Modeling Approaches for Predicting Climate Change Impacts on Natural Systems; From Inputs to Algorithms to Outputs and What They Can Tell Us

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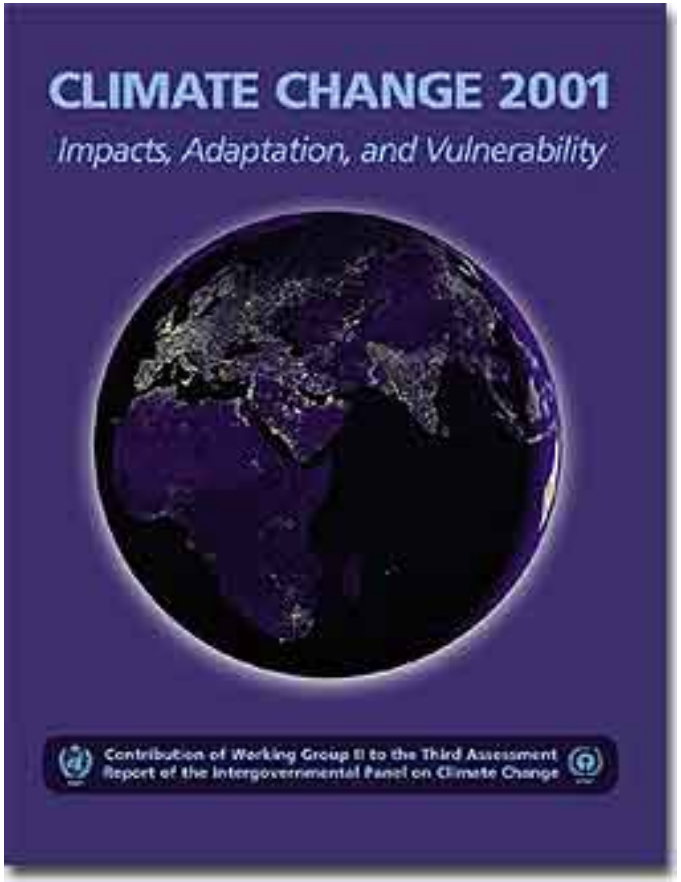
[1] **Merriam-Powell Center for Environmental Research, NAU**

MPCER Research Shown is Supported by the U.S. Department of Energy's Office of Biological and Environmental Research through the Western Regional Center of the National Institute for Climatic Change Research (**http://niccr2.bio.nau.edu/niccr/index.html**)

Overview

- "Diversity is valuable in providing alternative views of the future, although it can hamper attempts to summarize and interpret likely impacts by introducing inconsistencies within or between studies" (http://www.grida.no/climate/ipcc_tar/wg2/151.htm)
- Sources of Variability between studies & Why it creates so much uncertainty



James J. McCarthy, Osvaldo F. Canziani, Neil A. Leary, David J. Dokken and Kasey S. White (Eds.) **Climate Change 2001: Impacts, Adaptation & Vulnerability** Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) Cambridge University Press, UK. pp 1000

Overview

? Questionable Futures ?

OR

Anticipating Effects of Climate Change on Natural Systems

1. Units of Analysis: Species versus Communities
2. Establishing baselines for comparison
3. Variables: Extremes or Means?
4. Projections for Future Climates
5. Modeling Techniques

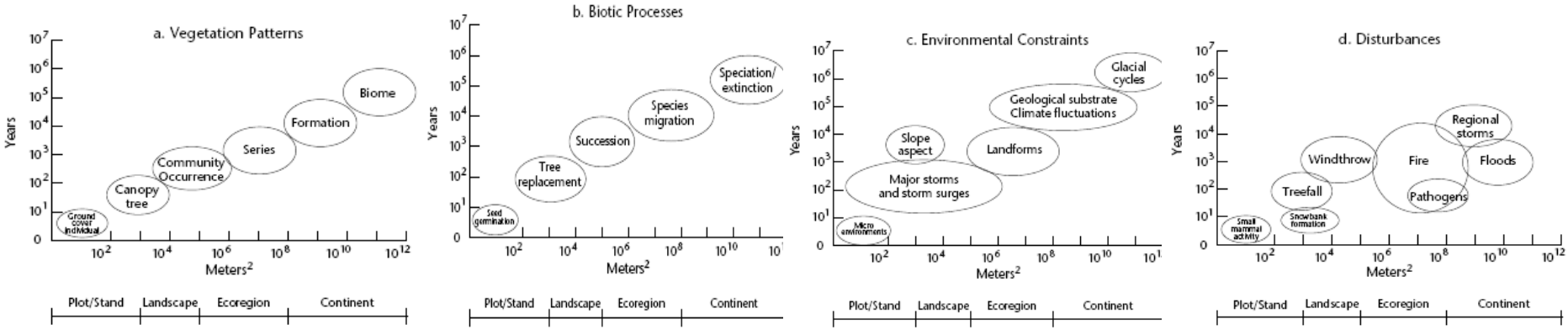
Model Interpretation

1. Spatial Scale
2. Temporal Scale
3. Assumptions

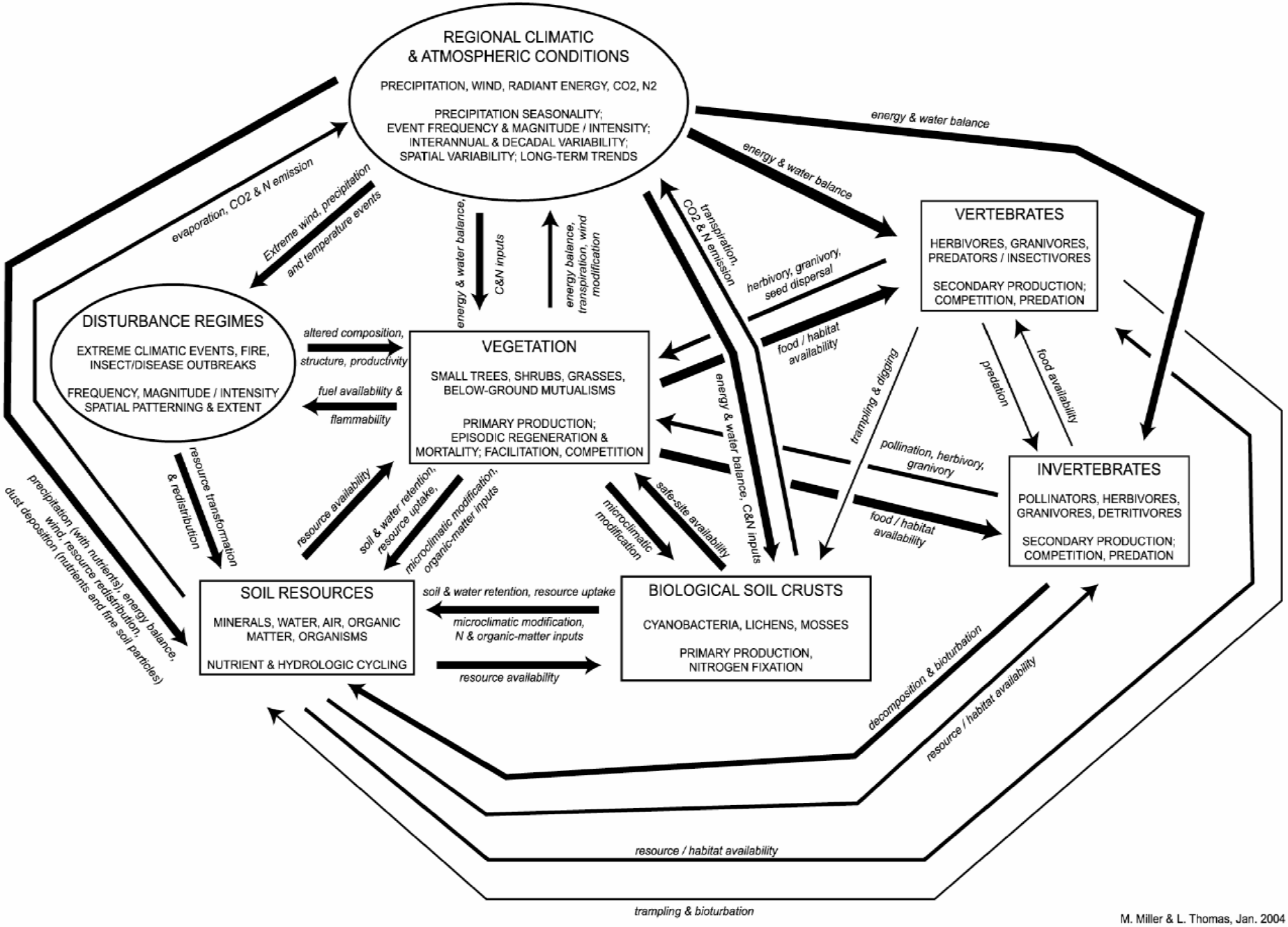
Background: The Temporal & Spatial Scale of Most Modeling Efforts

TABLE 1 *Characterizing ecosystems at different scales (from Bourgeron and Jensen 1994)*

Scale	Vegetation patterns	Biotic processes	Environmental constraints	Disturbances
Continent	Biomes/ formations	Speciation/ extinction	Climatic region	Glaciation
Ecoregion	Series	Species migration	Geology	Fire
Landscape	Communities (seral or climax)	Succession	Landforms	Windthrow (major storms)
Plot	Community/ tree dynamics	Tree replacement	Soils	Treefall



Background: The Temporal & Spatial Scale of Most Modeling Efforts



Units of Analysis: Species versus Communities

Can treat a species, subspecies, or population as a unit

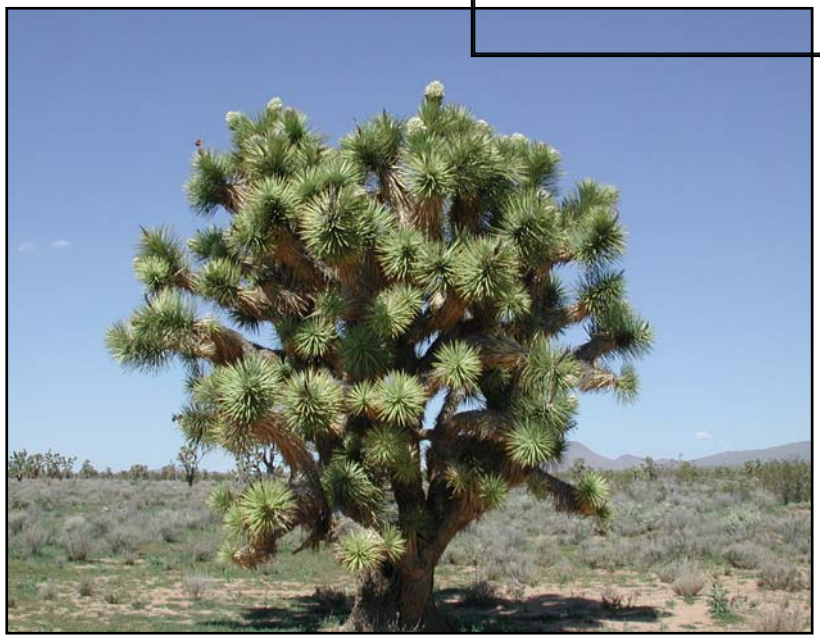


Photo by: Kenneth L. Cole

Can treat an assemblage of plants as a unit

Photo by: Dominic Oldershaw
http://mojave.usgs.gov/time-series/

The Unit of Analysis Should Represent a Coherent group that Responds similarly To Environmental Constraints

