Impacts of climate patterns on the vegetation dynamics of grasslands in the southwestern United States

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Southeastern Arizona: A century of vegetation change

- Significant increase in woody plants has occurred in southern Arizona over the last 100 years.

- Possible contributions to this change:
  - Introduction of livestock grazing around 1900
  - Fire suppression began around 1900
  - Climate variability throughout the century (namely severe droughts)

Repeat Photos: documentation of change

Southeastern Arizona: The issue of changing climate

- Interactions of climate, grazing, and fire have been disputed over the last 30 years as the cause of vegetation changes since 1900.

- Past climate may not have been the sole factor for vegetation change, but future climates may have a greater impact.
  - Rising temperatures and rising CO_2 are likely to alter global circulation patterns, impacting global and regional precipitation regimes.

Basic Questions

- How will different rates and magnitudes of change for temperature, CO_2, precipitation patterns, and cycles of wet and dry periods affect grasslands in the southwest?
- How will different intensities and frequencies of grazing and fire disturbances affect grasslands?
- What are the isolated and combined effects of each of these disturbances?
- What are the most vulnerable plant types to these changes?
- How will these changes alter human-ecosystem interactions?

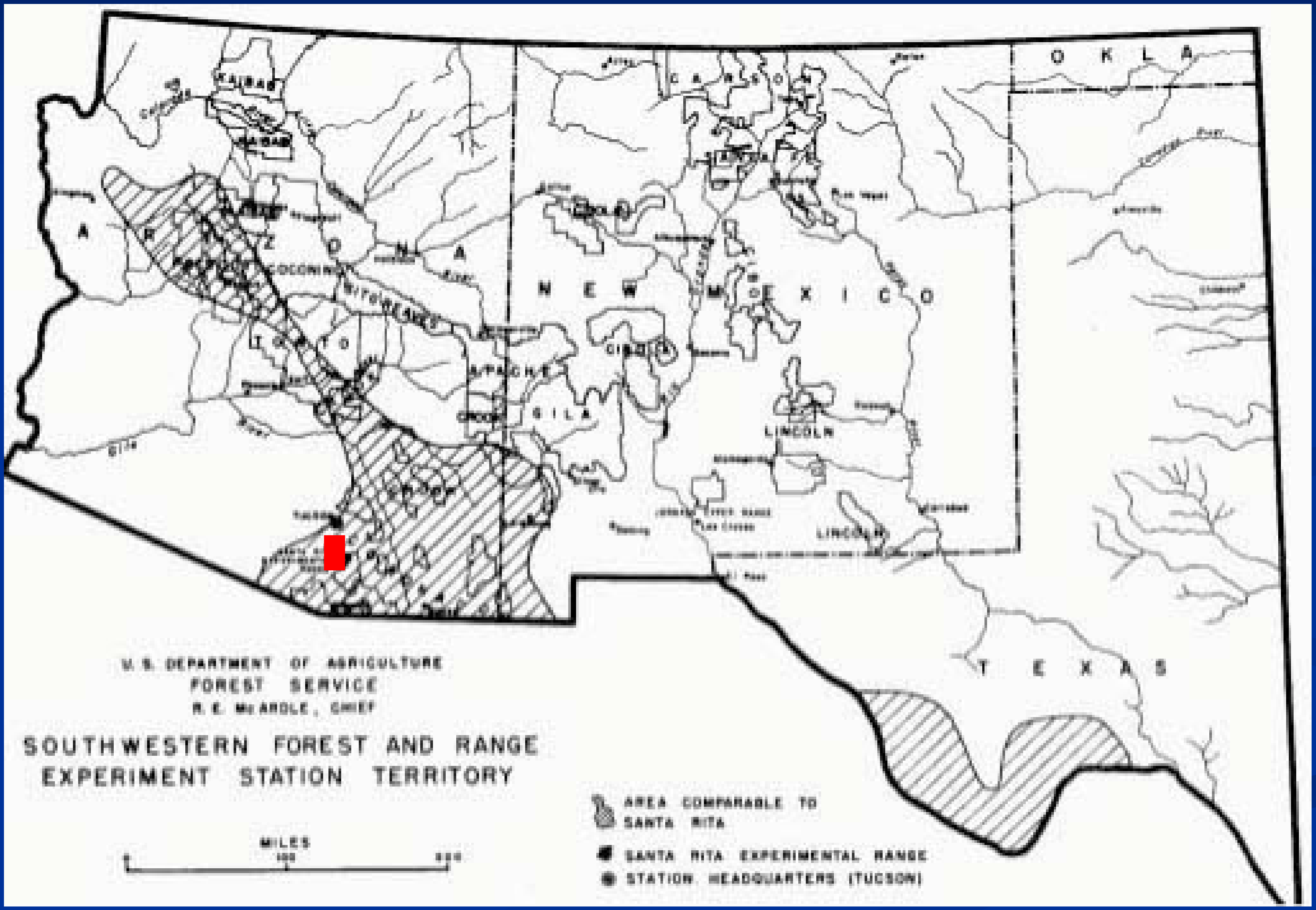
Methods – and Goals

- Ecosystem Models remain a cost- and time- efficient way to test wide-scale changes in climate and land-use practices, and one of few ways to make forecasts about future conditions.
- **Parameterize** a rangeland ecosystem model to accurately simulate vegetation-hydrology processes in a semi-arid environment (across several soil profiles).
- **Validate** the model for inter-annual and long-term behavior (over 30 years) using data collected at an experimental range site in southeastern Arizona.
- **Simulate** potential future conditions of southwestern grasslands based on various proposed climate changes.

