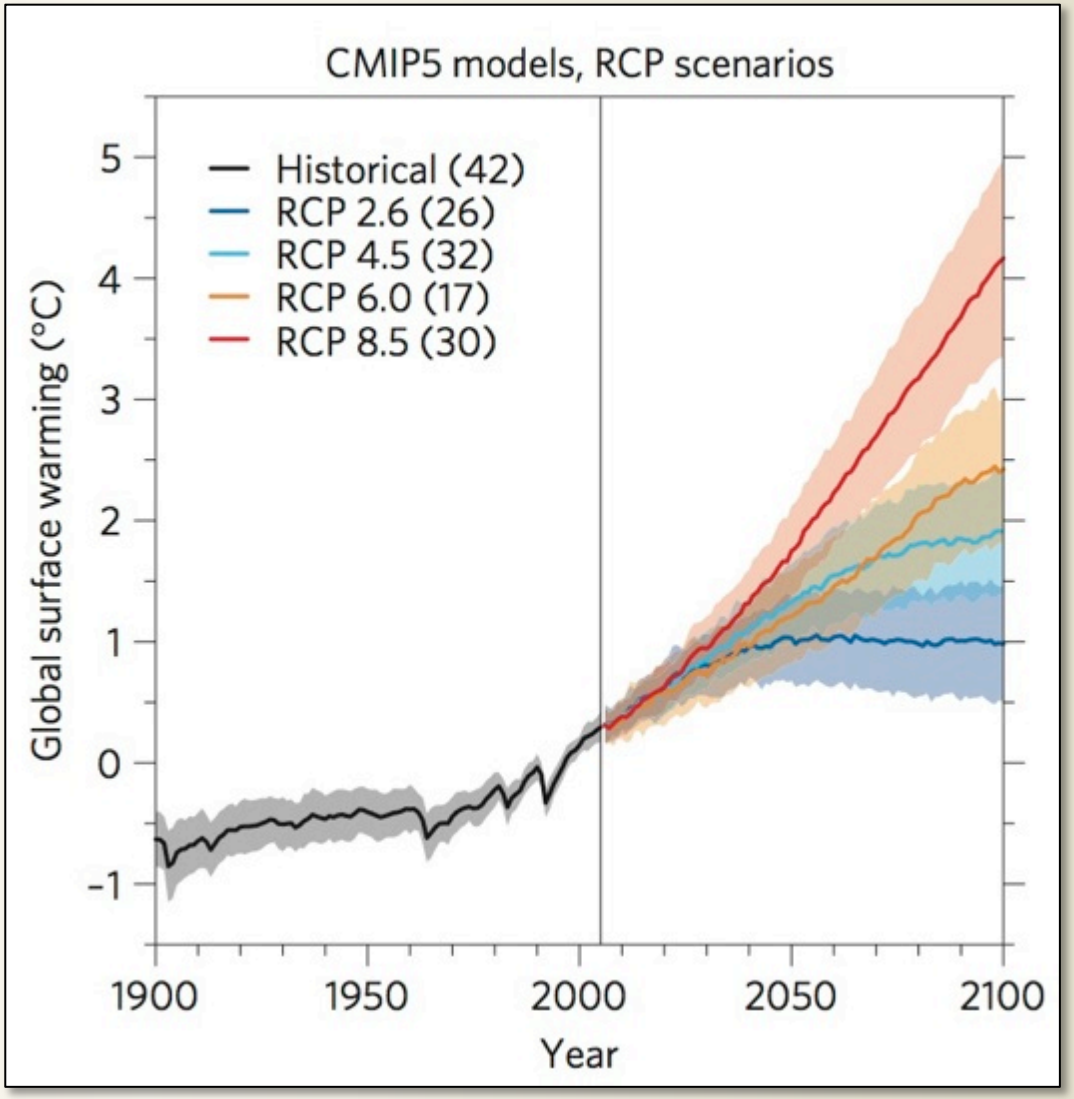
1. **Santa Rita Experimental Range**
   - Line intercept
   - 30-m transects (n=82)
2. **Jornada Basin LTER**
   - 3 plots in each of 5 vegetation communities
     - 7 x 7 grid of 1-m^2 quadrats for each plot
   - Only grassland sites used here (n=3)
3. **Arches, Canyonlands, and Natural Bridges**
   - 0.5-m^2 plots along transects at each site, 100 plots per site
   - 42 sites total
     - 10 for C_3 analysis
     - 11 for C_4 analysis

Approach

- Understand factors associated with past changes:
  - Climate (Maurer et al. 2002)
    - World clim bioclimatic variables
  - SOILWAT model
    - Daily time step, multiple layer, process-based model
      - Parton 1978, Sala et al. 1992, Bradford and Lauenroth 2006
    - Translate climate + soils → patterns of water availability
  - Long-term vegetation monitoring
    - Focus on desert grasslands here

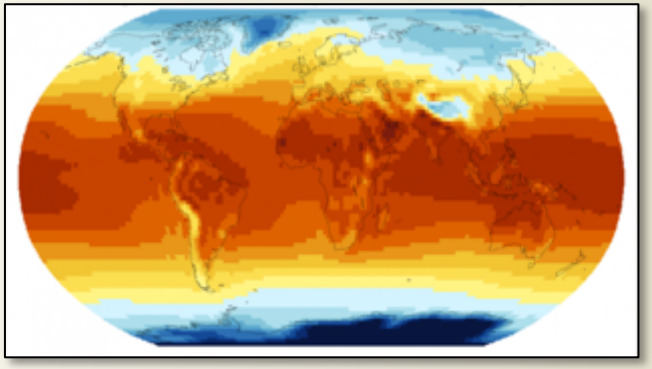
Climate Change

- CMIP5
- 2 Representative concentration pathways: RCP4.5 and RCP8.5
- 16 global circulation models



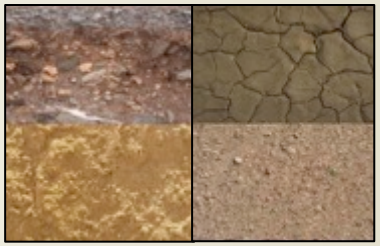
Climate and soils data

- Maurer database (Maurer et al. 2002)
  - 1/8 degree gridded daily weather from 1949-2010
- Climate maps of the United States
  - http://cdo.ncdc.noaa.gov/cgi- bin/climaps/climaps.pl
  - Relative humidity, cloud cover, wind speed
- National Elevation Dataset
  - http://ned.usgs.gov
  - Elevation estimates (30 x 30 m^2)
- NRCS STATSGO
  - Soil texture and depth (1 km^2)



Statistical analyses

1. Identify climate and soil water variables
   - Variable selection using ordination
     - 5 climate variables
     - 7 soil water variables
   - Means across sampling intervals



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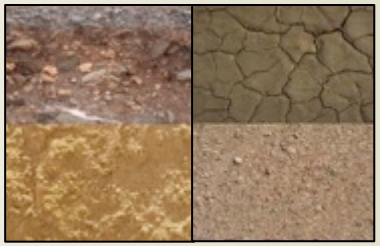
Site	Climate Variables	Soil water variables
Santa Rita	Mean annual temperature (MAT)	Mean number of dry days, dry_{days}
	Mean monthly temperature range (T_{range})	Annual number of wet spells, wet_{spells}
	Temperature seasonality (T_{seas})	Prop. of wet days in winter, $prop_{winter}$
	Precipitation of the driest quarter (P_{dry})	Prop. of transpiration from deeper layers, $trans_{depth}$
	Precipitation of the coldest quarter (P_{cold})	Months of the longest wet/dry spell, $month_{wet}$ & $month_{dry}$
Jornada	Mean annual temperature (MAT)	Mean number of dry days, dry_{days}
	Mean monthly temperature range (T_{range})	Annual number of wet spells, wet_{spells}
	Temperature seasonality (T_{seas})	Prop. of wet days in winter, $prop_{winter}$
	Mean annual precipitation (MAP)	Prop. of transpiration from deeper layers, $trans_{depth}$
	Precipitation of the driest quarter (P_{dry})	Months of the longest wet/dry spell, $month_{wet}$ & $month_{dry}$
	Monsoon precipitation ($P_{monsoon}$)	Prop. of transpiration from shallow soil layers, $trans_{shallow}$
CO Plateau	Mean monthly temperature range (T_{range})	Mean number of dry days, dry_{days}
	Temperature seasonality (T_{seas})	Annual number of wet spells, wet_{spells}
	Mean temp. of the wettest quarter (T_{wet})	Proportion of wet days in winter, $prop_{winter}$
	Mean annual precipitation (MAP)	Proportion of trans from shallow layers in the summer, summer $trans_{shallow}$
	Precipitation seasonality (P_{seas})	Months of the longest wet/dry spell, $month_{wet}$ & $month_{dry}$