Typically Done at the Species level of Taxonomy

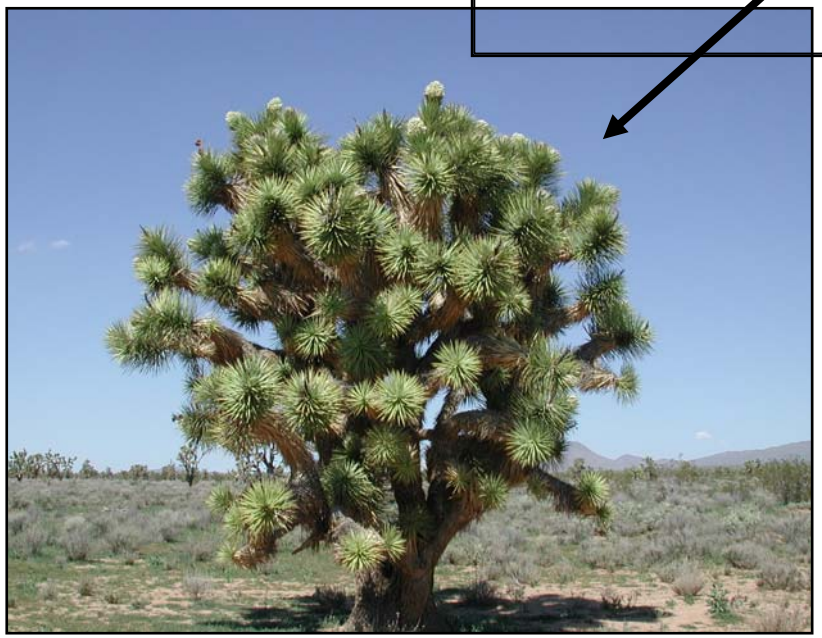


Photo by: Kenneth L. Cole

Typically Done at the Biome level of Classification

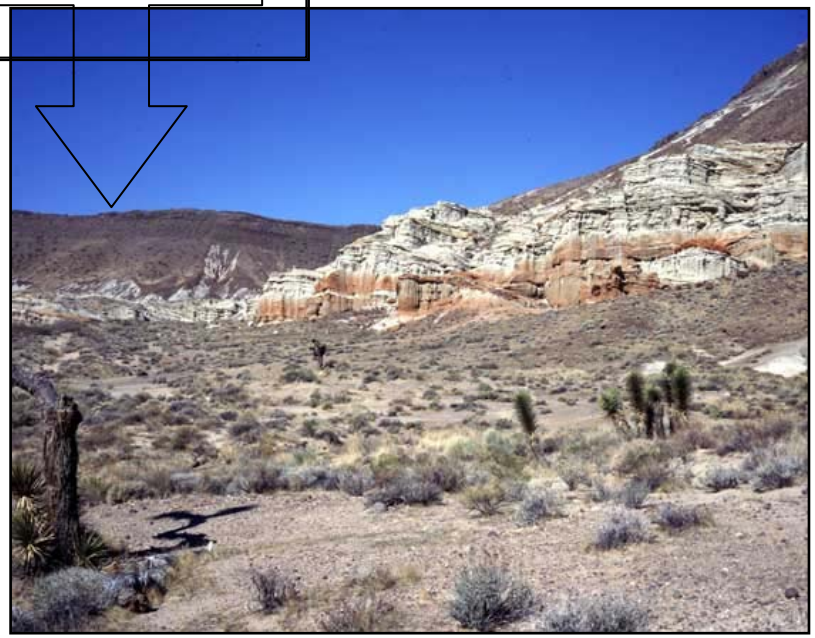
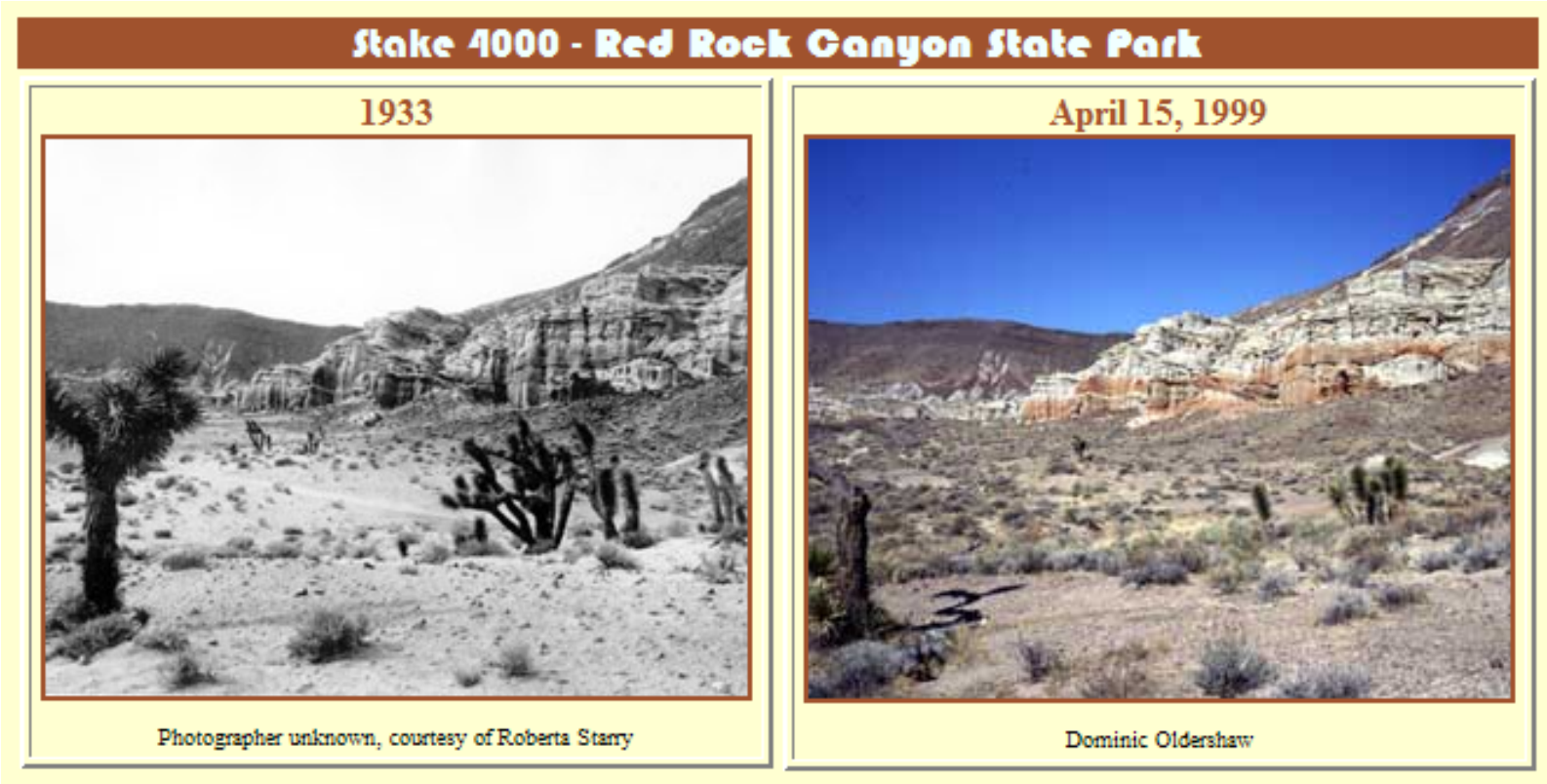


Photo by: Dominic Oldershaw
http://mojave.usgs.gov/time-series/

Establishing baselines for comparison



"No *Yuccas* or other plants have persisted over the 66 years between the dates of the photographs. In most of the repeat photography, few *Yuccas* appear to live longer than about 40 years." (Dominic Oldershaw)

http://mojave.usgs.gov/time-series/

"Johnson [46] indicates that large trees can be 300 years old, and Keith [54] suggests that Joshua tree has an average life span of 150 years. Little [61] suggests that Joshua tree is among the among the desert's "oldest living plants." An approximately 60-foot-tall (20 m) tree in California was an estimated 1,000 years old [61]." (Gucker, Corey L. 2006)

Establishing baselines for comparison

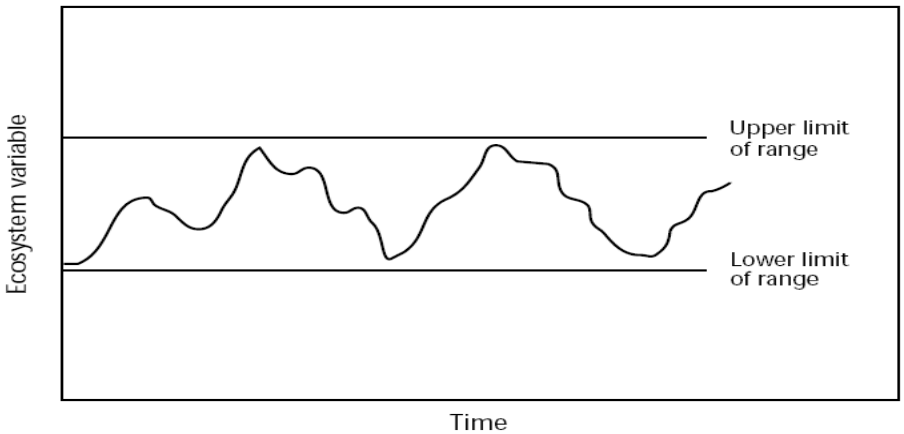
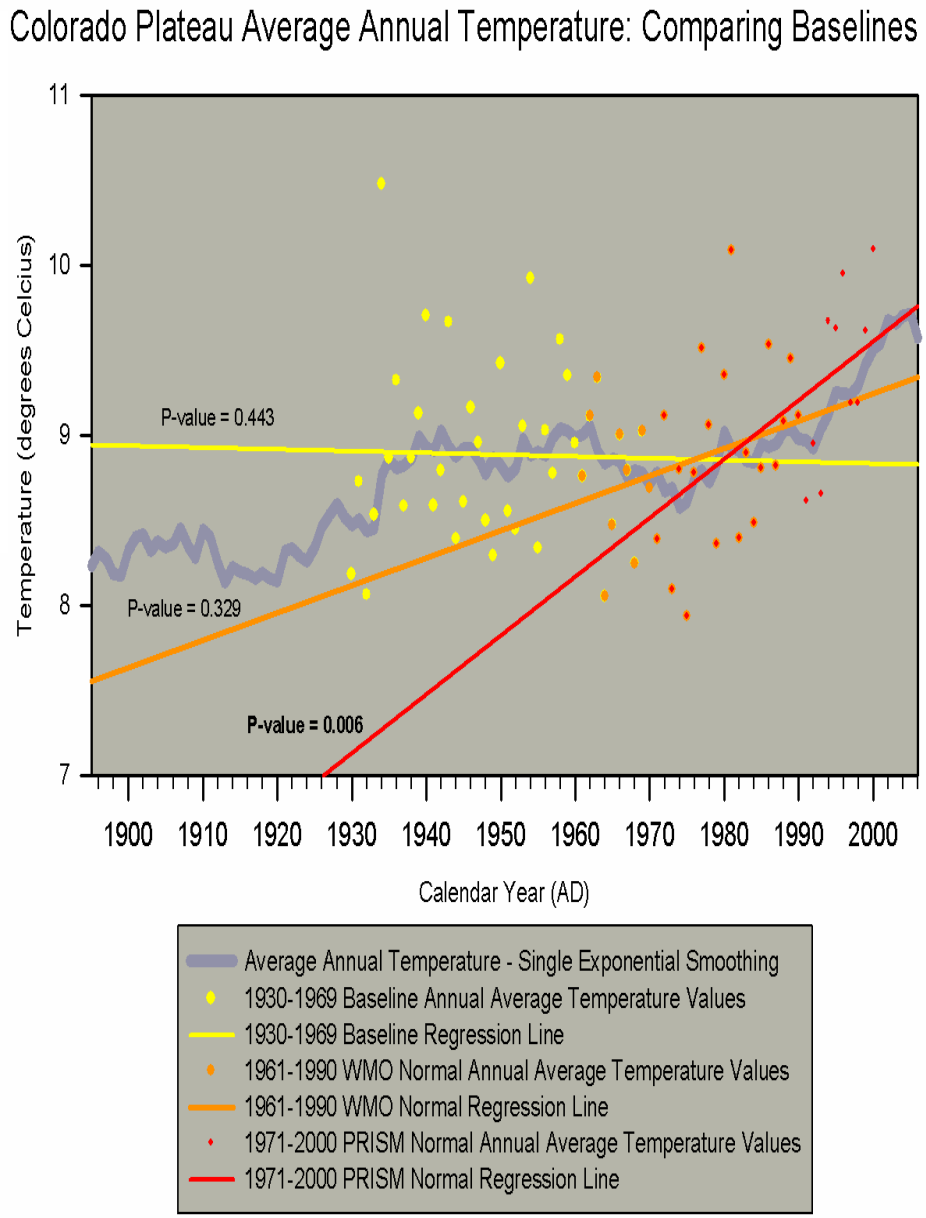
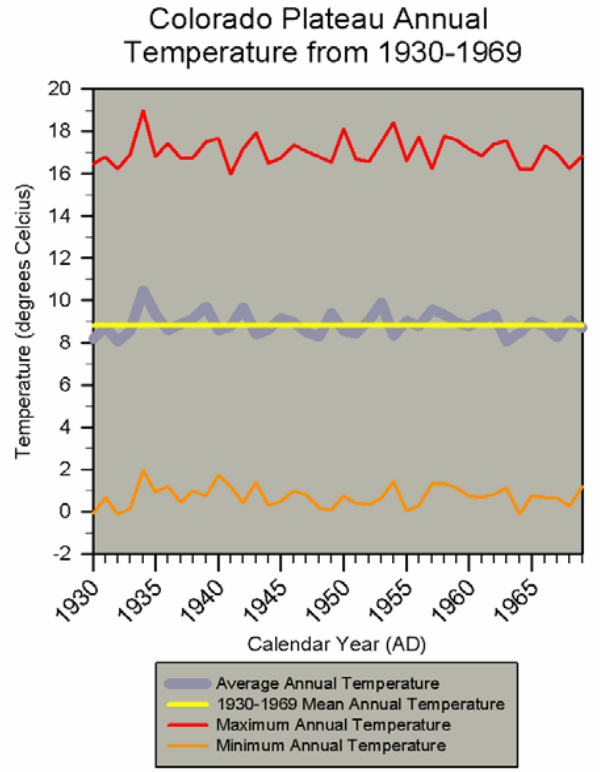