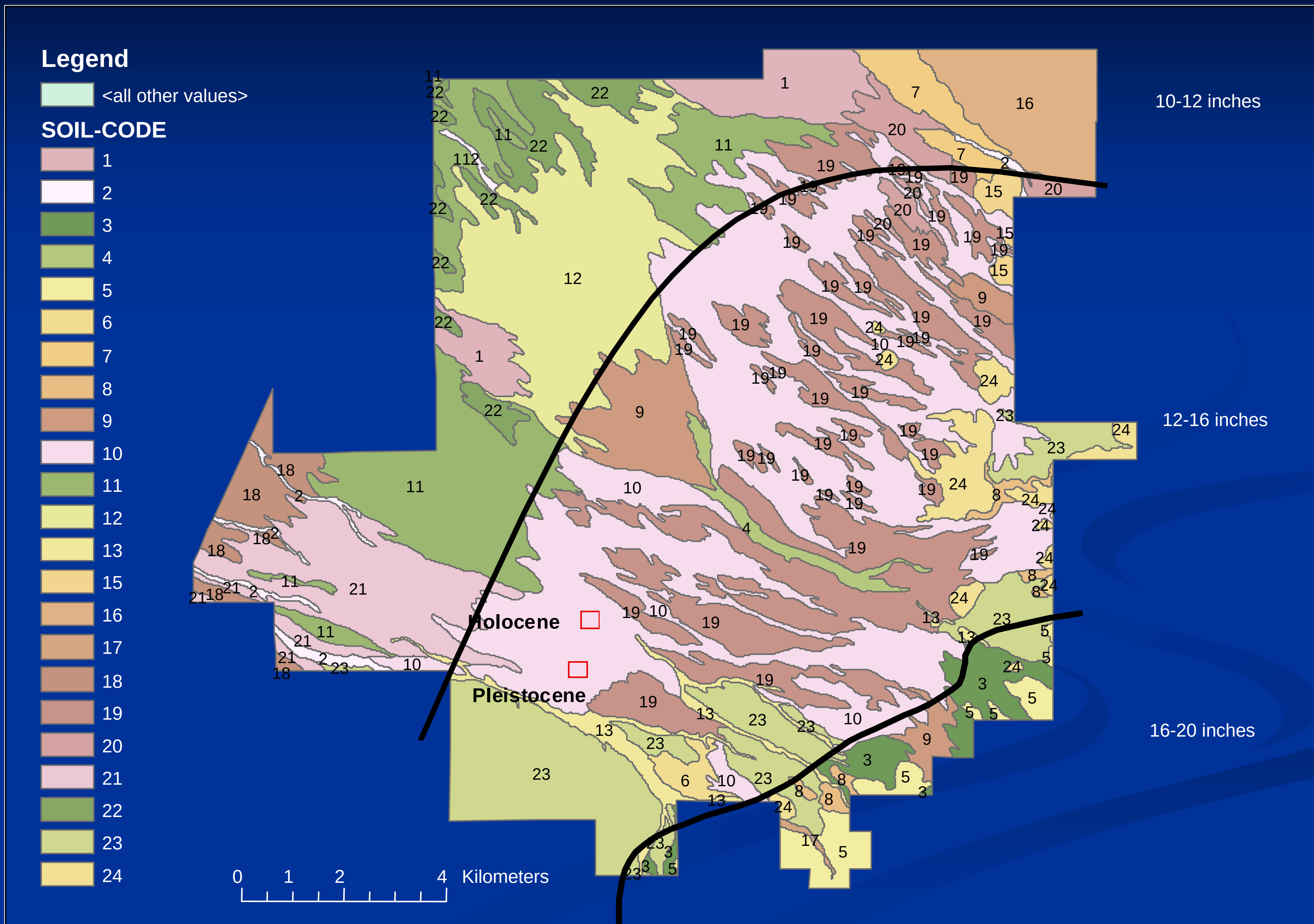
Desert Grasslands

- Experiences the hottest, driest, and sunniest climate of all North American grasslands
- One of lowest levels of primary production and rates of solar energy conversion
- Amount and timing of plant growth are mainly controlled by rainfall, plant physiology, and soil characteristics.