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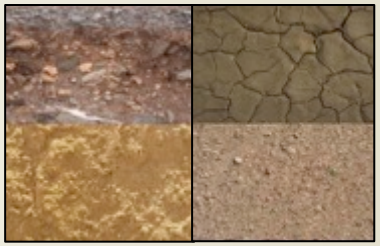
2. Relationships with cover
   - Perennial grasses analyzed together as functional groups
   - Mixed models
     - Random effect of plot (repeated measures)
     - Main effect of cover in previous year



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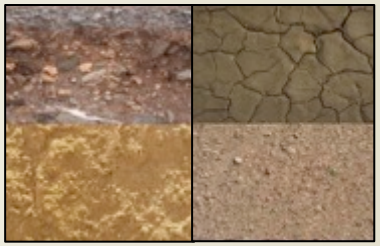
     - Main effect of cover in previous year
     - Repeated measures
3. Relative importance of variables
   - Hierarchical partitioning (Accounts for covariance)
   - Climate, soil = ƒ(residuals from previous cover)



Statistical analyses

<u>What to look for:</u>

- **Climate and moisture variables related to plant cover.**
- **Relative importance of climate vs. soil moisture.**
- **Expected future conditions of the importance variables.**

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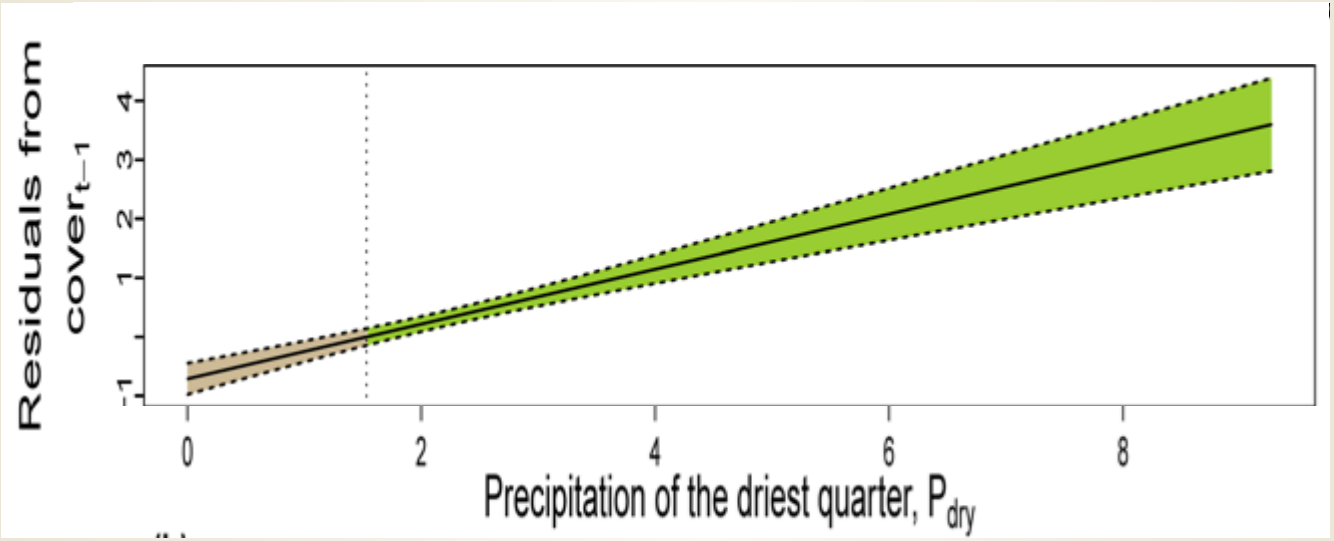

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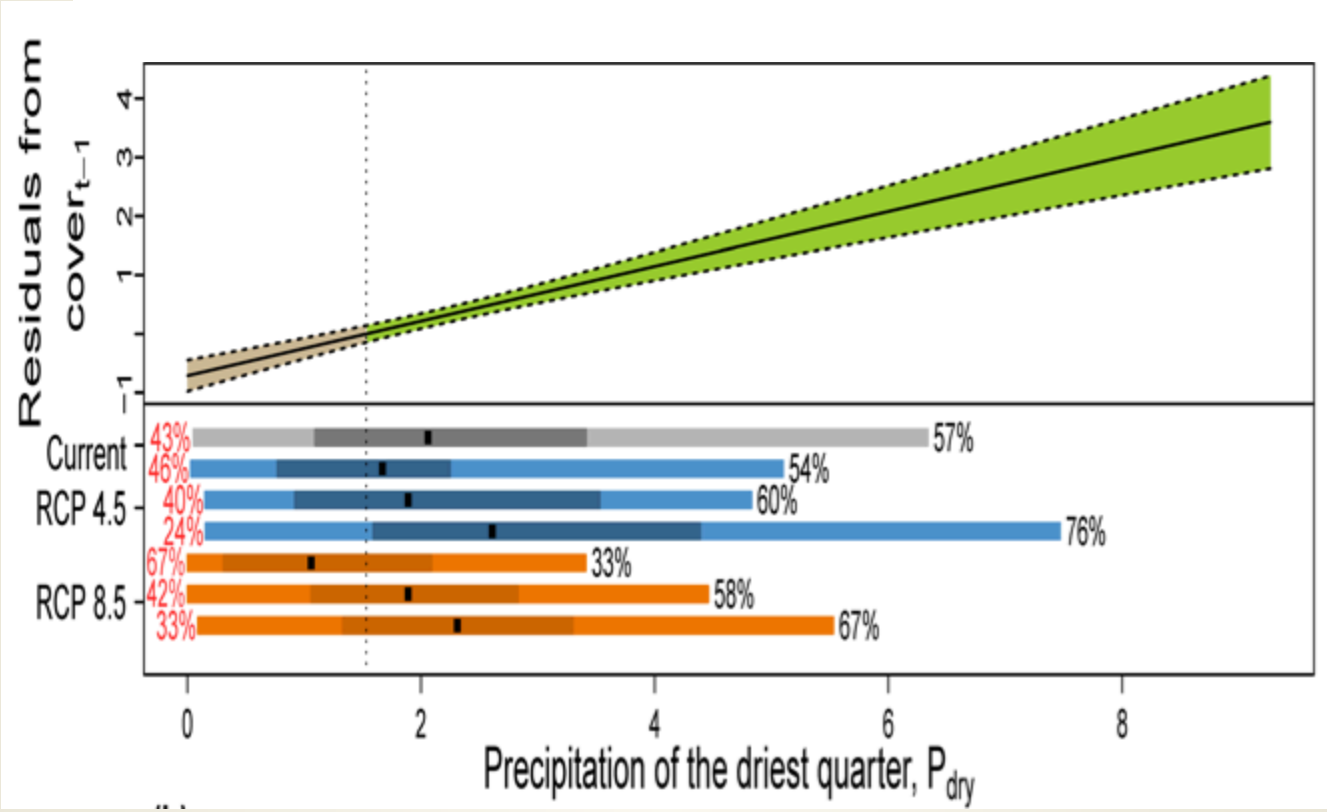

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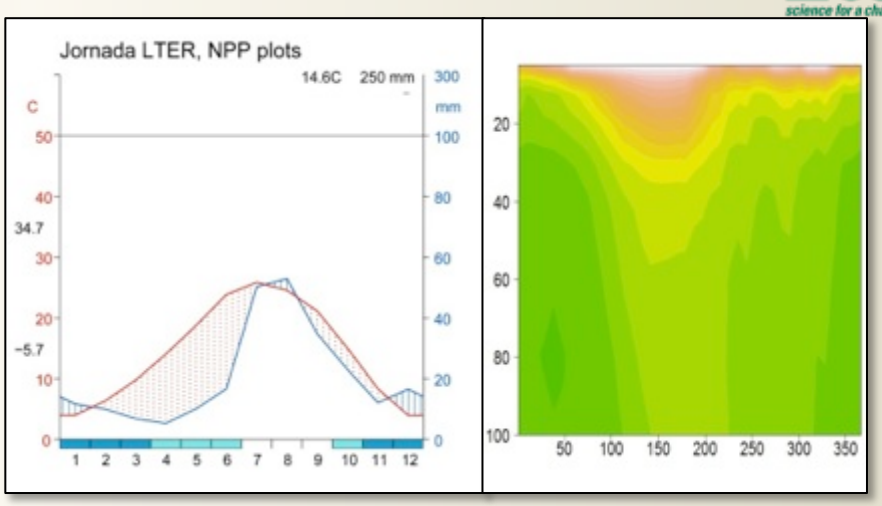
Objectives and analysis strategy

Results & Implications

Chihuahuan Desert

Jornada Basin LTER

- Data from 1989-2009
- C_4 grasses



Variable	Direction	Independent percentage
Temperature seasonality (BIO4)	**-**	**37.06**
Proportion transpiration from lower layers	**+**	**32.80**
Monsoon precipitation	+	12.93
Mean annual temperature (BIO1)	-	6.33
Proportion of wet days in winter	+	4.05
Number of wet spells	-	3.21
Month of the maximum dry spell	-	2.39
Month of the maximum wet spell	-	1.23
Climate total		**56%**
Soil water total		**44%**