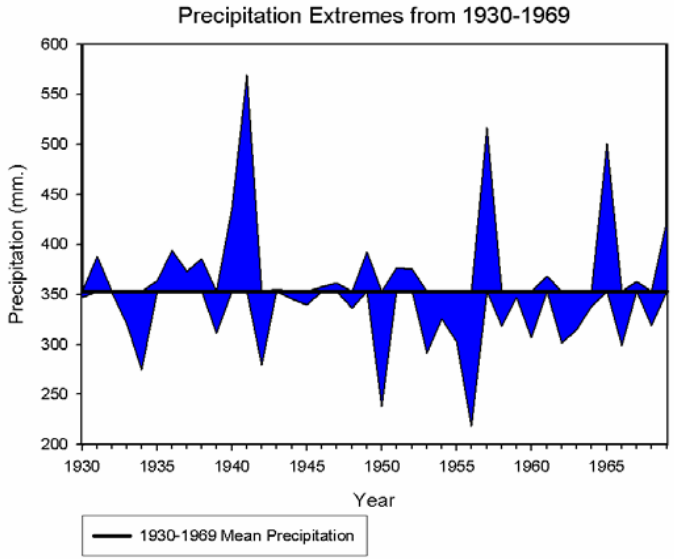
FIGURE 1 *Historical range of variability in ecosystem processes or structure over time (from Morgan et al. 1994).*

3.5.3.1. Baseline Period (IPCC 2001)

- Any climate scenario must adopt a reference baseline period from which to calculate changes in climate. **This baseline data set serves to characterize the sensitivity of the exposure unit to present-day climate** ..... it should be representative of the present-day or recent average climate in the study region and of a **sufficient duration to encompass a range of climatic variations**, including several significant weather anomalies (e.g., severe droughts or cool seasons).
- A popular climatological baseline period is a 30-year "normal" period, as defined by the WMO. The current WMO normal period is 1961-1990, which provides a standard reference for many impact studies. Note, however, that in some regions, observations during this time period may exhibit anthropogenic climate changes relative to earlier periods. http://www.grida.no/climate/ipcc_tar/wg2/144.htm





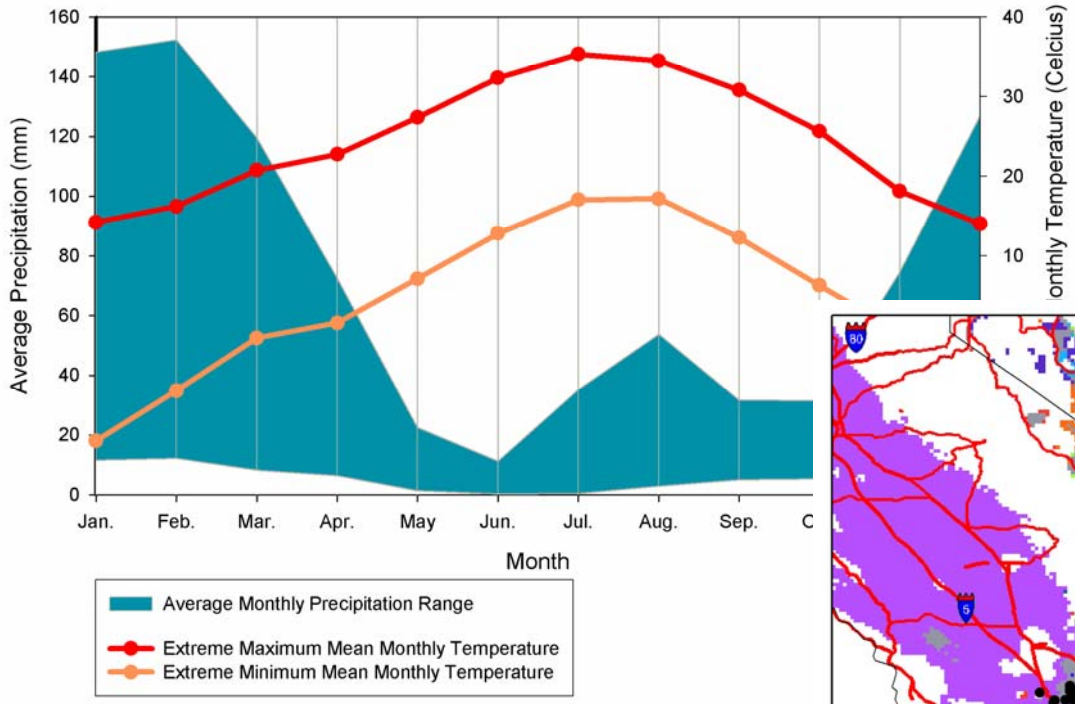


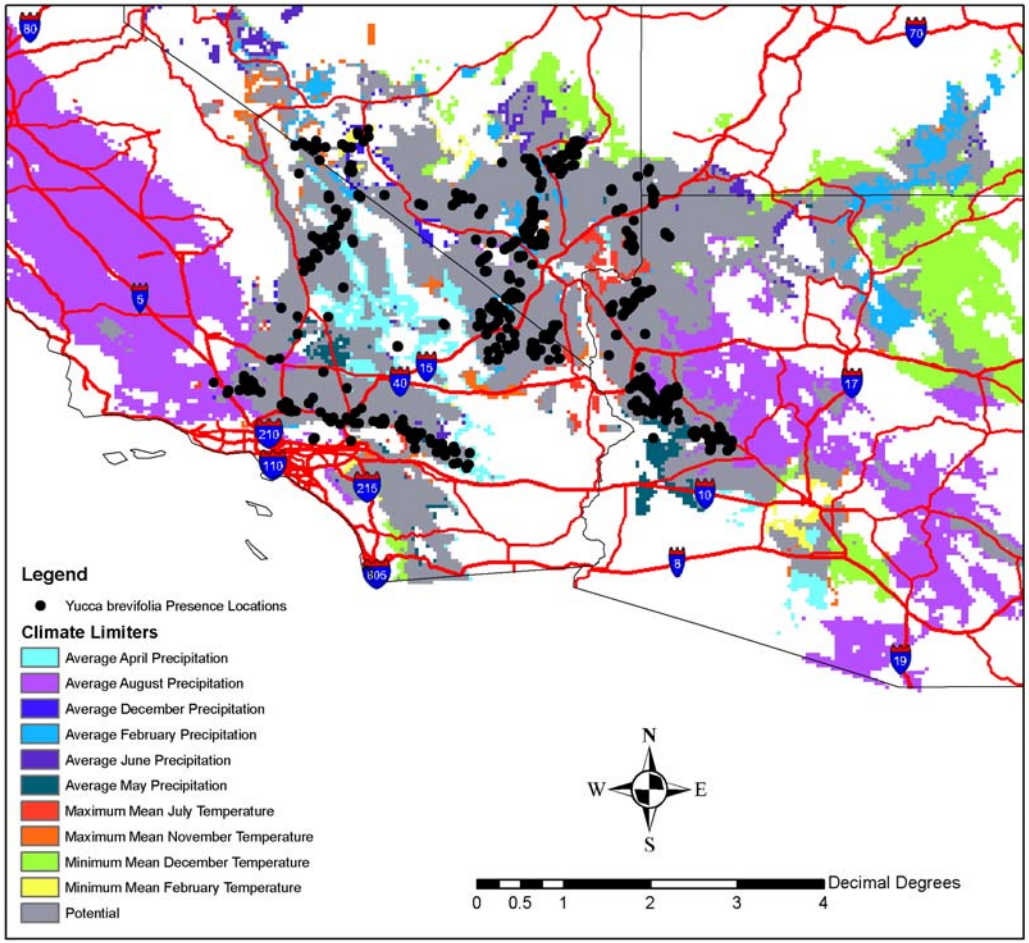
3.5.4.1. Choosing Variables of Interest (IPCC 2001)

- "**Most scenarios are conventionally based on changes in monthly mean climate**, although with greater quantities of model output now being saved operationally, daily output and information on certain types of extreme events ….. can be accessed readily. However, consideration must be given to whether model output regarding a **particular phenomenon is deemed "meaningful**.""
http://www.grida.no/climate/ipcc_tar/wg2/144.htm

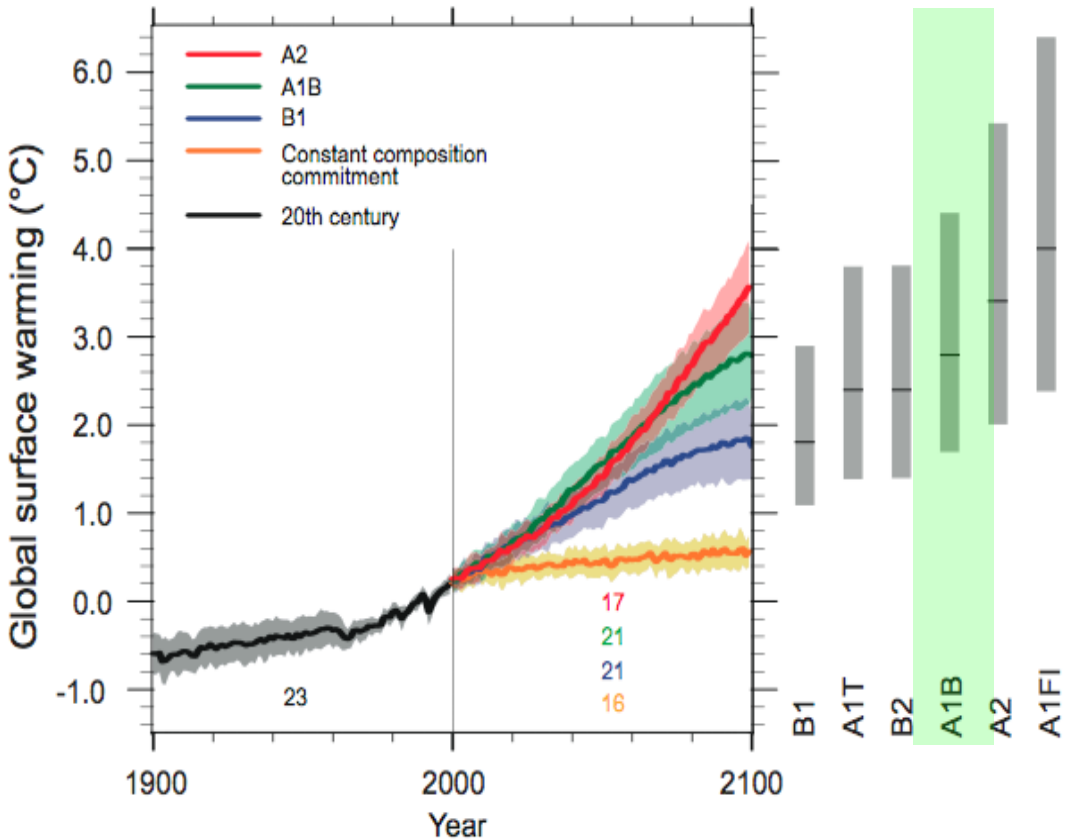
Variables: Extremes or Means?