Santa Rita Experimental Range



Santa Rita Experimental Range



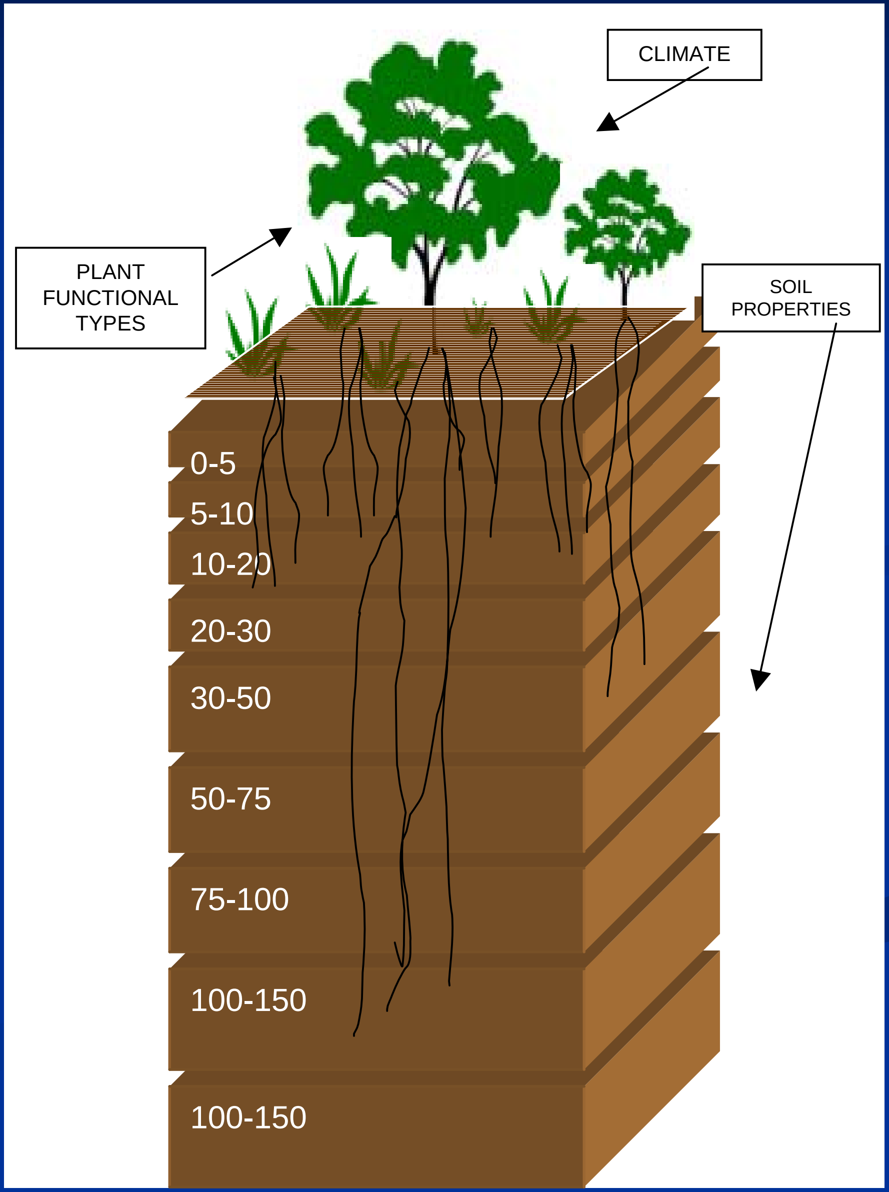
Sandy-Loam Soil

Clay-Loam Soil

Scientific Name	Common Name	Functional Type
Aristida spp.	threeawns	native warm season perennial bunchgrass
Erogrostis lehmannia	lehmann lovegrass	invasive warm season perennial bunchgrass
Prosopis velutina	velvet mesquite	deciduous, thorny shrub or small tree
Haplopappus tenuisectus	burroweed	compact, rounded subshrub

Ecosystem Models

- Input initial conditions
  - Climate
  - Soil Properties
  - Plant Functional Types
- Model updates processes daily, using climate file to direct changes
- Output
  - daily to annual states of plant and hydrology variables
  - Above and belowground biomass
  - Nutrient levels
  - Soil moisture conditions



Modeling: Assumptions and Generalizations

- Precipitation regime
  - Bimodal precipitation (duration and intensity of storms)
  - Water-limited conditions (soil moisture dynamics, root depths)
- Soil properties
  - Up to 8 soil layers, each one homogenous (porosity, water capacity, etc.)
  - Heterogeneity between layers
- Vegetation characteristics
  - Up to 15 different plants (I have used 3 for now)
  - Plant Functional Types grouped by life-form and photosynthetic pathway
  - Ecosystems may become resilient to some changes, creating a “buffering effect.”

SPUR Input Parameters

Simulation of Production and Utilization of Rangelands

- Initial conditions
  - Climate record
  - Soil properties
  - Plant functional types
  - (Land use)

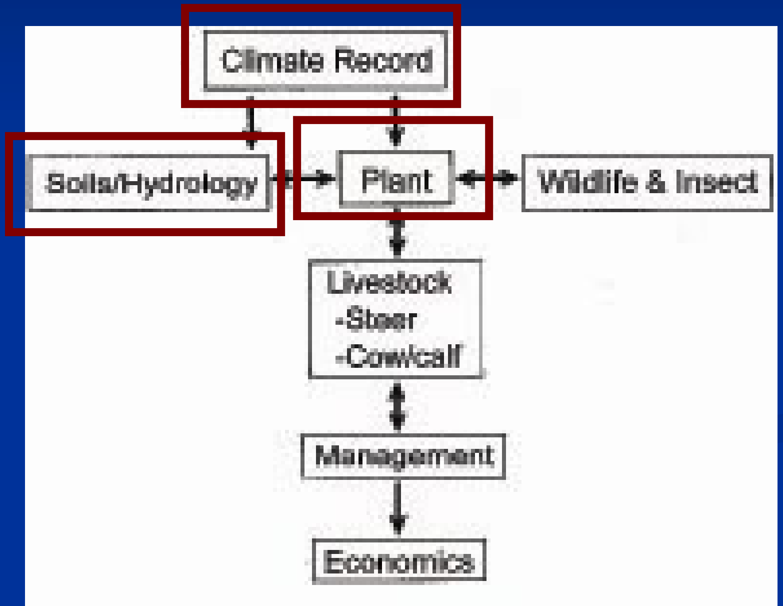


Fig. 1. Linkage of modules within SPUR 2.4.

Step 1: Parameterization

- Choose a site.
- Determine initial values for each model component.
- Test parameterization with various sensitivity tests to check the functionality of the model.

Input – Site Conditions

- Positional information
- Decomposition
- Soil organic matter

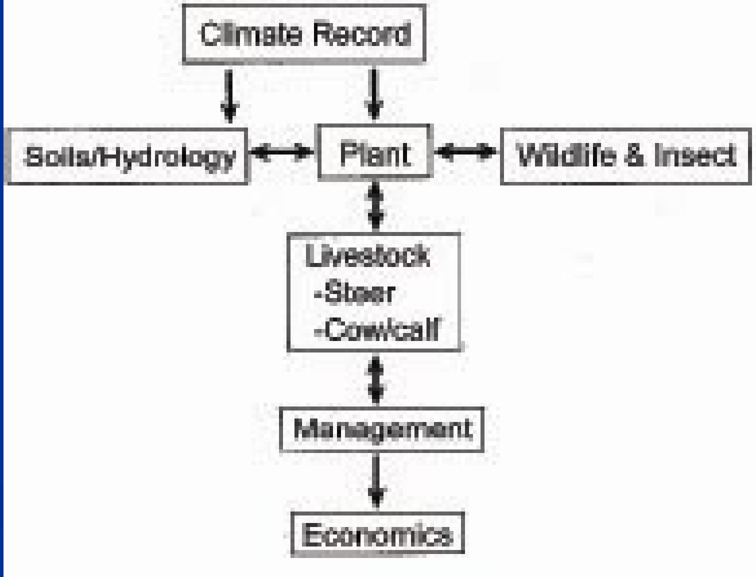


Fig. 1. Linkage of modules within SPUR 2.4.