Chihuahuan Desert

Jornada Basin LTER

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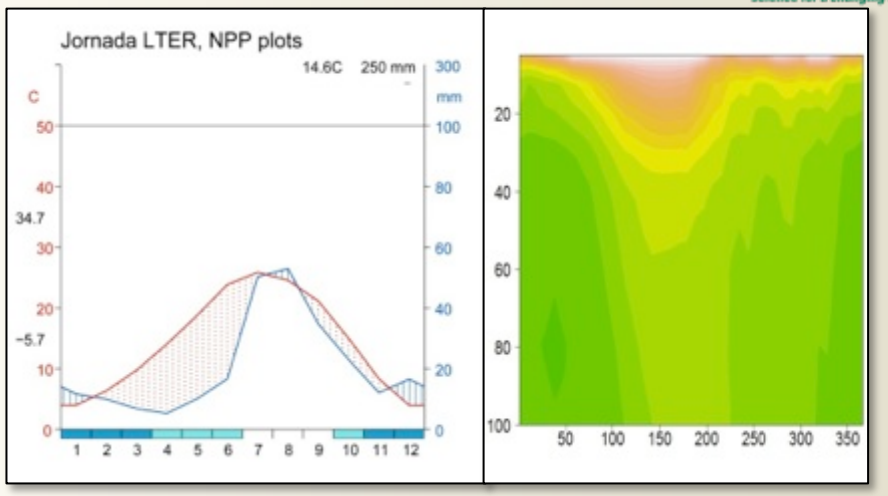
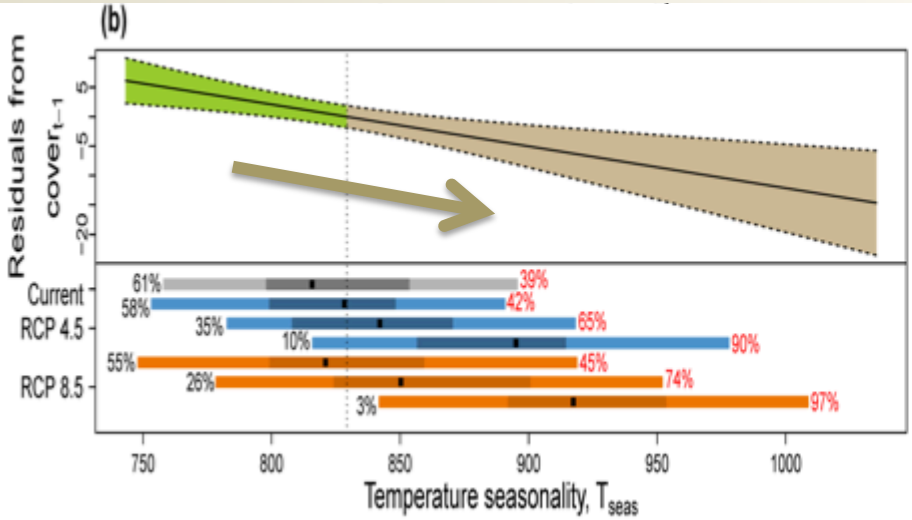
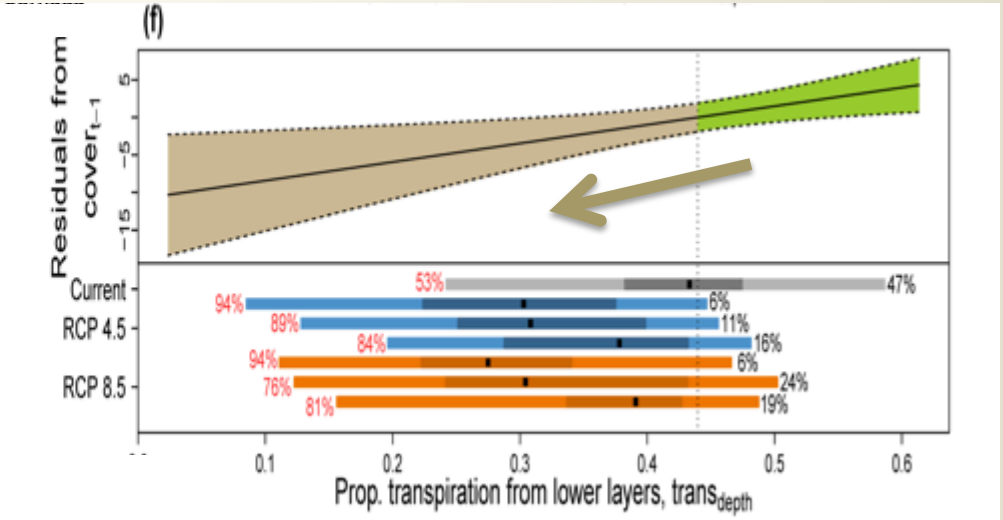
- C_4 grasses



Temperature Seasonality



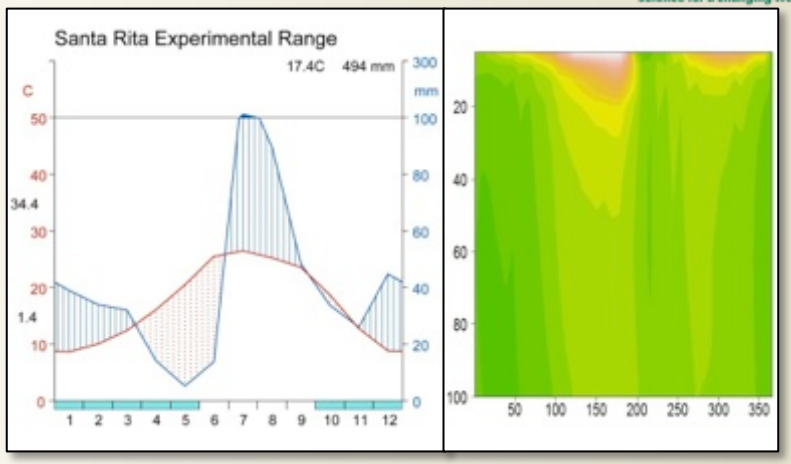
Transpiration from deep soils



Sonoran Desert

Santa Rita Experimental Range

- Data from 1953-2009
- C_4 grasses

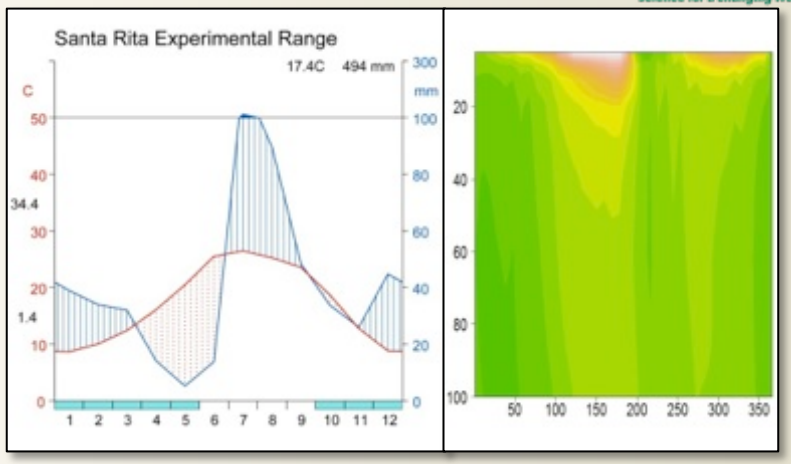


Variable	Direction of relationship	Independent percentage
Precipitation of the driest quarter (BIO17)	**+**	**31.82**
Temperature seasonality (BIO4)	**-**	**14.92**
Proportion of transpiration from lower layers	**-**	**14.28**
Mean soil dry days	**-**	**11.23**
Monthly temperature range (BIO2)	-	7.71
Month of the maximum dry spell	+	6.84
Precipitation of the coldest quarter (BIO19)	-	6.58
Number of wet spells	+	3.17
Month of the maximum wet spell	+	1.79
Mean annual temperature (BIO1)	+	1.67
Climate total		**63%**
Soil water total		**37%**