Yucca brevifolia Climatic Thresholds





- GCMs Results Vary in:
  - Emission Scenario
  - Version or Model Run
- Model Selection
  - Ability to simulate present climatic patterns
  - Range of predictions
  - To compare between other impact models

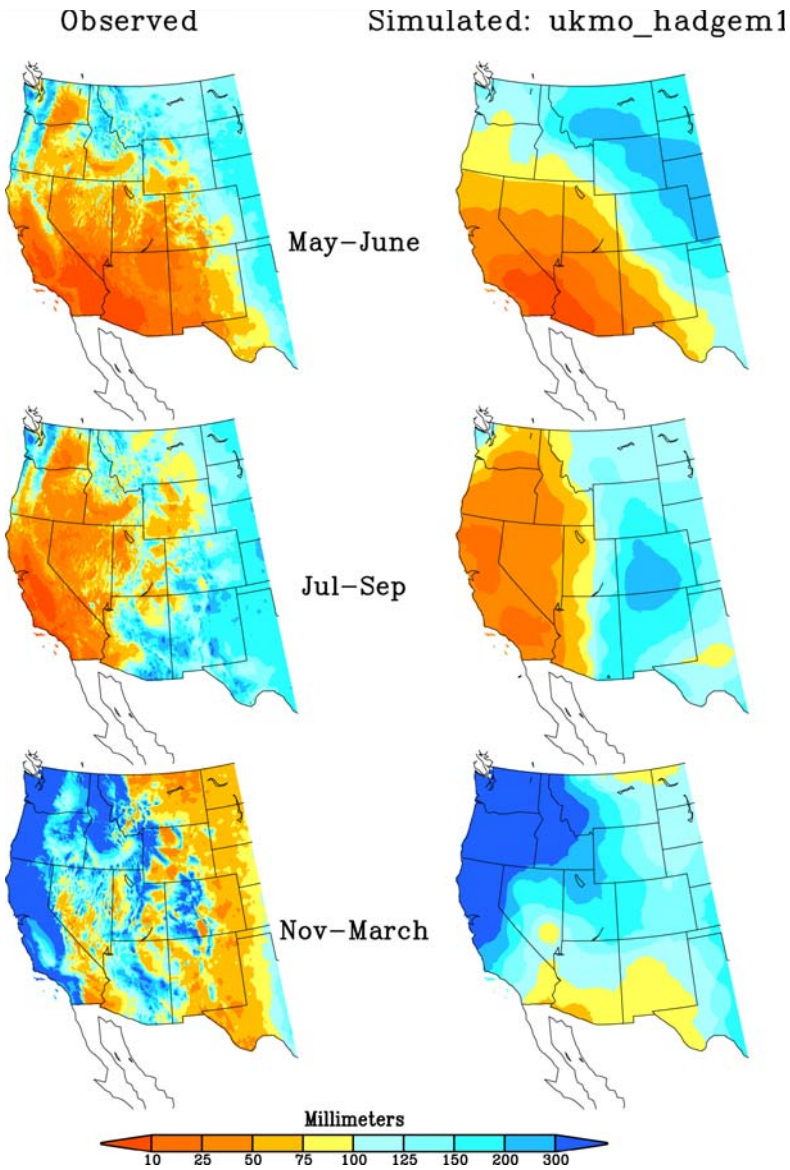


SRES A1b: Global Temperature

1.8°-4.4°C ≈ **5.4-7.9°F**

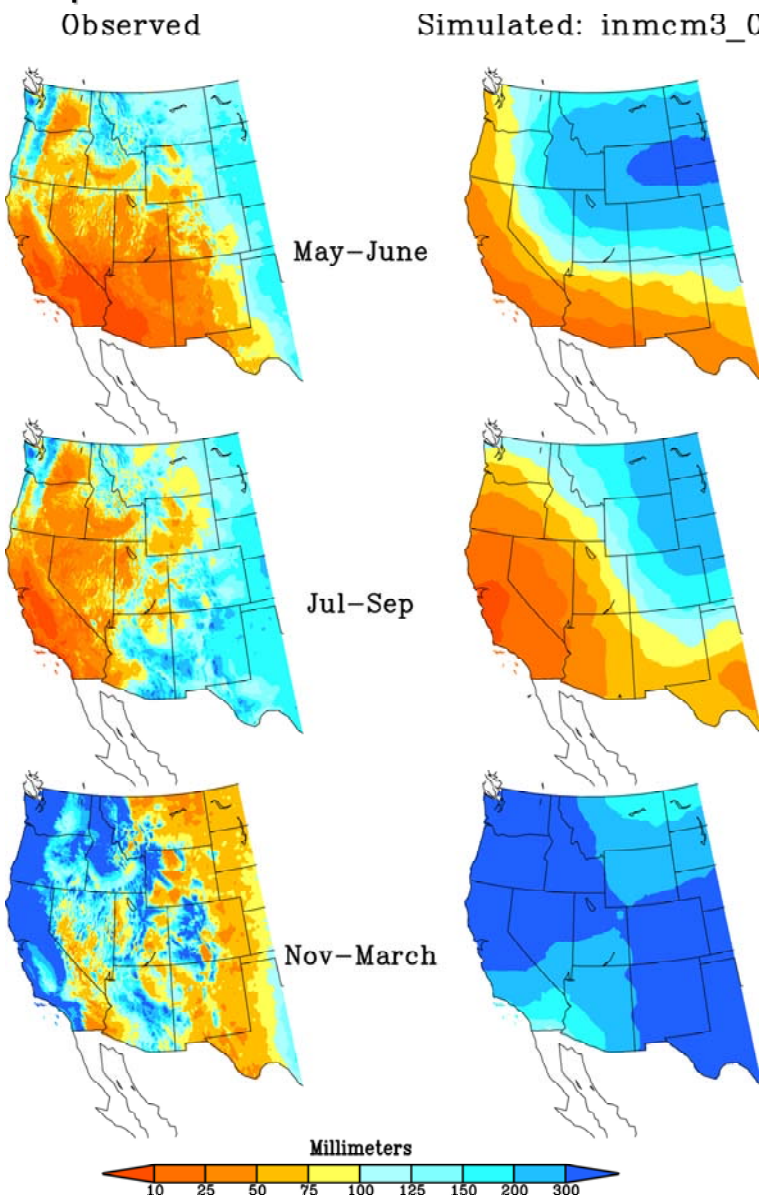
http://www.ipcc.ch

- Model Selection
  - Ability to simulate present climatic patterns: 1950-1999 Average Precipitation Patterns



#	Rank	Score	AR4 GCM using AIB Scenario
1	1	10	ukmo_hadgem1
2	2	26	mpi_echam5
3	3	27	ingv_echam4
4	4	29	mri_cgcm2
5	5	35	gfdl_cm21
6	6	37	ccma_cgcm3
7	6	37	giss_e_h
8	7	38	ukmo.hadcm3
9	8	39	miroc3_medres
10	9	42	cnrm_cm3
11	9	42	csiro_mk3
12	10	44	miroc3_hires
13	11	50	miub_echo
14	11	50	ncar_ccsm3
15	12	53	giss_e_r
16	13	56	ncar_pcm1
17	14	58	bccr_bcm2
18	15	62	gfdl_cm20
19	16	63	giss_aom
20	17	67	iap_fgoals
21	18	71	ispl_cm4
22	19	76	inmcm3

- Model Selection
  - Ability to simulate present climatic patterns: 1950-1999 Average Precipitation Patterns



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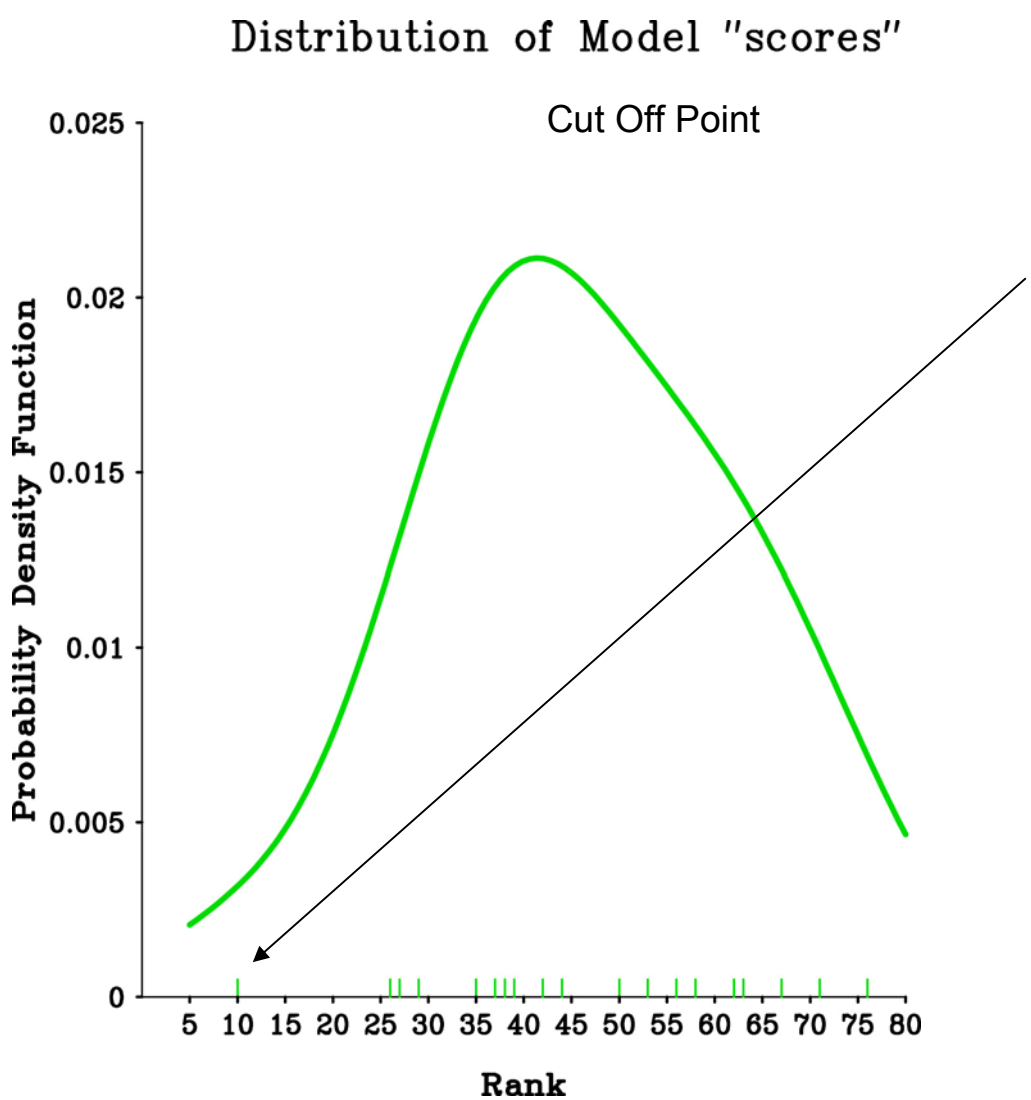
6	6	37	ccma_cgcm3
7	6	37	giss_e_h
8	7	38	ukmo.hadcm3
9	8	39	miroc3_medres
10	9	42	cnrm_cm3
11	9	42	csiro_mk3
12	10	44	miroc3_hires
13	11	50	miub_echo
14	11	50	ncar_ccsm3
15	12	53	giss_e_r
16	13	56	ncar_pcm1
17	14	58	bccr_bcm2
18	15	62	gfdl_cm20
19	16	63	giss_aom
20	17	67	iap_fgoals
21	18	71	ispl_cm4
22	19	76	inmcm3