Input – Soil / Hydrology

- Soil properties by layer
- Hydrology properties by layer
- Initial Nitrogen / Biomass
- Initial plant carbon state
- Initial soil carbon

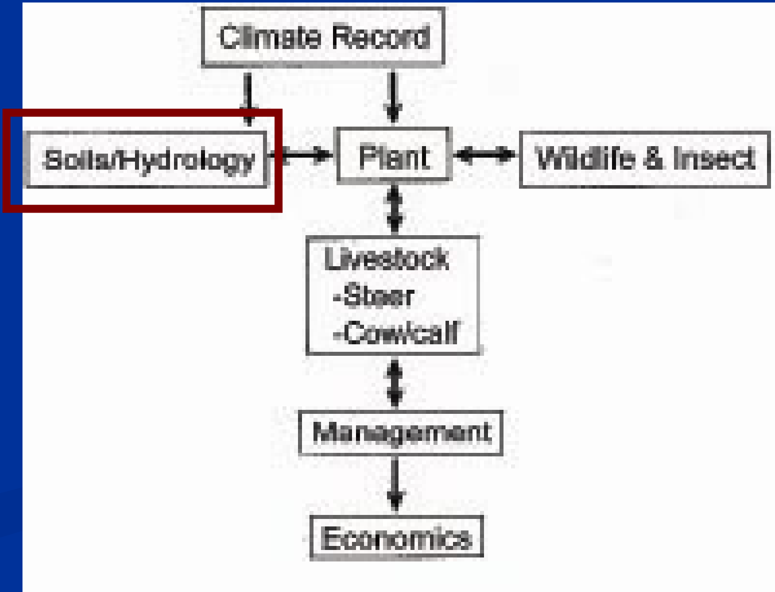


Fig. 1. Linkage of modules within SPUR 2.4.

Input - Plants

- General growth behavior
- Photosynthesis parameters
- Environmental tolerance coefficients
- Translocation
- Nitrogen cycling

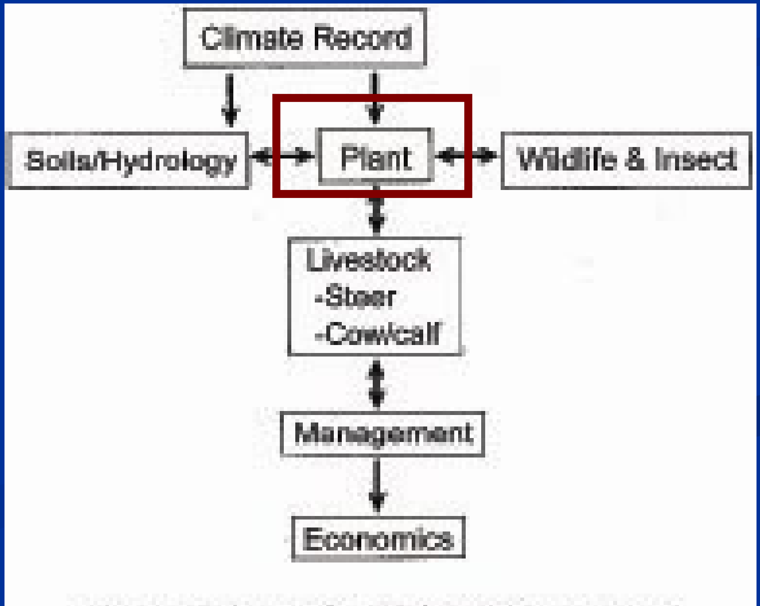


Fig. 1. Linkage of modules within SPUR 2.4.

Input – Climate File

- Precipitation
- Maximum daily temperatures
- Minimum daily temperatures
- Solar radiation
- Wind speed

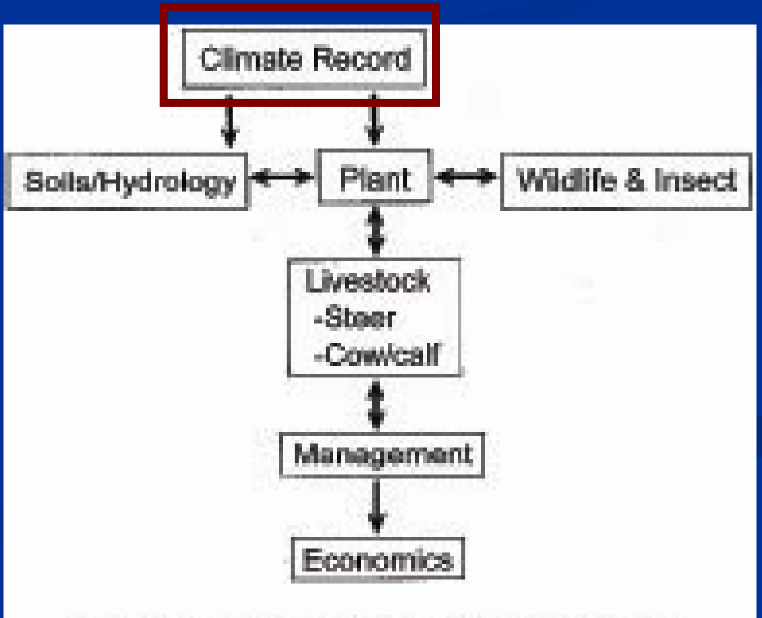


Fig. 1. Linkage of modules within SPUR 2.4.