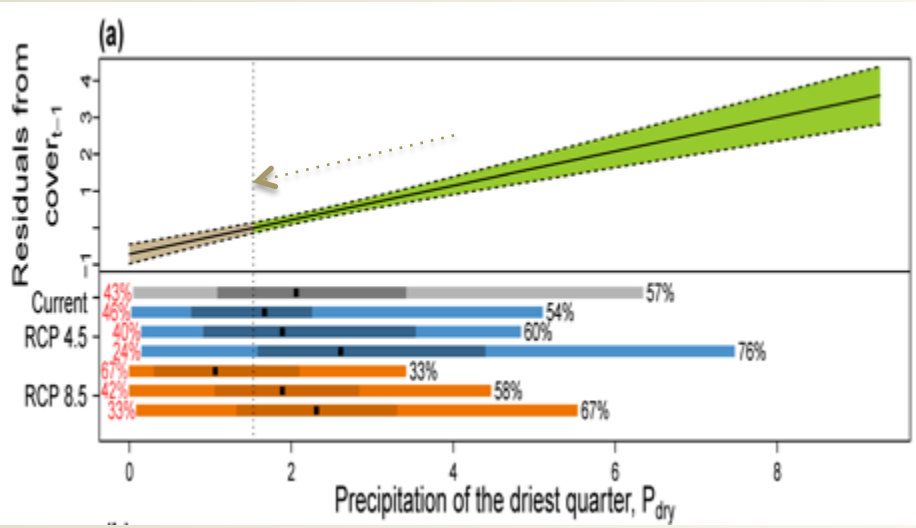
Sonoran Desert

Santa Rita Experimental Range

- Data from 1953-2009
- C_4 grasses



Precipitation in driest quarter



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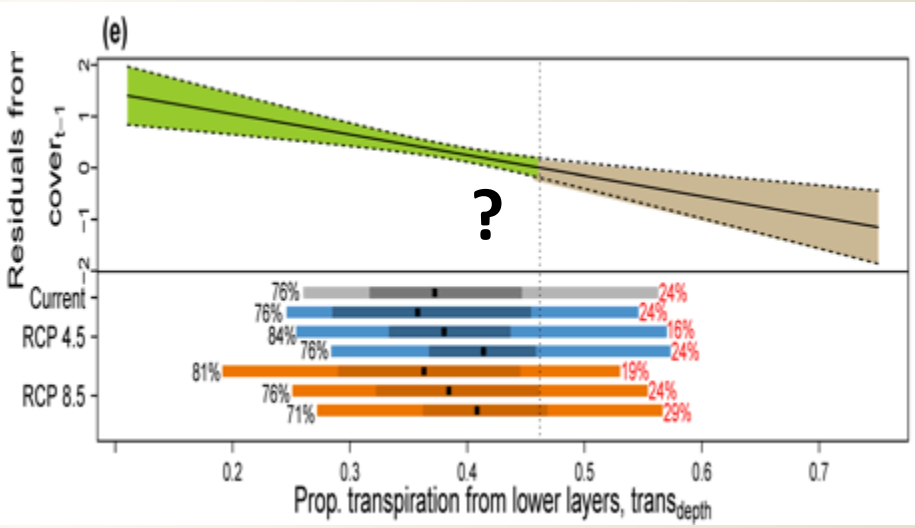
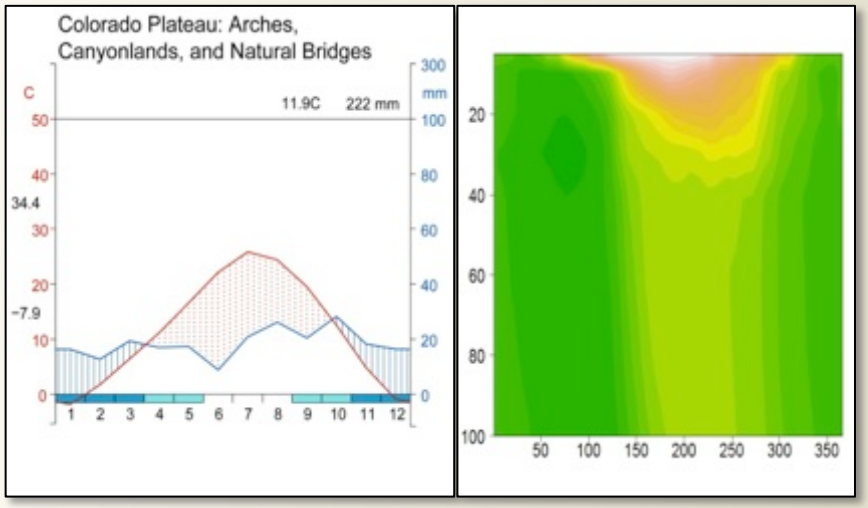


Colorado Plateau: C_3 grasses

Arches, Canyonlands,

& Natural Bridges

- Data from 1989-2009



C3 grasses:

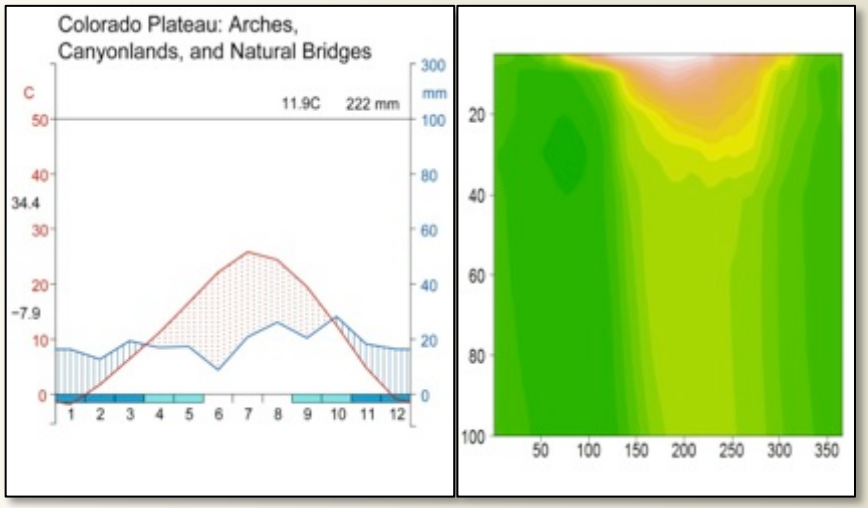
Monthly temperature range (BIO2)	**-**	**30.79**
Mean number of dry days	**-**	**22.62**
Month of maximum dry spell	+	19.30
Number of wet spells	+	16.59
Proportion transpiration from lower layers in summer	+	6.18
Month of maximum wet spell	+	2.19
Proportion of wet days that occur in winter	+	1.30
Mean temperature of the wettest quarter (BIO8)	+	1.05
Climate total		**32%**
Soil water total		**68%**