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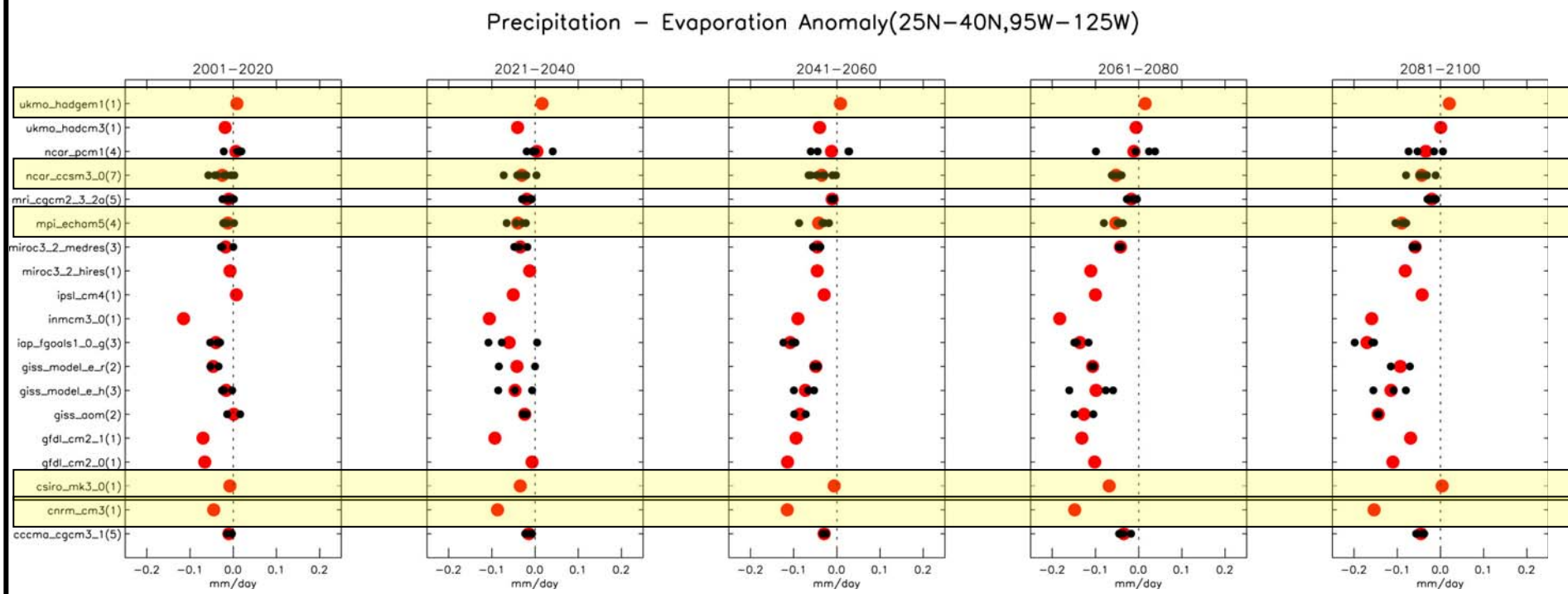


Sciencexpress Report

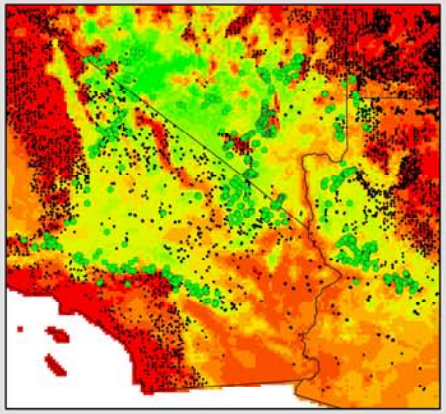
Model Projections of an Imminent Transition to a More Arid Climate in Southwestern North America

Richard Seager,[1] Mingfang Ting,[1] Isaac Held,[2,3] Yochanan Kushnir,[1] Jian Lu,[4] Gabriel Vecchi,[2] Huei-Ping Huang,[1] Nili Harnik,[5] Ants Leetmaa,[2] Ngar-Cheung Lau,[2,3] Cuihua Li,[1] Jennifer Velez,[1] Naomi Naik[1]

[1]Lamont Doherty Earth Observatory of Columbia University, Palisades, NY, USA. [2]NOAA Geophysical Fluid Dynamics Laboratory, Princeton, NJ, USA. [3]Program in Atmospheric and Oceanic Sciences, Department of Geosciences, Princeton University, Princeton, NJ, USA. [4]National Center for Atmospheric Research, Boulder, CO, USA. [5]Tel Aviv University, Tel Aviv, Israel.

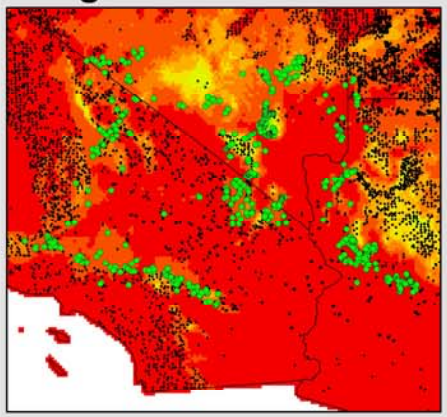
Present: 1930-1969

PRISM

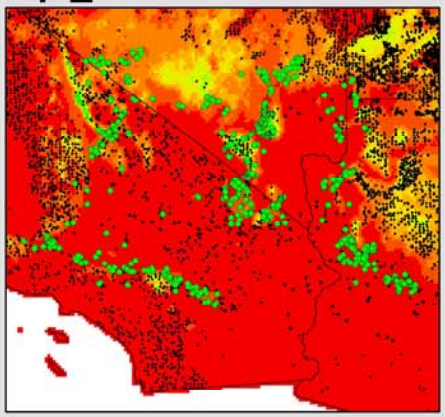


Future: 2060-2099

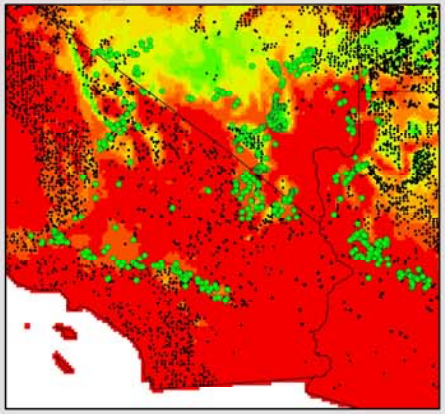
Hadgem1



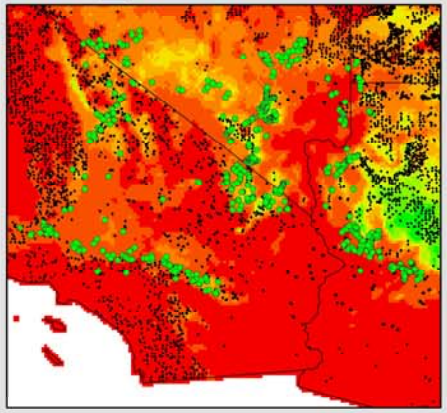
Mpi_echam5



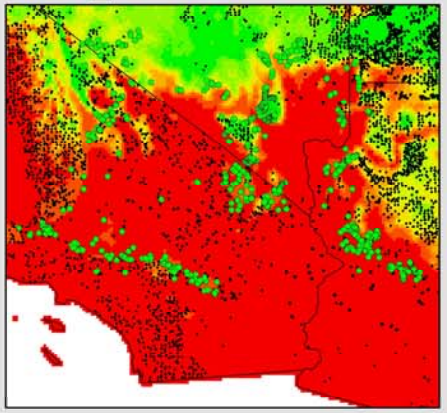
Cnrm_cm3



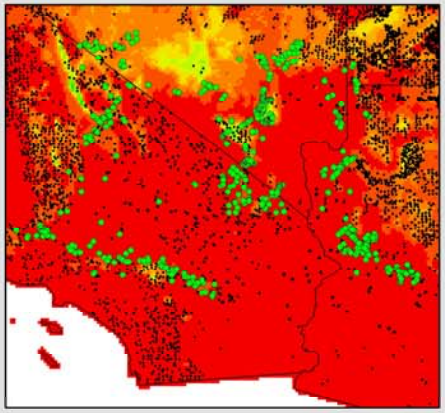
Csiro_mk3



Ncar_ccsm3



48 AR4 Run Ensemble



Legend

Yucca brevifolia

Locations

- Absent
- Present

Suitable Climate Probability

- 0% - 3%
- 4% - 10%
- 11% - 17%
- 18% - 26%
- 27% - 36%
- 37% - 46%
- 47% - 56%
- 57% - 68%
- 69% - 81%
- 82% - 98%

N
W E
S

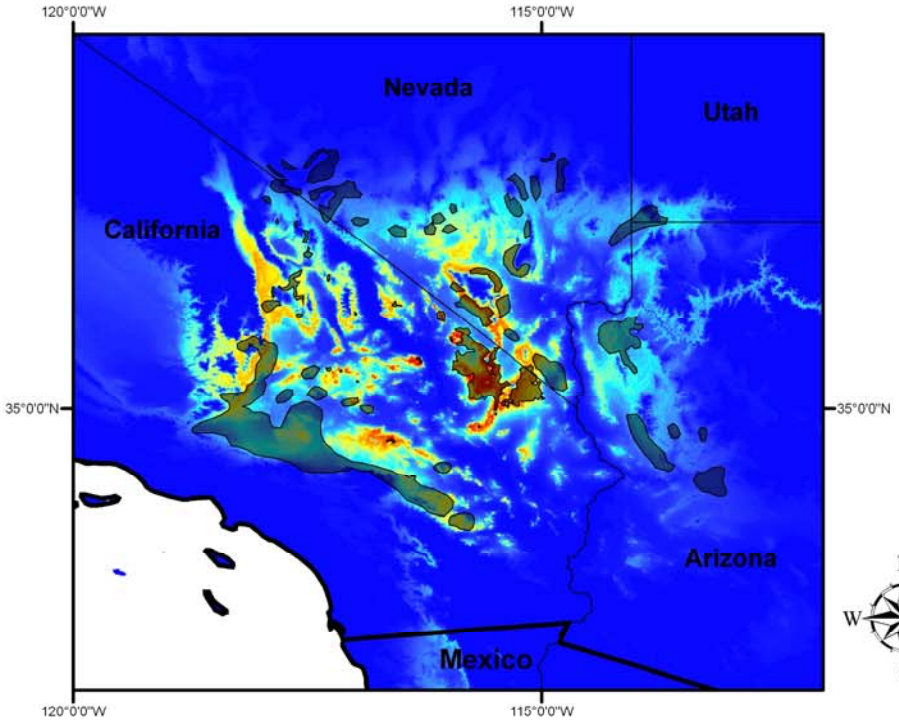
1 Decimal Degrees

Ironside, K. E., K. L. Cole, and J. Eischeid. 2008. Unpublished Data

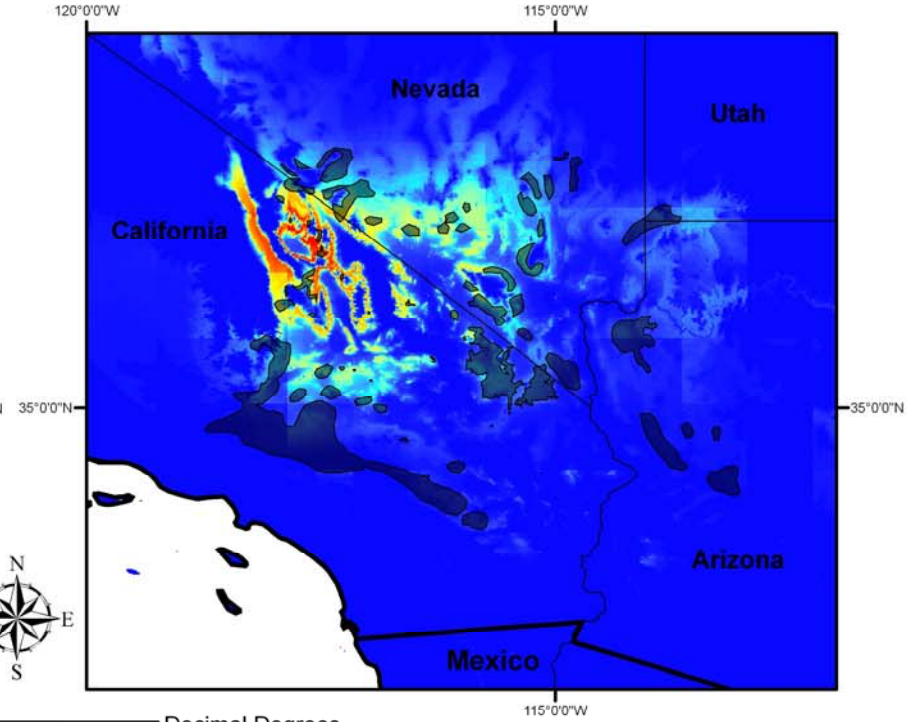
Coordinate System: Geographic, WGS 1972

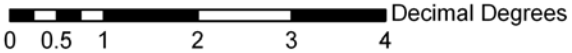
Likelihood of *Yucca brevifolia* Presence for the 20th Century and Future 2xCO_2 Climate