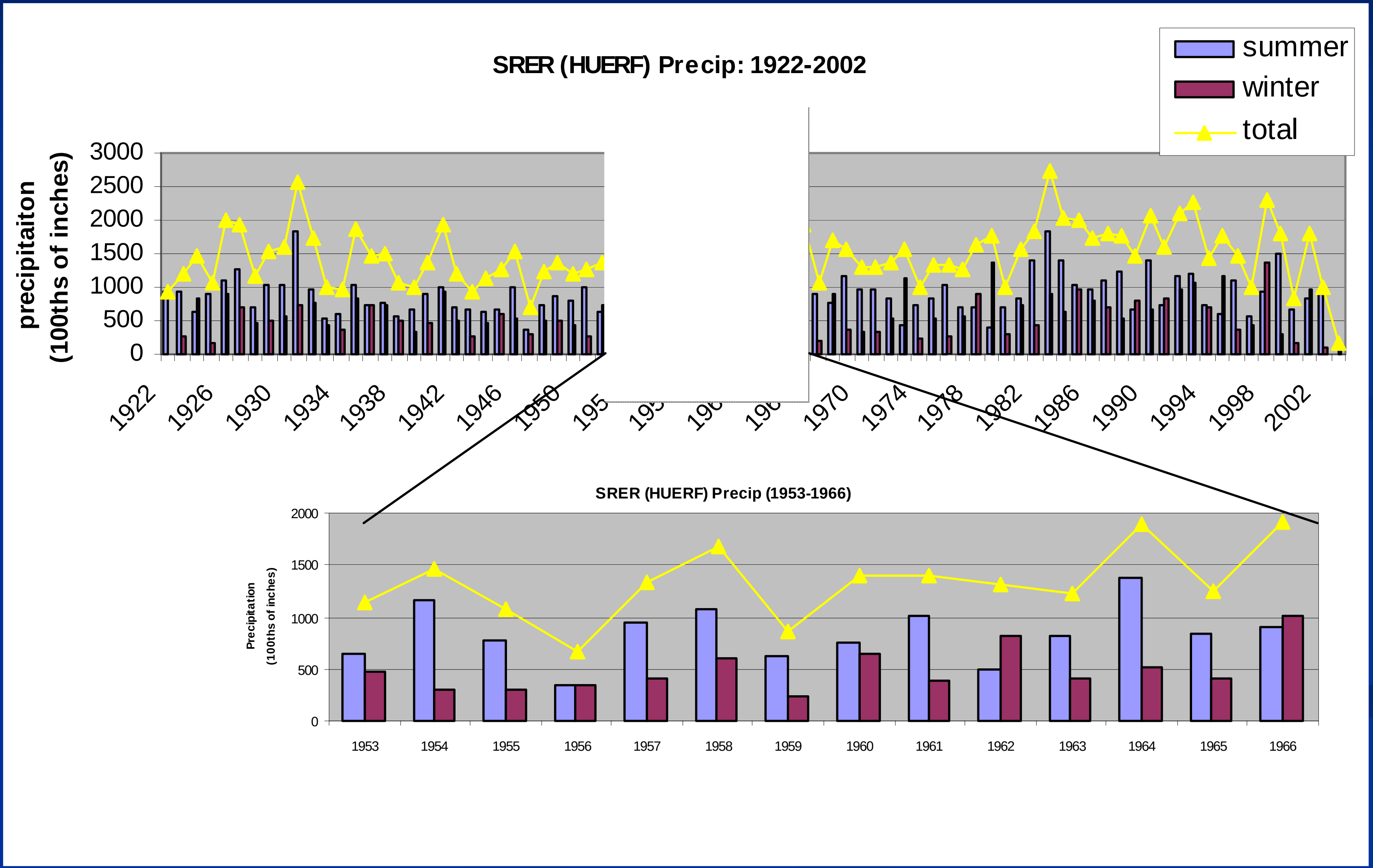
Step 2: Validation

Validation

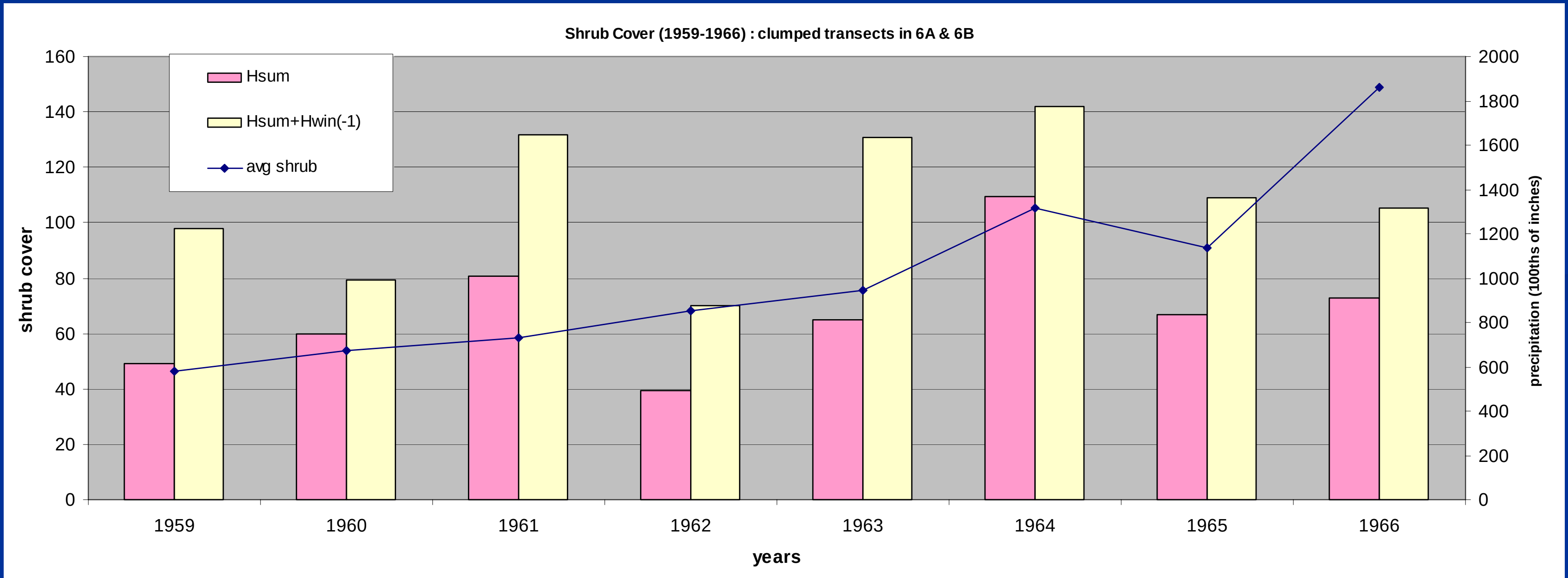
- Use long-term records from SRER (1903) to determine if model is simulating plant growth correctly.