Colorado Plateau: C_3 grasses

Arches, Canyonlands,

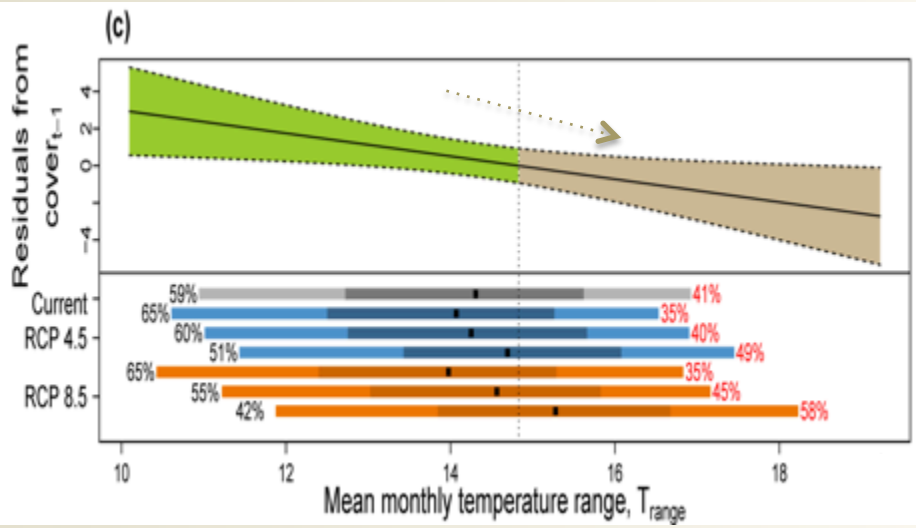
& Natural Bridges

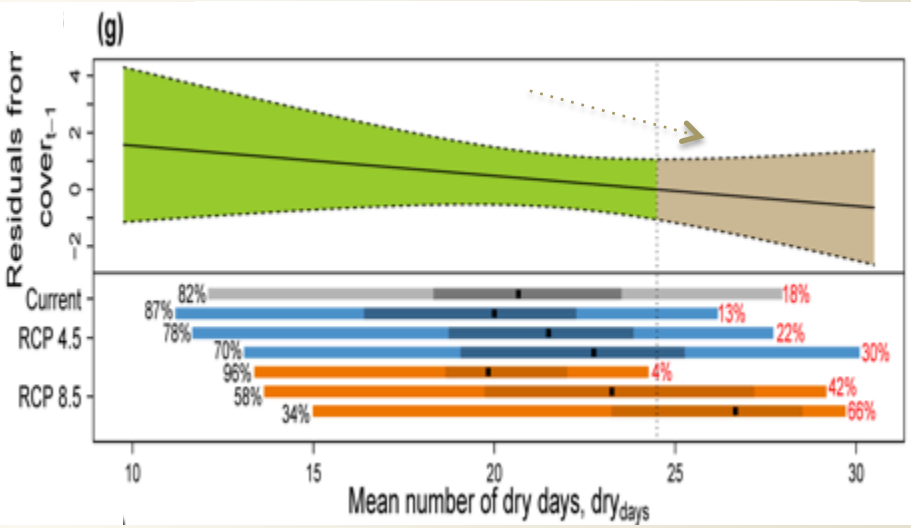
- Data from 1989-2009



Monthly temperature range

Dry Days

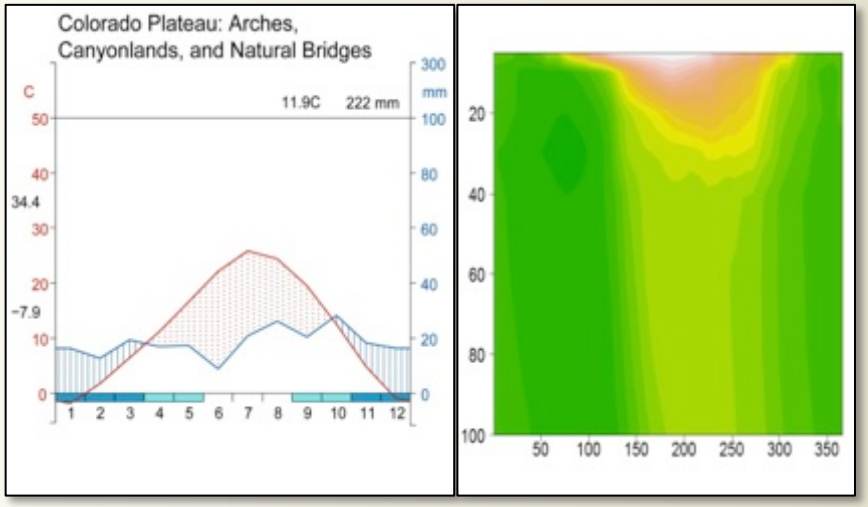




Colorado Plateau: C_4 grasses

Arches, Canyonlands,
& Natural Bridges

- Data from 1989-2009



C4 grasses:

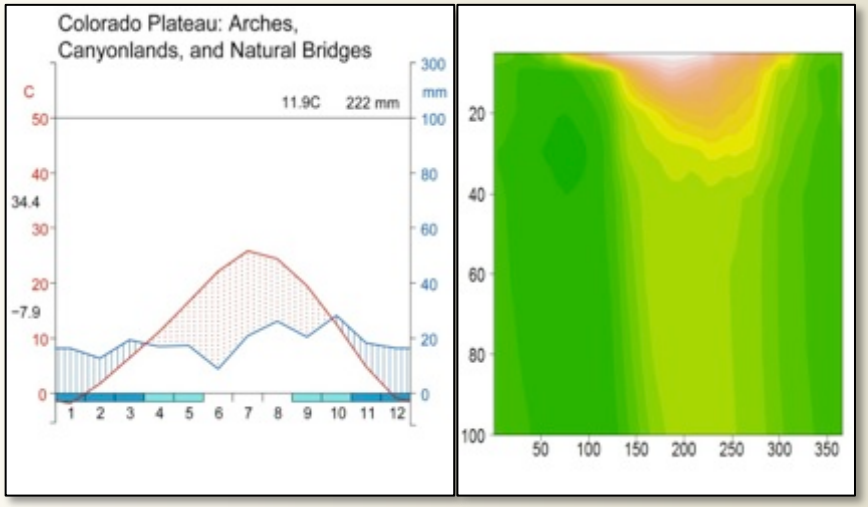
Variable	Direction	Independent percentage
Precipitation seasonality (BIO15)	**-**	**53.83**
Mean annual precipitation (BIO12)	+	24.13
Monthly temperature range (BIO2)	-	14.28
Month of maximum wet spell	-	3.21
Month of maximum dry spell	+	2.70
Temperature seasonality (BIO4)	-	1.85
Climate total		**94%**
Soil water total		**6%**

Colorado Plateau: C_4 grasses

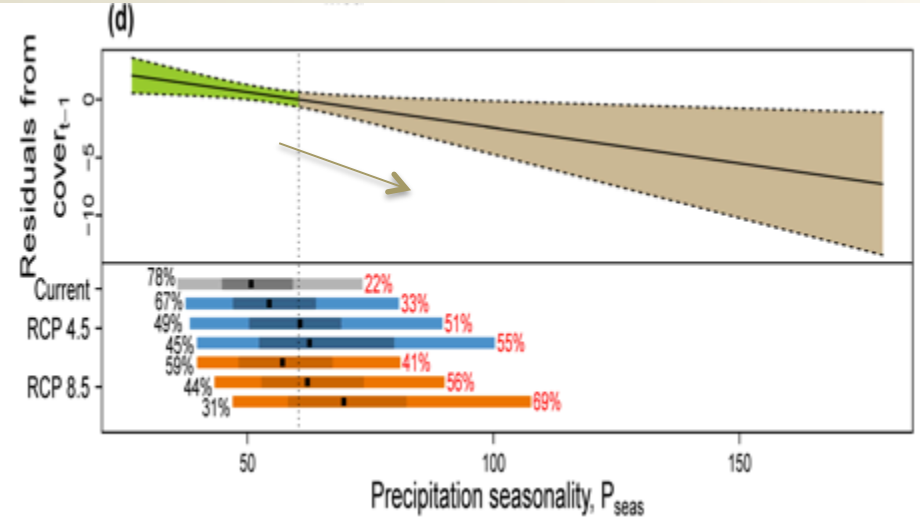
Arches, Canyonlands,

& Natural Bridges

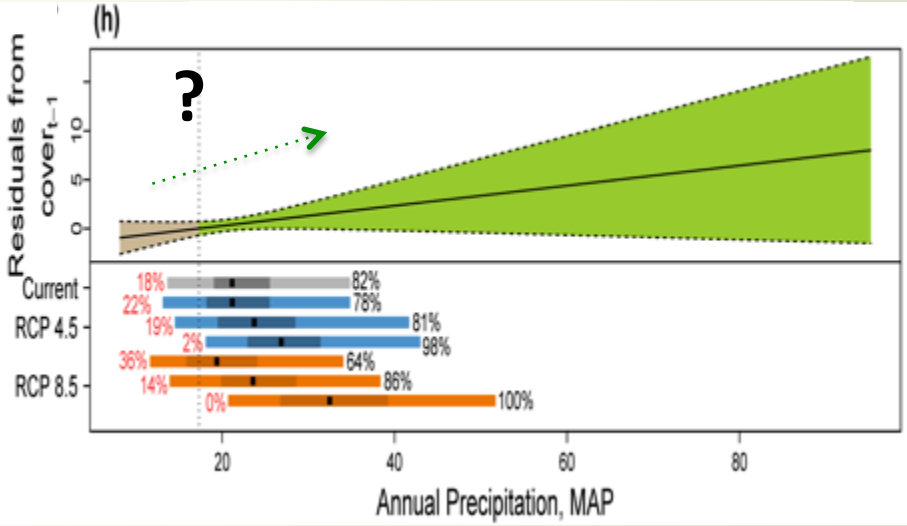
- Data from 1989-2009



Precipitation Seasonality



Mean Annual Precipitation



What aspects of climate and soil water explain past grassland dynamics?

- Important climate variables:
  - Extension of wet growing seasons (+)
  - Variability in temperature and precipitation (-)

What aspects of climate and soil water explain past grassland dynamics?

- Most important soil water variables:
  - Availability of soil water: # days with dry soil (-)
  - Timing of soil water availability (+/-)
  - Location of water available
    - Surface versus lower layers
    - Differences between sites in direction

Does incorporating soil water dynamics enhance our ability to explain responses?

- Yes, but enhancement varies
  - Differences among sites
    - 30% to 70%
    - May be more important for sites relying on storage
  - Differences among functional types
    - Very important for C_3 grasses

What do forecasts of climate & soil moisture imply about grassland vulnerability to climate change?

- Chihuahuan desert: increasing challenges for perennial grasses (high vulnerability)
- Colorado plateau: conditions trending negative (intermediate vulnerability)
- Sonoran desert: uncertain trends in important climate /soil moisture variables

More information…..