20th Century Climate



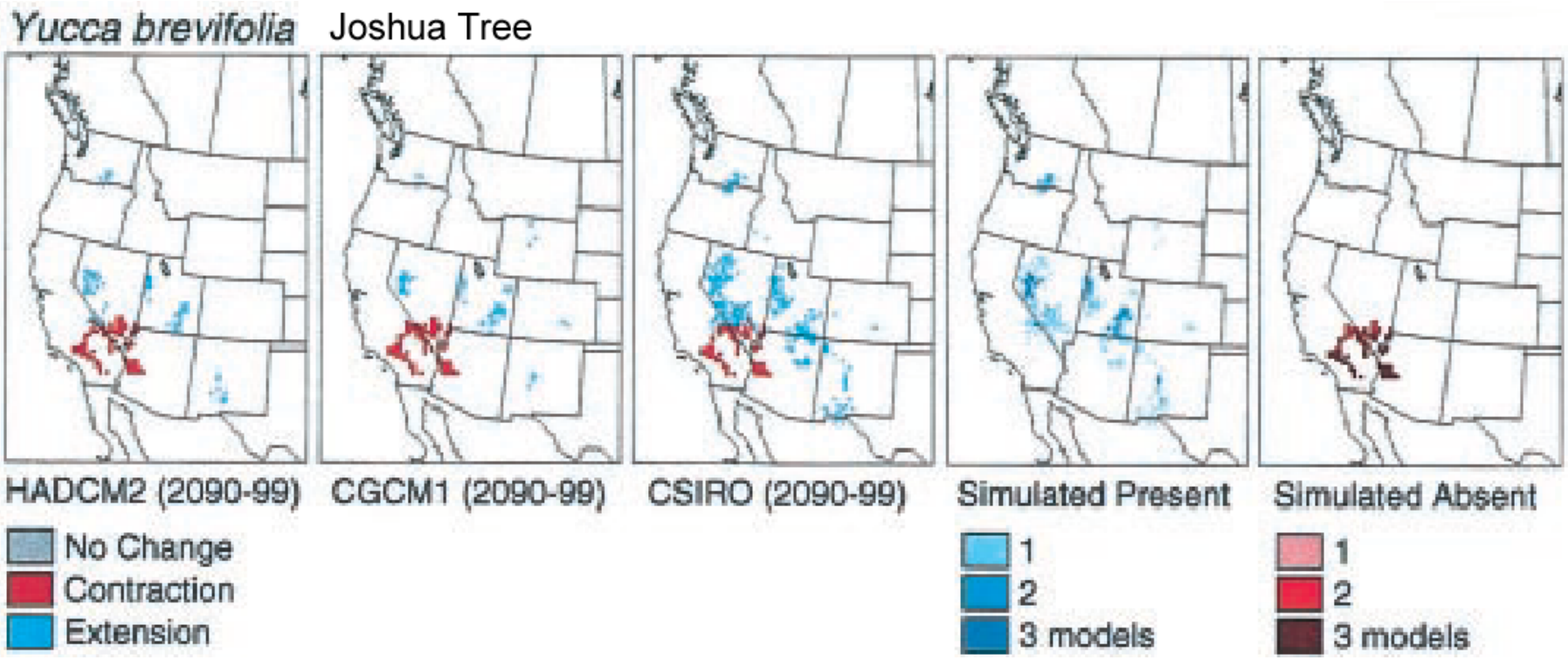
Potential Future 2xCO_2 Climate





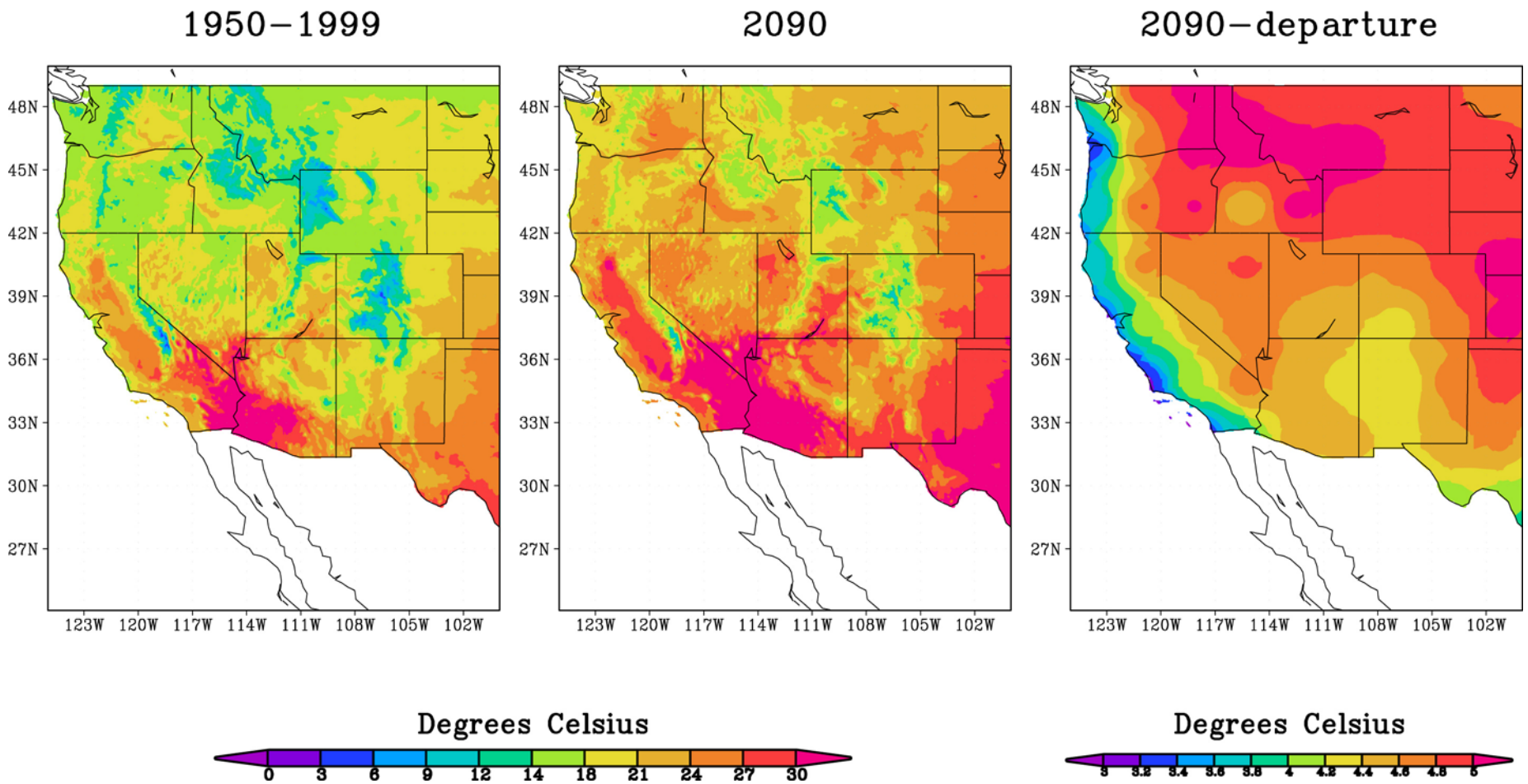
Legend

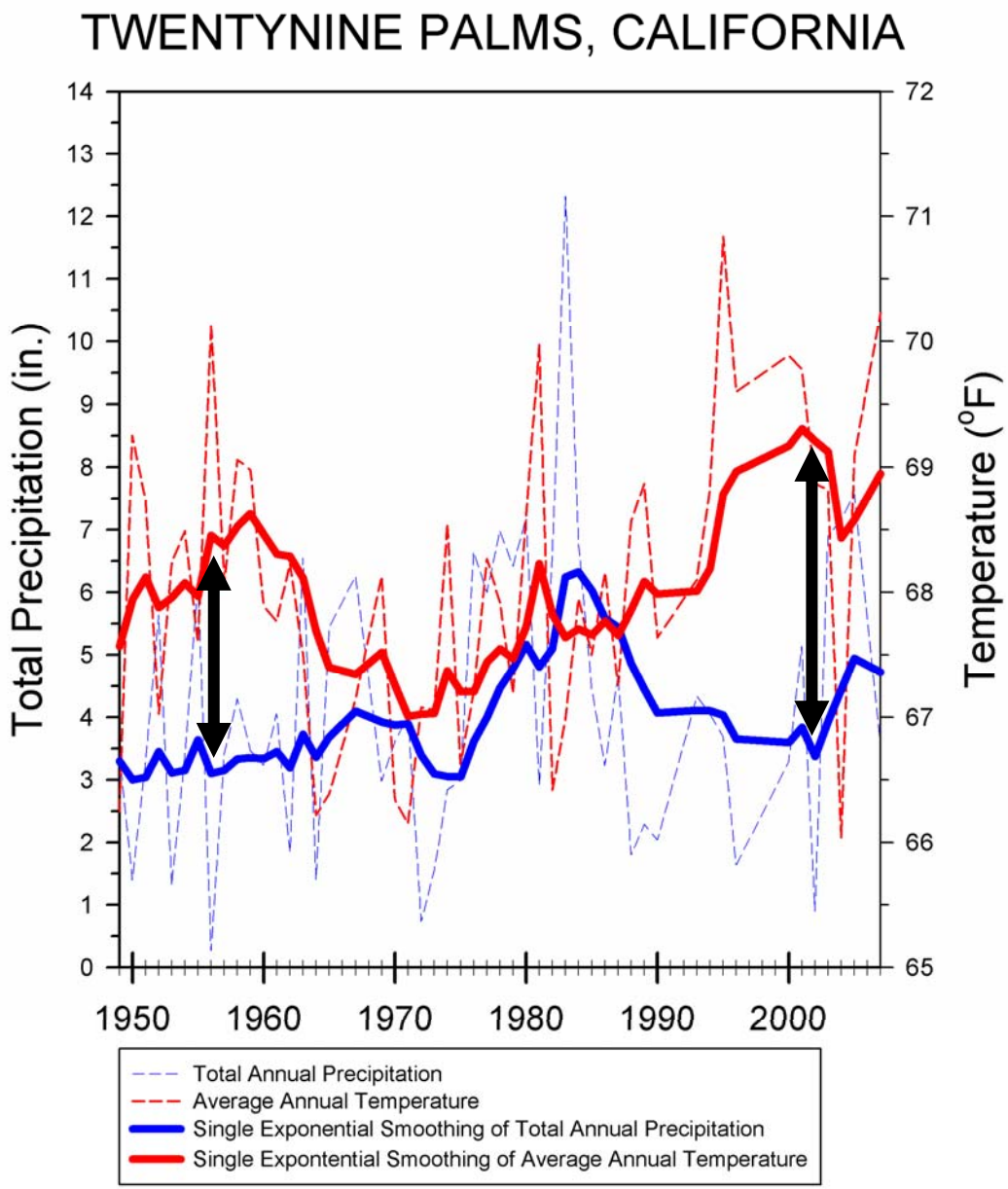
Comparison to other Predictions



Shafer, S. L., P. J. Bartlein, and R. S. Thompson. 2001. Potential changes in the distributions of Western North America tree and shrub taxa under future climate scenarios. Ecosystems 4: 200-215.