Farmers at Santa Rita Experimental Range

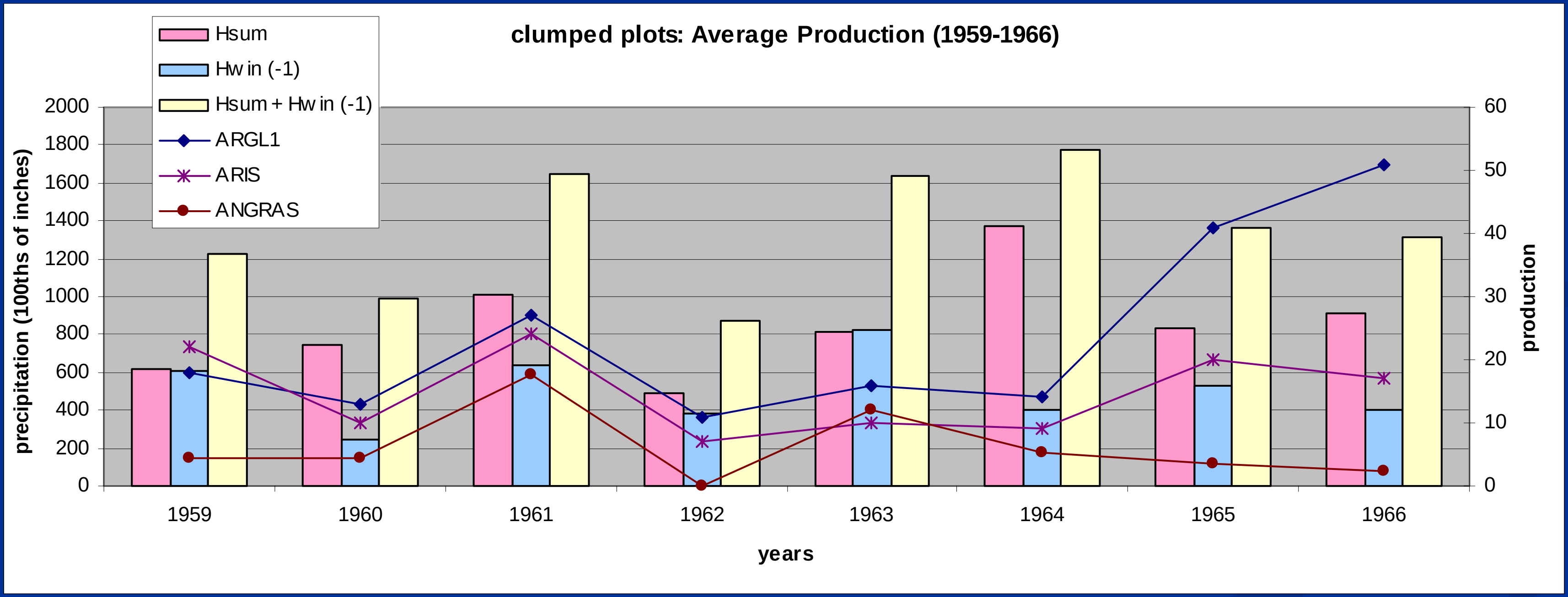
SRER Climate Record (1922-2002)



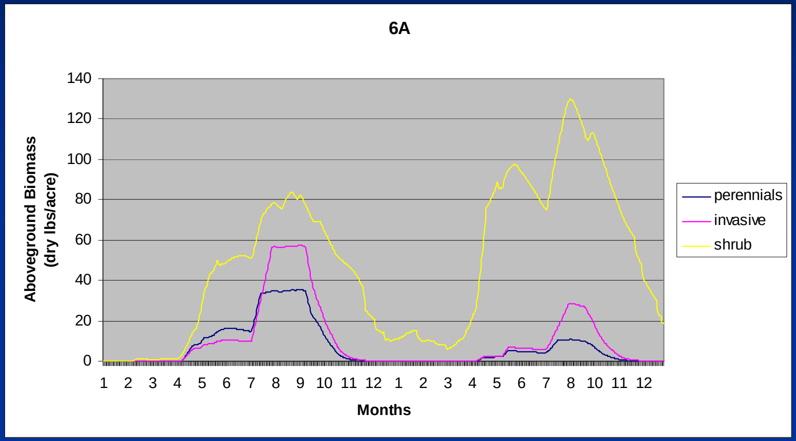
Observational Shrub Cover (1959-1966)

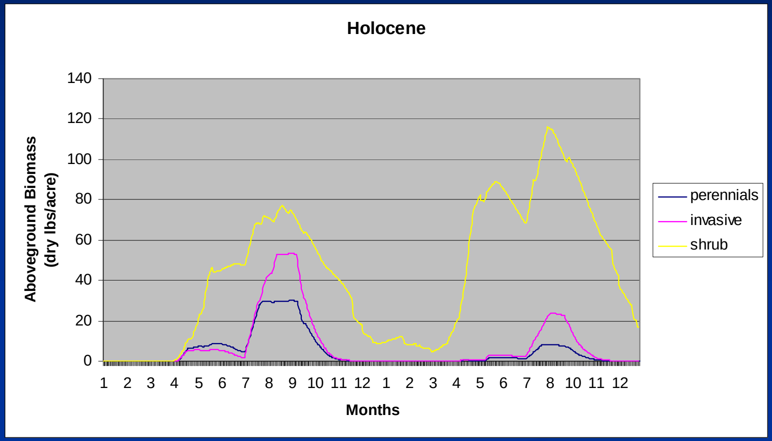


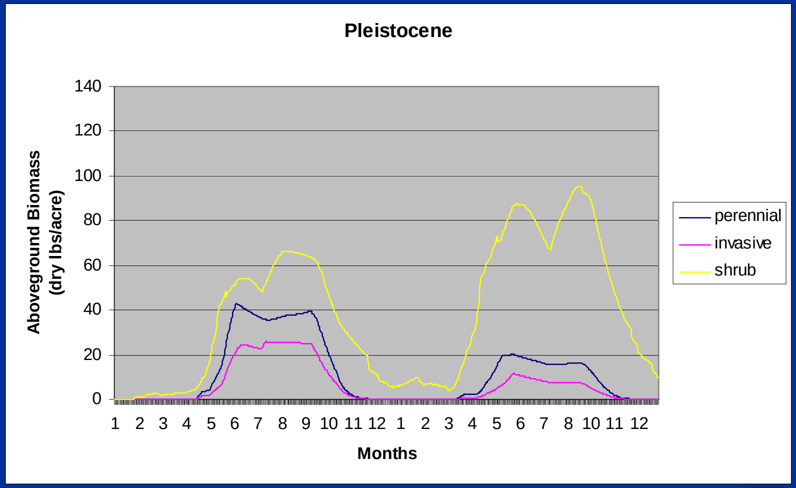
Observational Grass Cover (1959-1966)