Global Change Biology

Global Change Biology (2015) **21**, 4049–4062, doi: 10.1111/gcb.13043

Desert grassland responses to climate and soil moisture suggest divergent vulnerabilities across the southwestern United States

JENNIFER R. GREMER[1], JOHN B. BRADFORD[1], SETH M. MUNSON[1] and MICHAEL C. DUNIWAY[2]

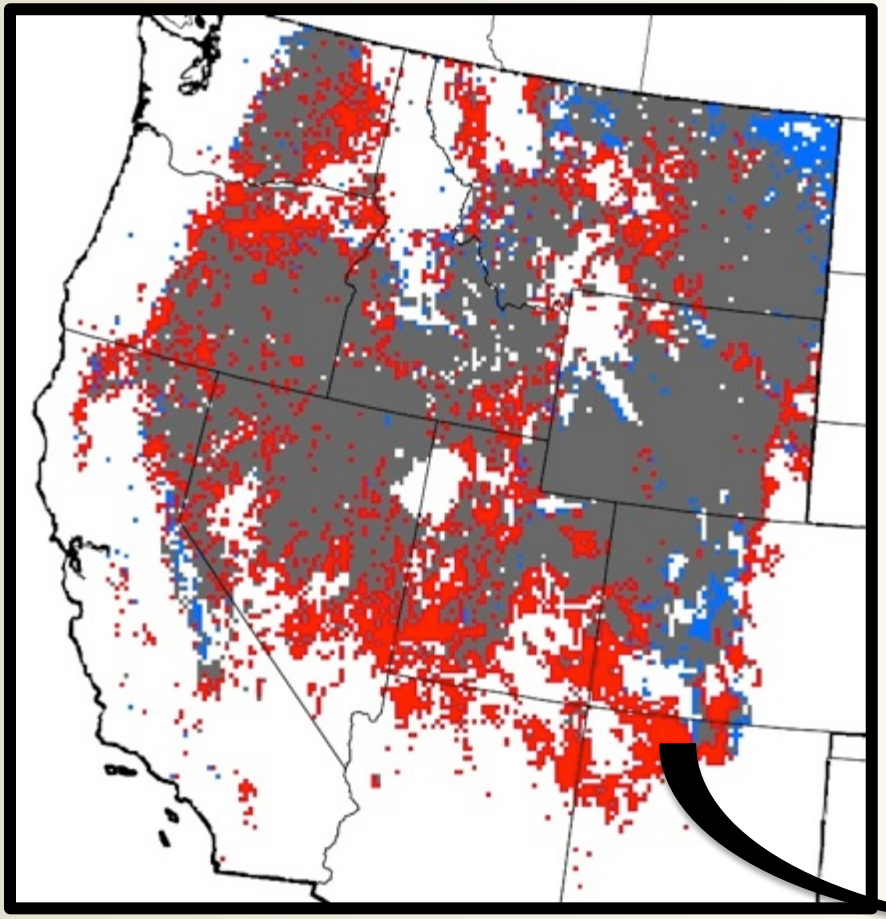
[1]*U.S. Geological Survey, Southwest Biological Science Center, Flagstaff, AZ 86001, USA,* [2]*U.S. Geological Survey, Southwest Biological Science Center, Moab, UT 84532, USA*

…& fact-sheet coming soon.

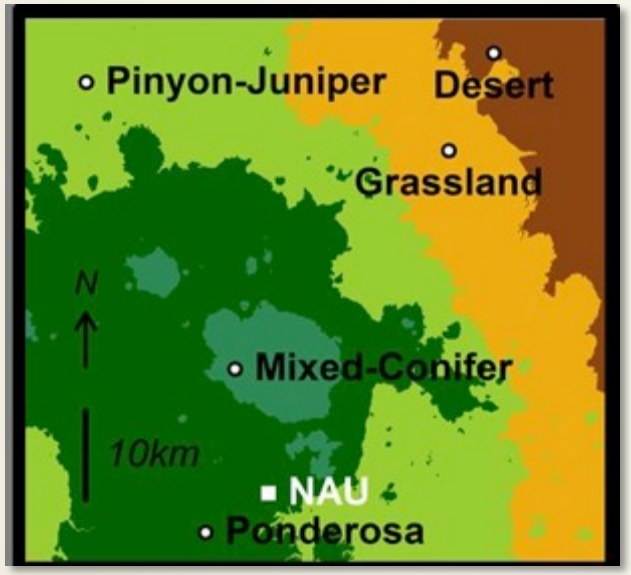
Implications

- Variability is important:
  - Grasslands respond to climate variability & season length
- Soil water dynamics help understand response
  - Soil water explains 30-70% of plant response.
  - Translate climate into conditions plants experience
- Vulnerability to climate change varies among deserts.
  - Highest in Chihuahuan and C_3 grasses on CO Plateau
  - Lowest in Sonoran and C_4 grasses on CO Plateau

Next steps: Other plant functional groups



Next steps: Experimental manipulation

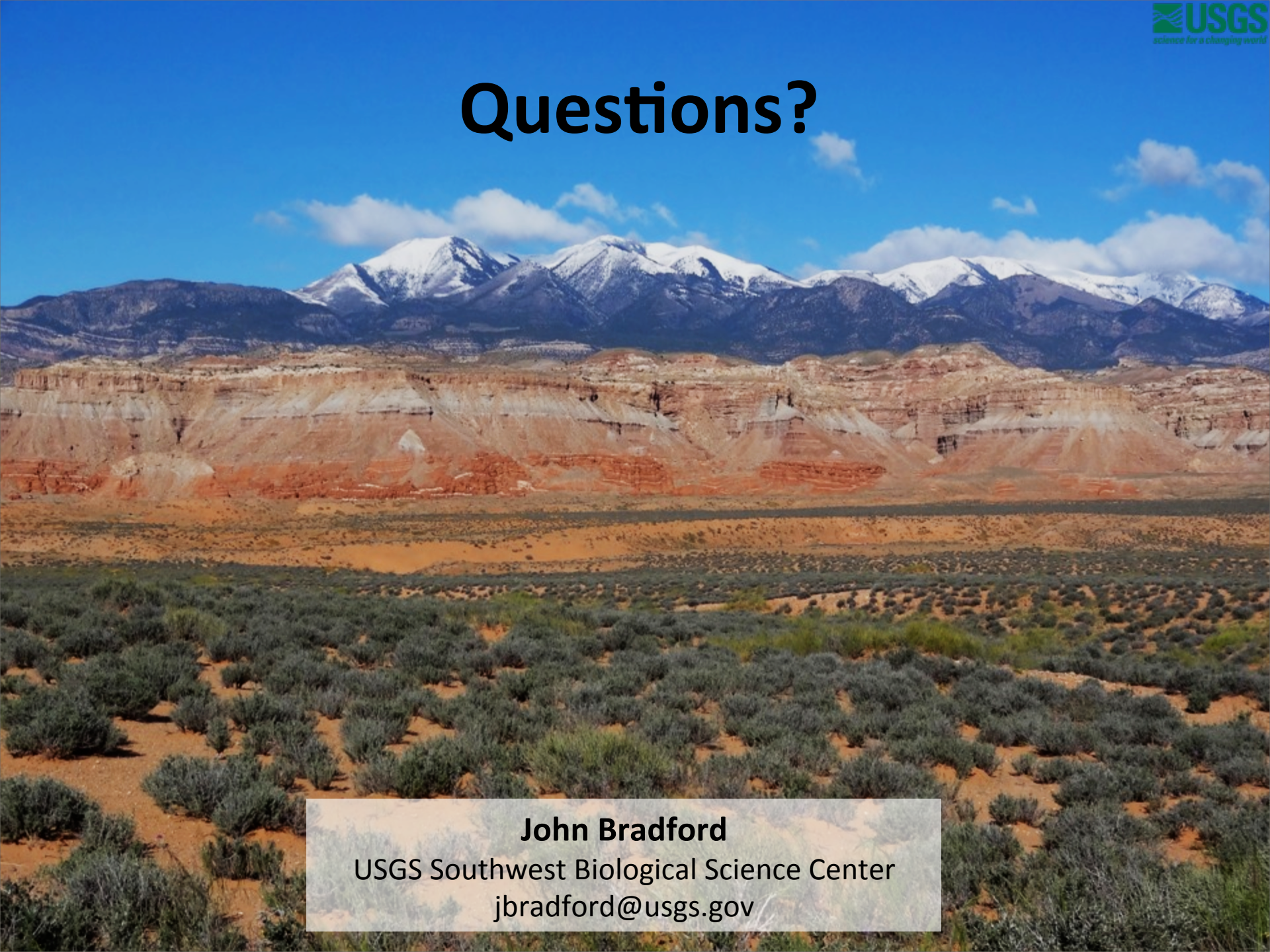


- Detailed examination of ecosystem response to water availability
- Effects of plant species and functional traits

Acknowledgements

- Researchers that collected long term data
  - Jornada LTER (http://jornada.nmsu.edu)
  - Santa Rita Experimental Range (http://ag.arizona.edu/SRER)
  - National Park Service
- Funding:
  - Desert and Southern Rockies Landscape Conservation Cooperatives (LCCs)
  - Bureau of Reclamation

Questions?