Jul/Aug/Sep Temperature



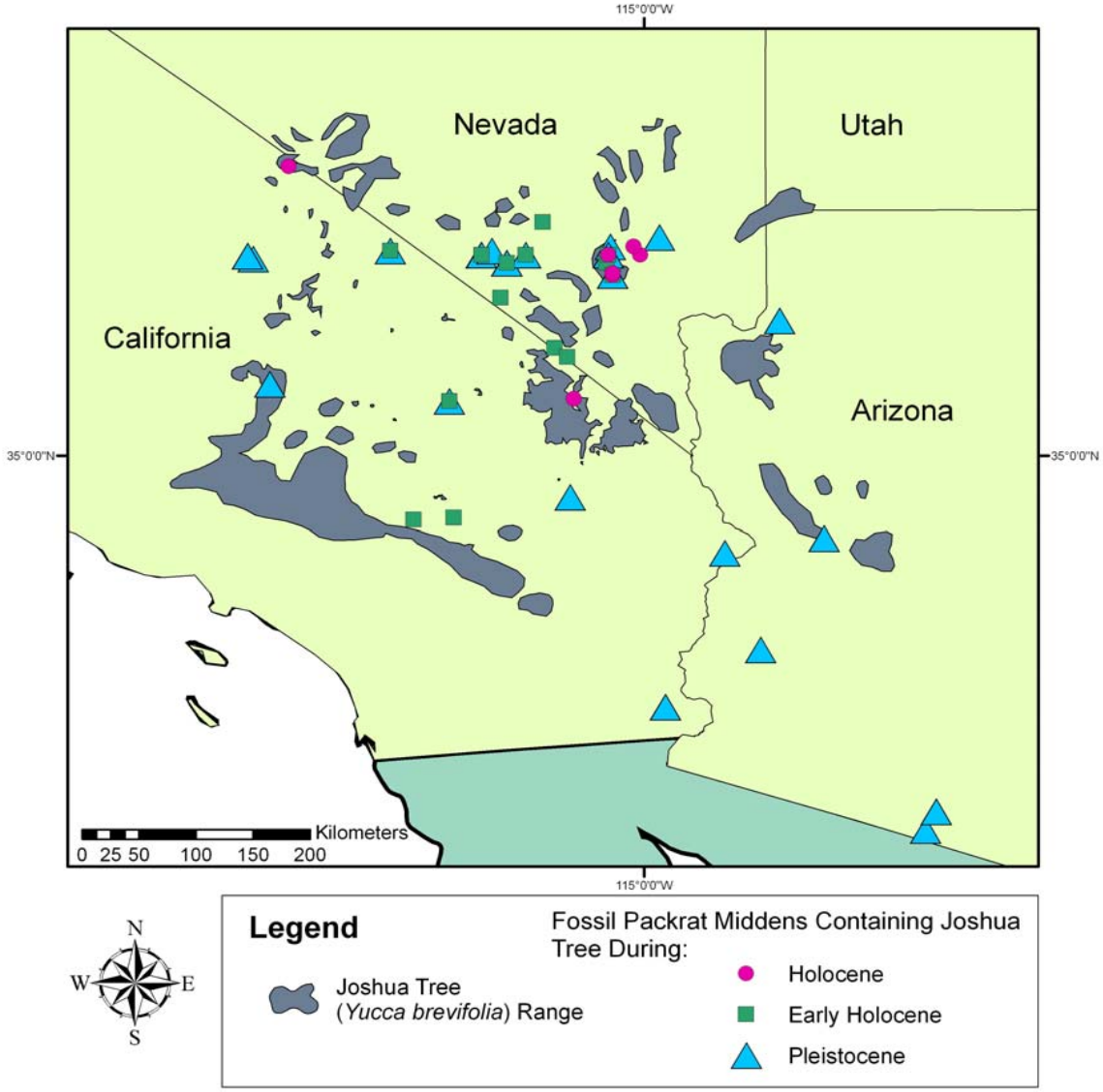


Data Obtained from the Western Regional Climate Center, Historical Climate Information
http://www.wrcc.dri.edu/summary/Climsmsca.html, April 2008

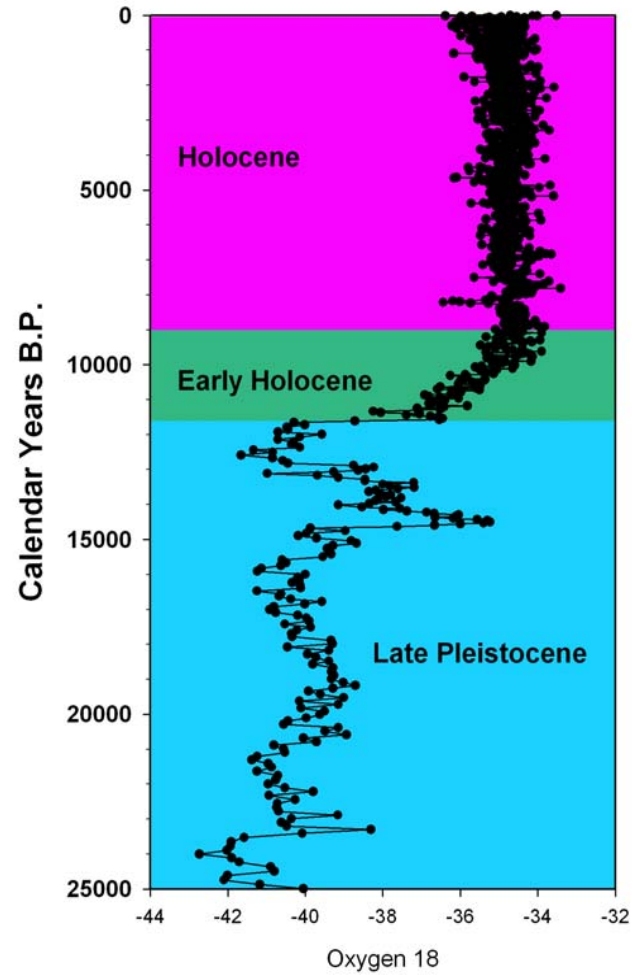
- Because Temperatures are increasing the disparity between temperature and precipitation are increasing, making dry years extremely stressful for perennial plant species and wildlife

- Even if average precipitation remains constant or even increases, periodic events with low precipitation combined with increasing temperatures will be stressful for perennial plant species

Joshua Tree (*Yucca brevifolia*) Macrofossil Record



GISP2 Ice Core



Grootes, P.M., and M. Stuiver. 1997. Oxygen 18/16 variability in Greenland snow and ice with 10^3 to 10^5-year time resolution. Journal of Geophysical Research 102:26455-26470.

Algorithms used to Predict

- Two Basic Types
  - Dynamic Vegetation Models
    - Simulations often including disturbance regimes (fire), nutrient cycling, and carbon budgets
    - Rule based and often parameterized
    - Measures typically are in terms of biomass or leaf area indices
    - Examples include: VEMAP, MAPSS, MC1
  - Statistical Models
    - Various statistical procedures used to derive a mathematical relationship between independent variables and a dependent variable
    - Measures typically are species occurrences, sometimes vegetation types
    - Common Statistics Used: Regression Trees, Various types of Regression, GARP, BIOCLIM, Maxent

Dynamic Vegetation Models

From: Climate Change Effects on Vegetation distribution and Carbon Budget in the U.S.
D. Bachelet, R.P. Neilson, J.M. Lenihan, and R.J. Drapek.
Ecosystems 4(3):164-185 (2001)

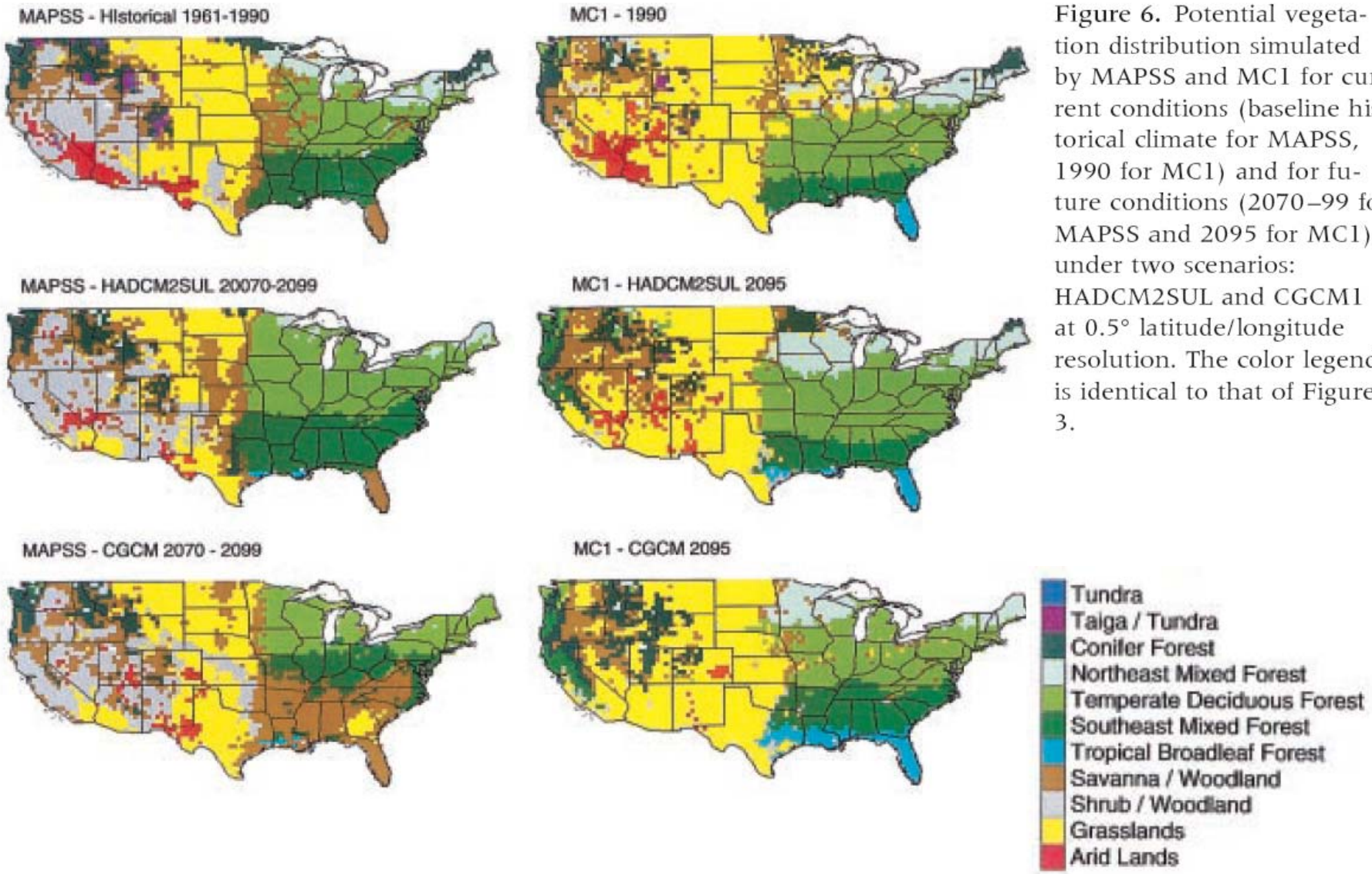
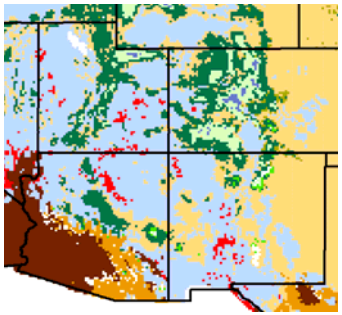


Figure 6. Potential vegetation distribution simulated by MAPSS and MC1 for current conditions (baseline historical climate for MAPSS, 1990 for MC1) and for future conditions (2070–99 for MAPSS and 2095 for MC1) under two scenarios: HADCM2SUL and CGCM1 at 0.5° latitude/longitude resolution. The color legend is identical to that of Figure 3.