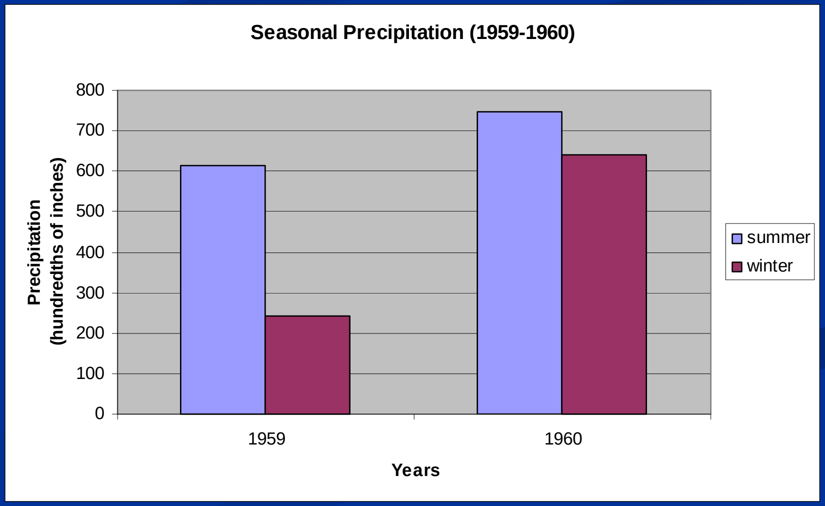


SPUR Simulations (1959-1960)

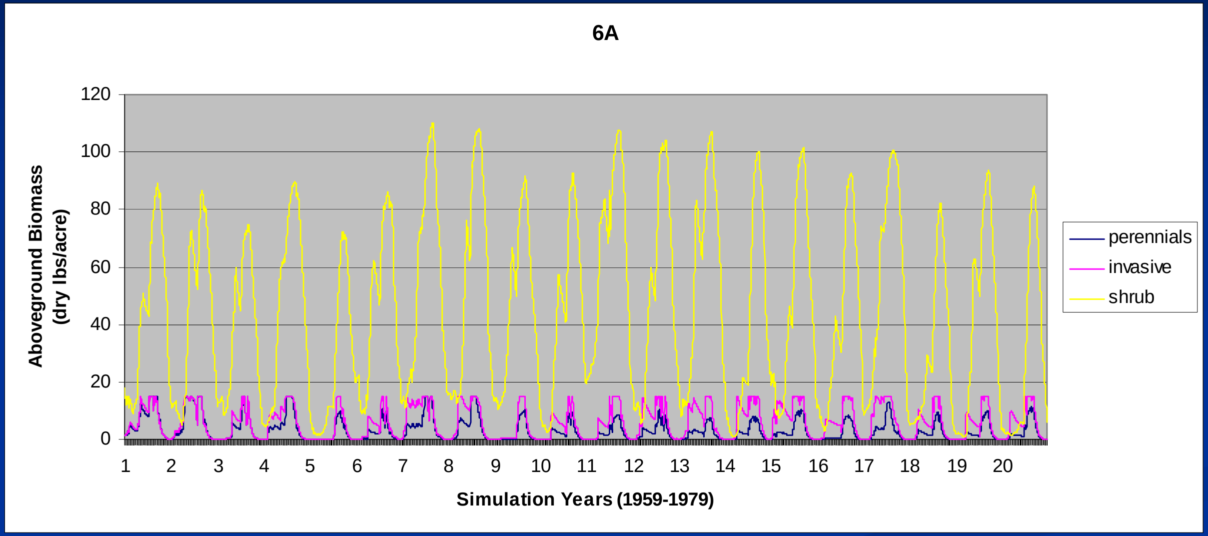


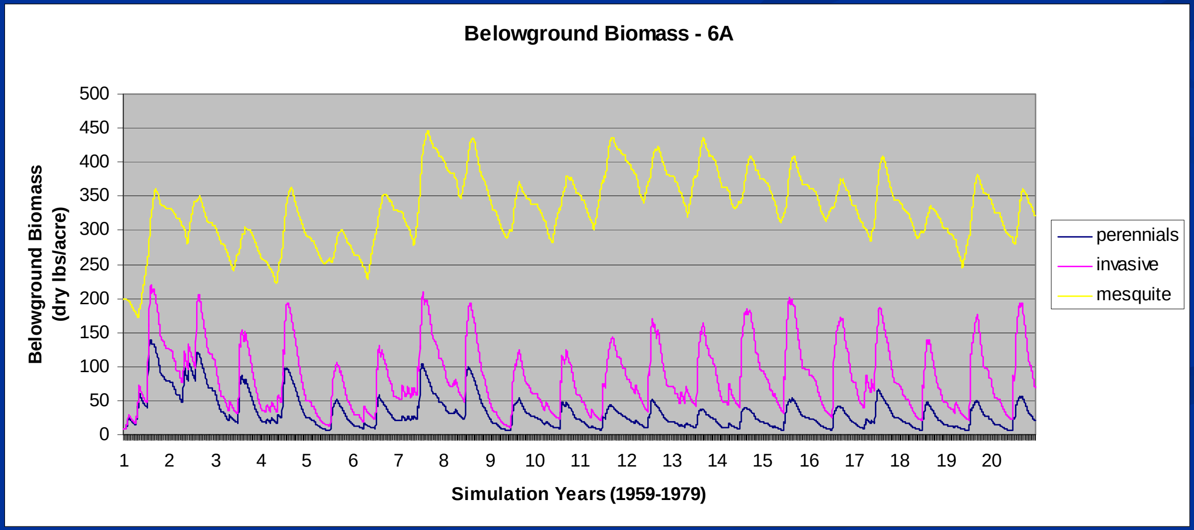






20-Year Simulations





Step 3: Prediction

Prediction

- After model is parameterized, scenarios of potential future climates and management strategies can be simulated.