John Bradford
USGS Southwest Biological Science Center
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Site scale: Long-term vegetation monitoring

Objectives:

Quantify vulnerability of desert grasslands to climate change

Assess benefits of including soil moisture metrics

Jodi Norris
&
Lisa Thomas

Seth Munson
&
Mike Duniway

Jennifer Gremer

Mixed models for perennial grass cover

Site	Marginal R^2	Conditional R^2 (includes random effects)
Santa Rita Experimental Range	0.53	0.53
Jornada LTER	0.70	0.73
Colorado Plateau, C4 grasses	0.39	0.57
Colorado Plateau, C3 grasses	0.71	0.75

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[1]U.S. Geological Survey, Southwest Biological Science Center, Moab, UT 84532, USA, [2]U.S. Geological Survey, Southwest Biological Science Center, Flagstaff, AZ 86001, USA,

Abstract

Climate change predictions include warming and drying trends, which are expected to be particularly pronounced in the southwestern United States. In this region, grassland dynamics are tightly linked to available moisture, yet it has proven difficult to resolve what aspects of climate drive vegetation change. In part, this is because it is unclear how heterogeneity in soils affects plant responses to climate. Here, we combine climate and soil properties with a mechanistic soil water model to explain temporal fluctuations in perennial grass cover, quantity where and the degree to which incorporating soil water dynamics enhances our ability to understand temporal patterns, and explore the potential consequences of climate change by assessing future trajectories of important climate and soil water variables. Our analyses focused on long-term (20–56 years) perennial grass dynamics across the Colorado Plateau, Sonoran, and Chihuahuan Desert regions. Our results suggest that climate variability has negative effects on grass cover, and that precipitation subsidies that extend growing seasons are beneficial. Soil water metrics, including the number of dry days and availability of water from deeper (>30 cm) soil layers, explained additional grass cover variability. While individual climate variables were ranked as more important in explaining grass cover, collectively soil water accounted for 40–60% of the total explained variance. Soil water conditions were more useful for understanding the responses of C_3 than C_4 grass species. Projections of water balance variables under climate change indicate that condi- tions that currently support perennial grasses will be less common in the future, and these altered conditions will be more pronounced in the Chihuahuan Desert and Colorado Plateau. We conclude that incorporating multiple aspects of climate and accounting for soil variability can improve our ability to understand patterns, identify areas of vulnerability, and predict the future of desert grasslands.

Keywords: arid and semiarid, Chihuahuan Desert, climate change, climate variability, Colorado Plateau, drought, soil water dynamics, Sonoran Desert

Received 12 February 2015; revised version received 18 May 2015 and accepted 27 May 2015

Introduction

Climate in the arid and semiarid regions of the southwestern United States is characterized by high temperatures, combined with low and variable precipitation (Noy-Meir, 1973; Davidowitz, 2002). The southwestern United States has already experienced significant warming and drying, and has been identified as a hotspot for increasing aridity as well as increasing variability in temperature and precipitation (Seager *et al.*, 2007; Archer & Predick, 2008; Diffenbaugh *et al.*, 2008). These changes have the potential to push southwestern ecosystems beyond tolerance thresholds, resulting in species loss, declining ecosystem services, and habitat alteration and degradation. Anticipating such consequences requires understanding what aspects of climate drive temporal patterns of vegetation change and how these changes will be manifested on the landscape. This challenge is especially pronounced in ecosystems that are particularly vulnerable to climate change such as desert grasslands. Grasslands are regionally important sources of biodiversity, net primary production, livestock forage, and wildlife habitat (Bähre, 1995; McClaran, 1995; Sala & Paruelo, 1997). Losses of perennial grasses in dryland regions can contribute to desertification of soils, which in turn results in reduction of nutrient availability and water-holding capacity, and increases soil erosion and dust storm activity (Schwinning *et al.*, 2008; Munson *et al.*, 2011b; Belnap *et al.*, 2014). Therefore, loss of grass cover can trigger ecological state transitions and further vegetation losses in desert regions, which can feedback into further loss of ecosystem function. In addition, grasslands may be particularly at risk to climate change because they contain

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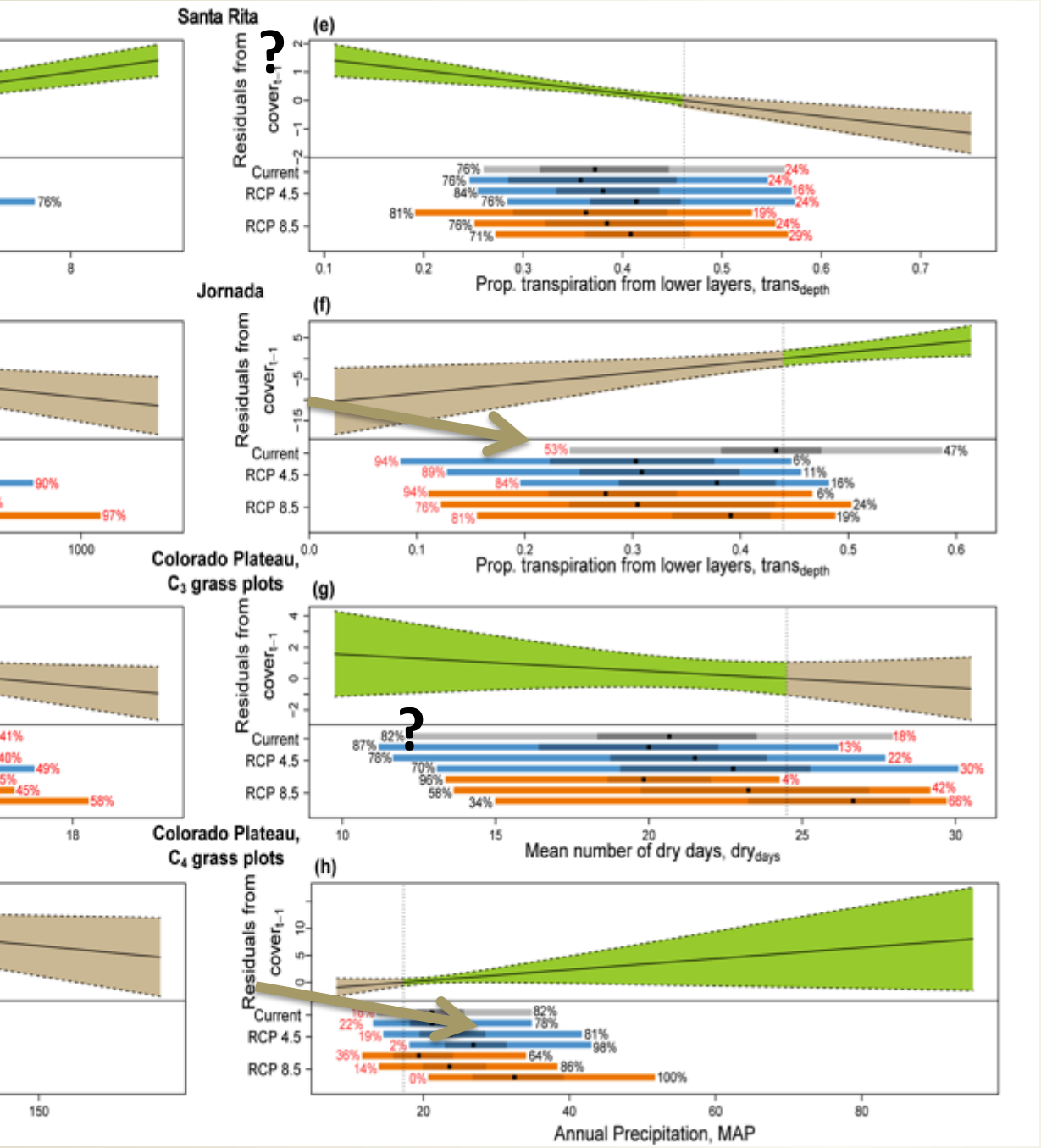

Santa Rita
(e)
Residuals from cover$_{t-1}$
Current
RCP 4.5
RCP 8.5
Prop. transpiration from lower layers, trans$_{depth}$
Jornada
(f)
Prop. transpiration from lower layers, trans$_{depth}$
Colorado Plateau, C$_3$ grass plots
(g)
Mean number of dry days, dry$_{days}$
Colorado Plateau, C$_4$ grass plots
(h)
Annual Precipitation, MAP

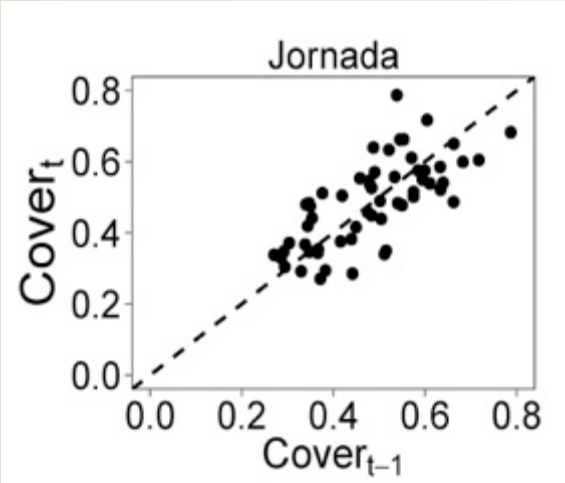
?