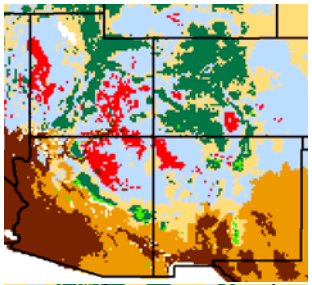
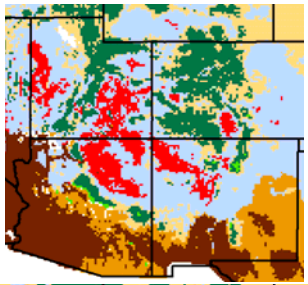
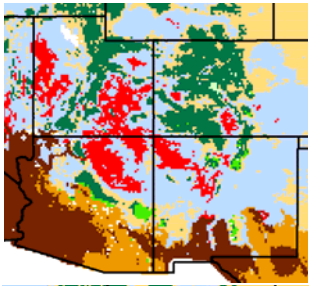
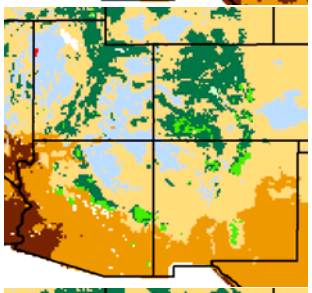
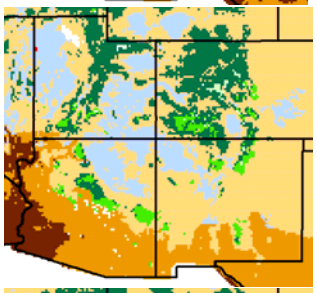
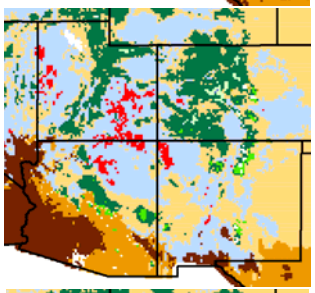
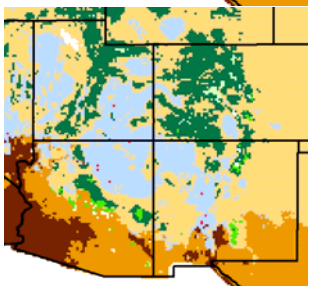
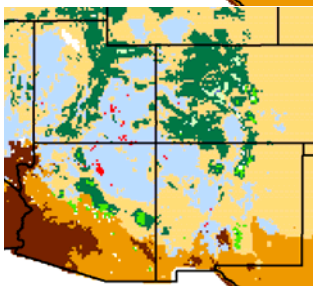
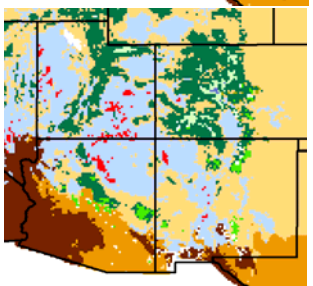
From: Ron Neilson. 2007. Climate Change, Uncertainty and Forecasts of Global to Landscape Ecosystem Dynamics, Presentation Given at the Colorado Plateau 9th Biennial Conference, Flagstaff, AZ.



Vegetation 2070-2099

- Tundra
- Subalpine Forest
- Temperate Evergreen Needleleaf Forest
- Temperate Deciduous Broadleaf Forest
- Temperate Evergreen Needleleaf Woodland
- Temperate Shrubland
- Temperate Grassland
- Temperate Desert
- Subtropical Grassland
- Subtropical Desert

Historical Vegetation (1961-1990)

	A2	A1B	B1
MIROC			
HADLEY			
CSIRO			

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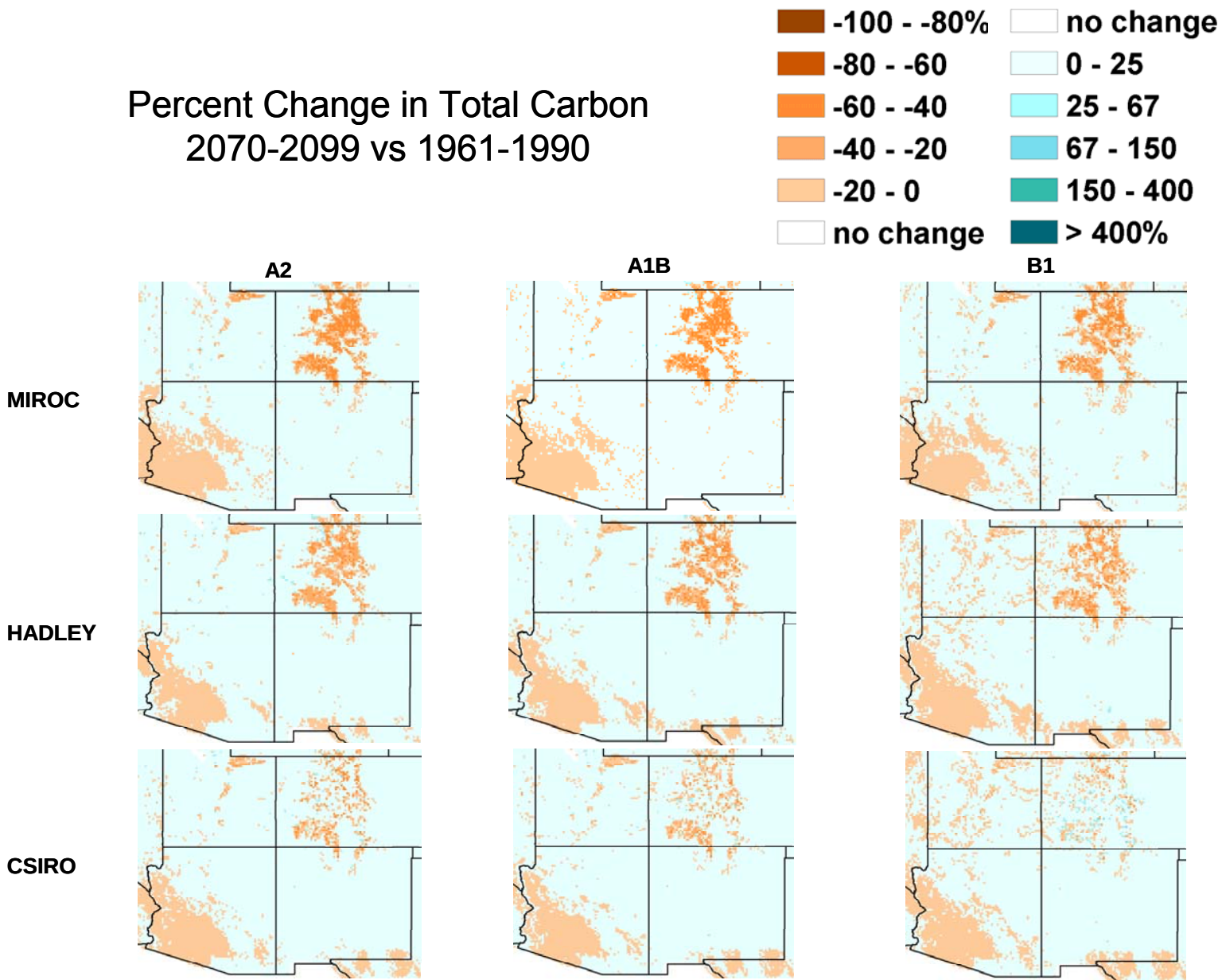

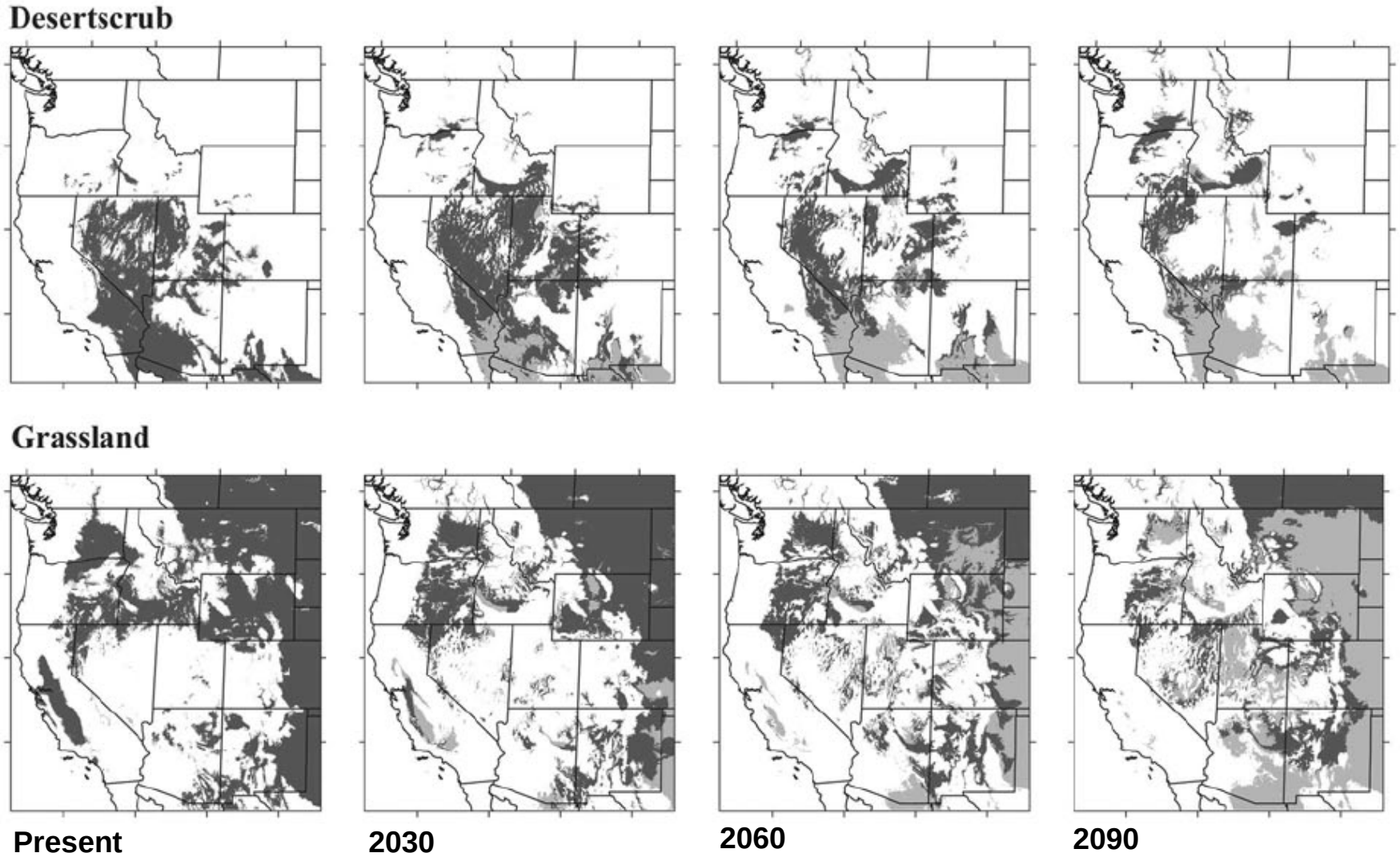

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Summary

- Recent Predictions from a variety of Predictive Modeling Efforts are Consistent in their predictions SW Desert Regions are likely to Lose Their Existing Vegetation Types
  - An already extreme environment is predicted by GCMs to become even more extreme by increasing temperatures
- Assumptions and Uncertainties
  - Long term increased CO2 affects on plants
  - Migration Potentials
  - Selection pressure and ability to adapt
  - Changes in community dynamics such as competition, predation, etc
  - Most Predictions Predict Potential niches either from assuming equilibrium with environmental constraints or not being able to include all limiting factors

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