Climate Scenarios
Magnitudes and Rates of Change

- Temperature
- Carbon Dioxide
- Winter and Summer Precipitation
  - Most variable across regional models
- Duration of Wet and Dry Cycles
  - Most pertinent to wildfire risk in the southwest

Global Climate Model (GCM) Average Predictions:

Temperature °C							
Year	**2030**		**2060**			**2090**	
Model	HC	CC	HC	CC	RM	HC	CC
Winter	2.5	3	2	4	4	4	7
Spring	1.5	2	1.5	3	4	2	6
Summer	1.5	2	2.5	3	5	3	5
Fall	1.5	1.5	3	4	4	3	5

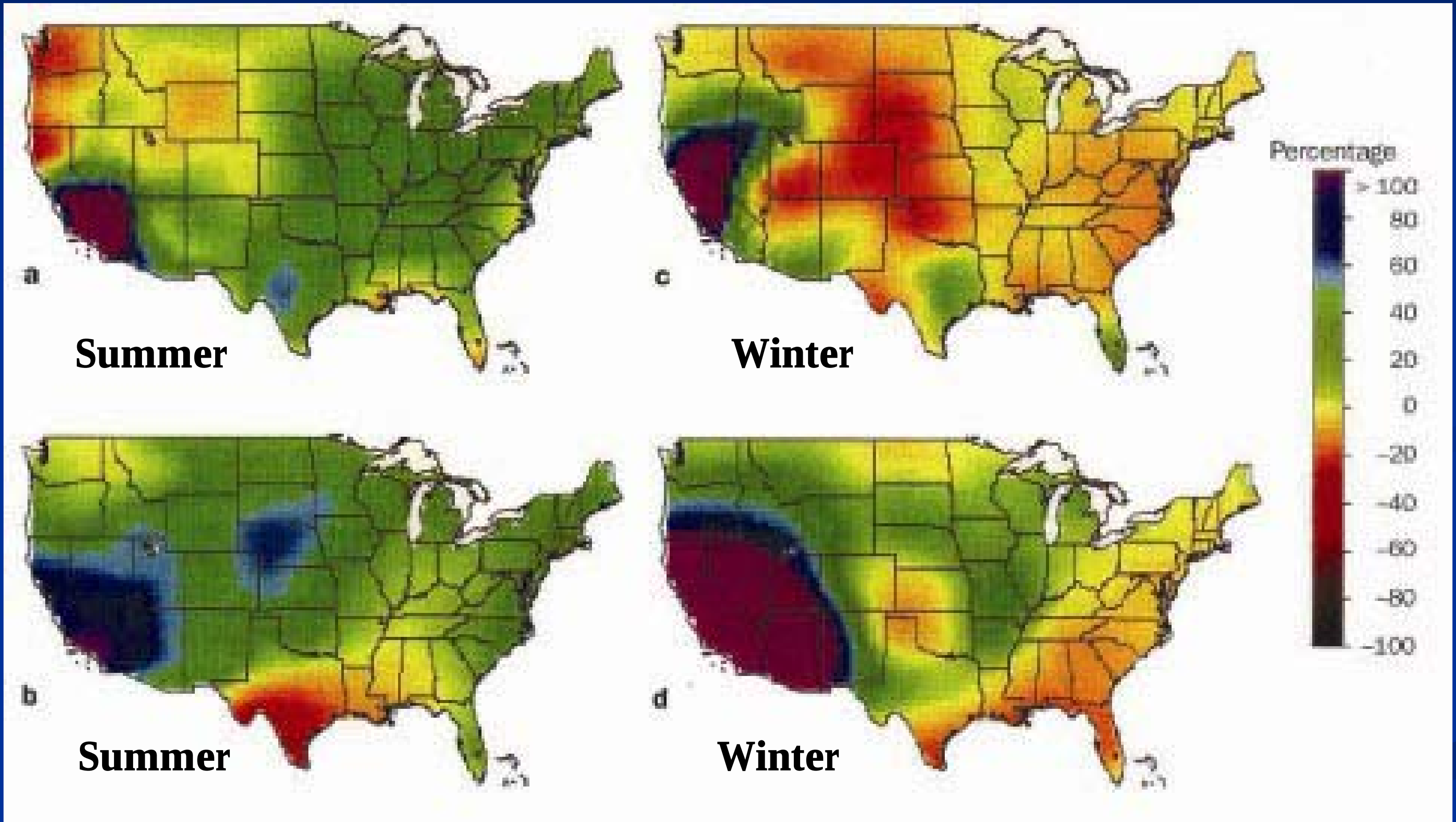
Precipitation (mm/day)							
Year	**2030**		**2060**			**2090**	
Model	HC	CC	HC	CC	RM	HC	CC
Winter	1	1.5	1.5	1.5	-1	5	4.5
Spring	0.5	0.3	0.3	0.5	0.3	2	1
Summer	0.3	0	0	-0.3	-0.3	0	0
Fall	0	0.5	-0.3	1	0	3	1

Doherty and Mearns, 1999; Giorgi et al., 1998

Precipitation Predictions (2090)

Hadley Centre

Canadian Centre



US Global Change Research Program public archives; Weltzin et al., 2003

Climate Scenarios
Magnitudes and Rates of Change

- Temperature
- Carbon Dioxide
- Winter and Summer Precipitation
- Duration of Wet and Dry Cycles

Example Scenarios

Winter Precipitation

Summer Precipitation

	0	+0.5	+1	+3	+5
0					
+0.5					
+1					
+3					
+5					

Winter Precipitation

Summer Precipitation

	0	-0.5	-1	-3	-5
0					
-0.5					
-1					
-3					
-5					

Example Scenarios

Winter Precipitation

Summer Precipitation

	0	+0.5	+1	+3	+5
0					
-0.5					
-1					
-3					
-5					

Winter Precipitation

Summer Precipitation

	0	-0.5	-1	-3	-5
0					
+0.5					
+1					
+3					
+5					

Conclusions

- Model status
  - Still working on parameterizing and validating model
  - Future work will include incorporating the impacts of grazing and fire disturbances
- Model simulations will be pertinent to future management, especially with respect to finding ecosystem thresholds to potential future climate regimes.
- Modeling benefits
  - Generate hypotheses for future studies
  - Complex disturbance interactions
  - Large scales
  - Low cost

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Thanks!