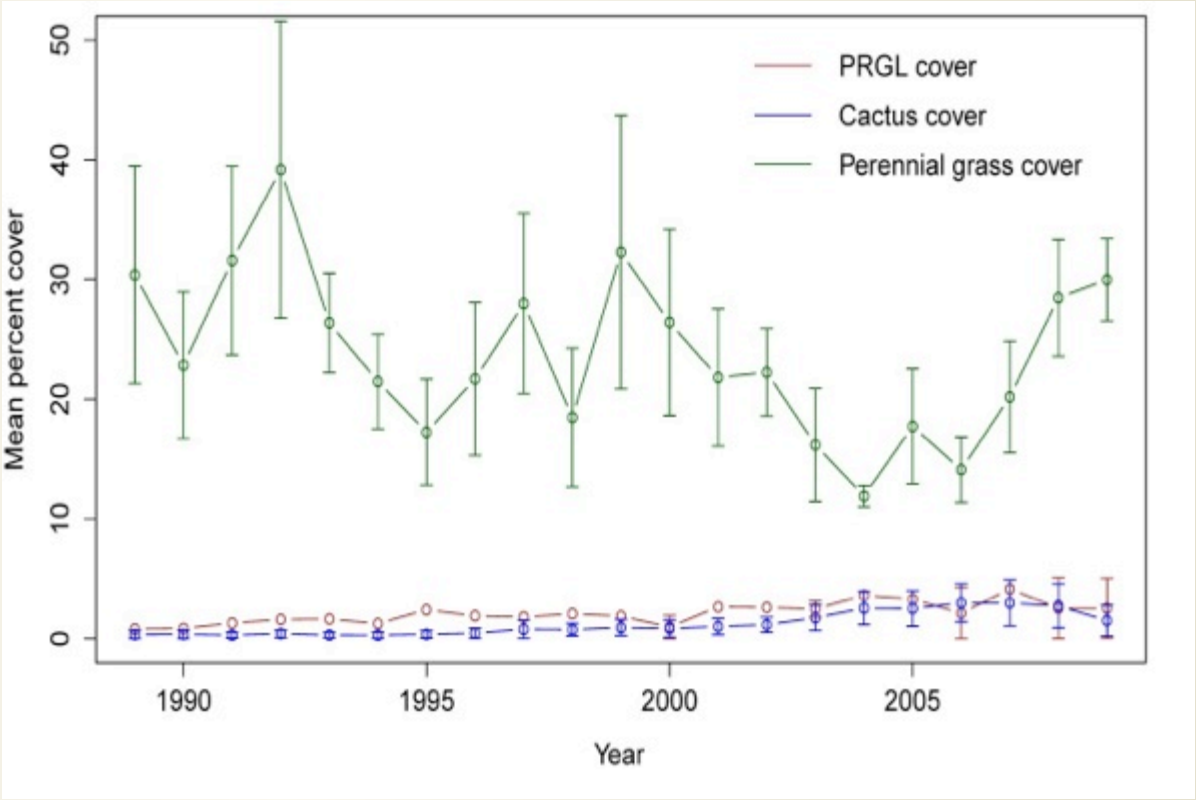
?

Chihuahuan Desert

Jornada Basin LTER

- Data from 1989-2009
- C4 grasses



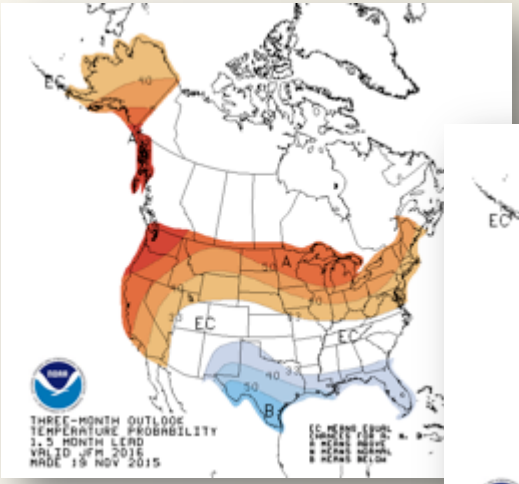


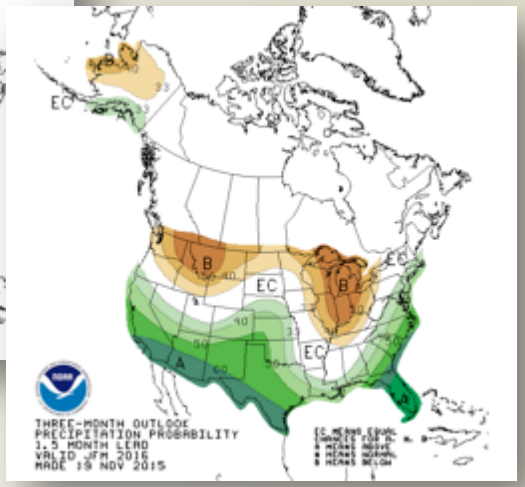
Short-term: months to seasons

Management Need

Enhancing outcomes over months to seasons

Climate knowledge





- El Niño-Southern Oscillation (ENSO)
- Madden-Julian Oscillation (MJO)
- Arctic Oscillation (AO)
- Pacific-North American teleconnection pattern (PNA)

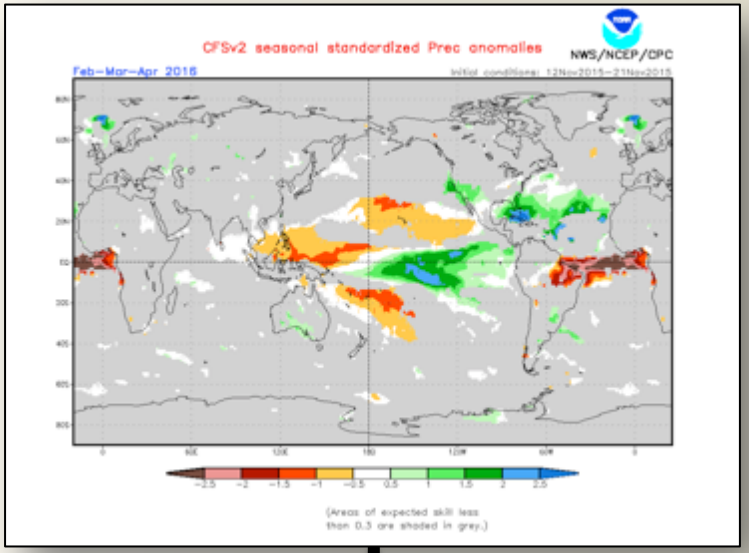
Demonstration Project:

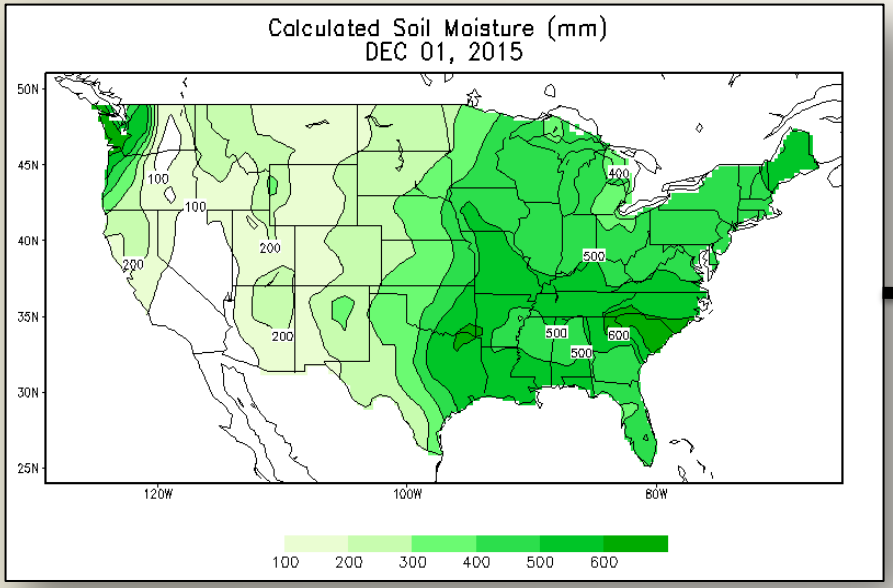
Restoration decision support tool to avoid drought failure

Uses short-term forecasts from:

National Weather Service
Climate Prediction Center

http://www.cpc.ncep.noaa.gov/products/CFSv2/CFSv2seasonal.shtml).





http://www.cpc.ncep.noaa.gov/products/Soilmst_Monitoring/US/Soilmst/Soilmst.shtml

Species: big sagebrush (Artemisia tridentata) **Ecoregion:** Northern Basin and Range

Forecasted Precipitation Anomaly for 3 months post-seeding (mm)

Soil Moisture at seeding (mm)

	-200	-180	-160	-140	-120	-100	-80	-60	-40	-20	0	20	40	60	80	100	120	140	160	180	200
20	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.9
40	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9
60	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9
80	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9
100	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9
120	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9
140	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9
160	0.1	0.1	0.2	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9
180	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9
200	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9
220	0.1	0.2	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9
240	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9
260	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9
280	0.2	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9
300	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9
320	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9
340	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9
360	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9
380	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9
400	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
420	0.3	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
440	0.3	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
460	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
480	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
500	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
520	0.4	0.4	0.5	0.6	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
540	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
560	0.4	0.5	0.5	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
580	0.4	0.5	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
600	0.5	0.5	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
620	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
640	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
660	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
680	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
700	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
720	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
740	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
760	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
780	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
800	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
820	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
840	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
860	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
880	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
900	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
920	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
940	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
960	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
980	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
1000	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9

Probability of seeds having adequate water for successful establishment

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