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Improving Paleoecology Studies for Future Predictions—Role of Spatial and Temporal Scales for Understanding Ecology of the Arid and Semiarid Landscape of the Southwest

By David M. Miller, Gene-Hua Crystal Ng, and Katherine Maher

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Improving Paleoecology Studies for Future Predictions—Role of Spatial and Temporal Scales for Understanding Ecology of the Arid and Semiarid Landscape of the Southwest

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Paleoecology (or Ecological Biogeography)

- Past distribution of species or communities (Swetnam and others, 1999):
    - Describes changes in concert with environmental changes
    - Illustrates lags (for example, Pinyon Pine (*Pinus* spp.) invasion following climate change)
    - Informs on tolerance limits of species
    - Describes resilience of species in the face of change
- Paleoecology describes real systems—uses a broad suite of environmental variables, which may provide a more comprehensive view than will individual measures of climate.
- Changes over the past several thousand years happened in the presence of landscape manipulations by humans—adds relevance but increases difficulty of interpretation.

Desert Tortoise: An Example

- **The desert tortoise (*Gopherus agassizii*) has lived in the Southwest for several million years. This persistence is potentially meaningful.**
- **It has adapted through stable warm periods and several patterns of ice ages and interstadials.**
- **Imagine if we developed regional datasets for:**
    - **Its habitat range through time, as well as**
    - **climate variables**
    - **plant community ranges**
    - **soil conditions**
- **Over the time of tortoise survival, this would be very useful for evaluating its resilience to change and making predictions for the future of this listed species.**
- **Developing this kind of paleoecology data is much more difficult than the already difficult job of establishing paleoclimate, yet powerful for interpreting the climate data.**

What paleo-records are needed?

- **Understanding past climate-driven changes?**
  - ***climate proxies***
- **Resolving species sensitivity to and resilience against change?**
  - ***biogeographical data***
- **Understanding past ecosystem function and changes?**
  - ***environmental data***

How do we apply this knowledge for predictions?

- **What information is most urgently needed for ecosystem forecasts?**
- **Are there kinds of monitoring we need to start now so that we will have ground truth in the near future?**

These are major questions. Answering them in part relies on careful thought about the spatial and temporal scales of data needed.

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Spatial Resolution: Mojave Desert Piedmonts

At face value, a uniform “plant-scape” of isolated shrubs stretching off into the distance?

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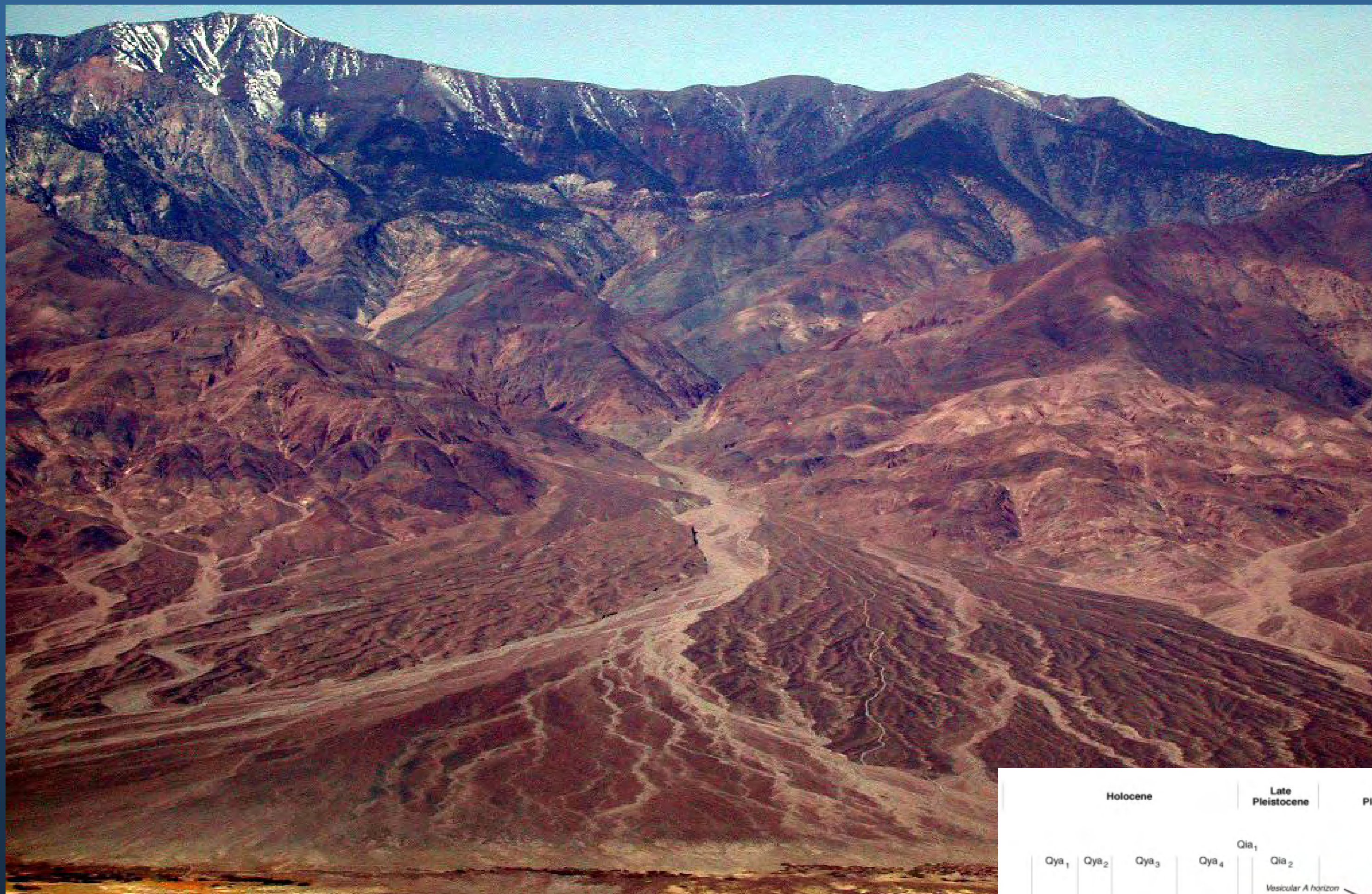
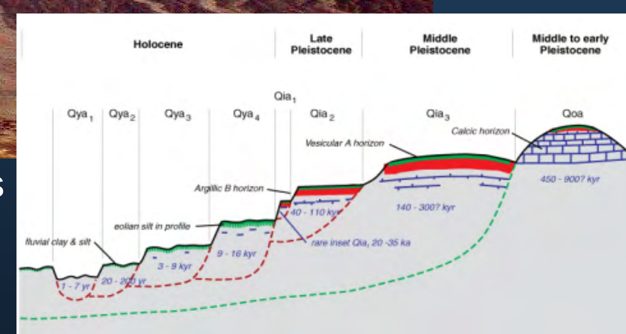
Spatial Resolution: Mojave Desert Piedmont Reality—Soils Control Plant Distribution



Colors on the fan are caused by desert varnish, which illustrates that soils form intricate patterns; soils control plants.



From Miller and others, 2009

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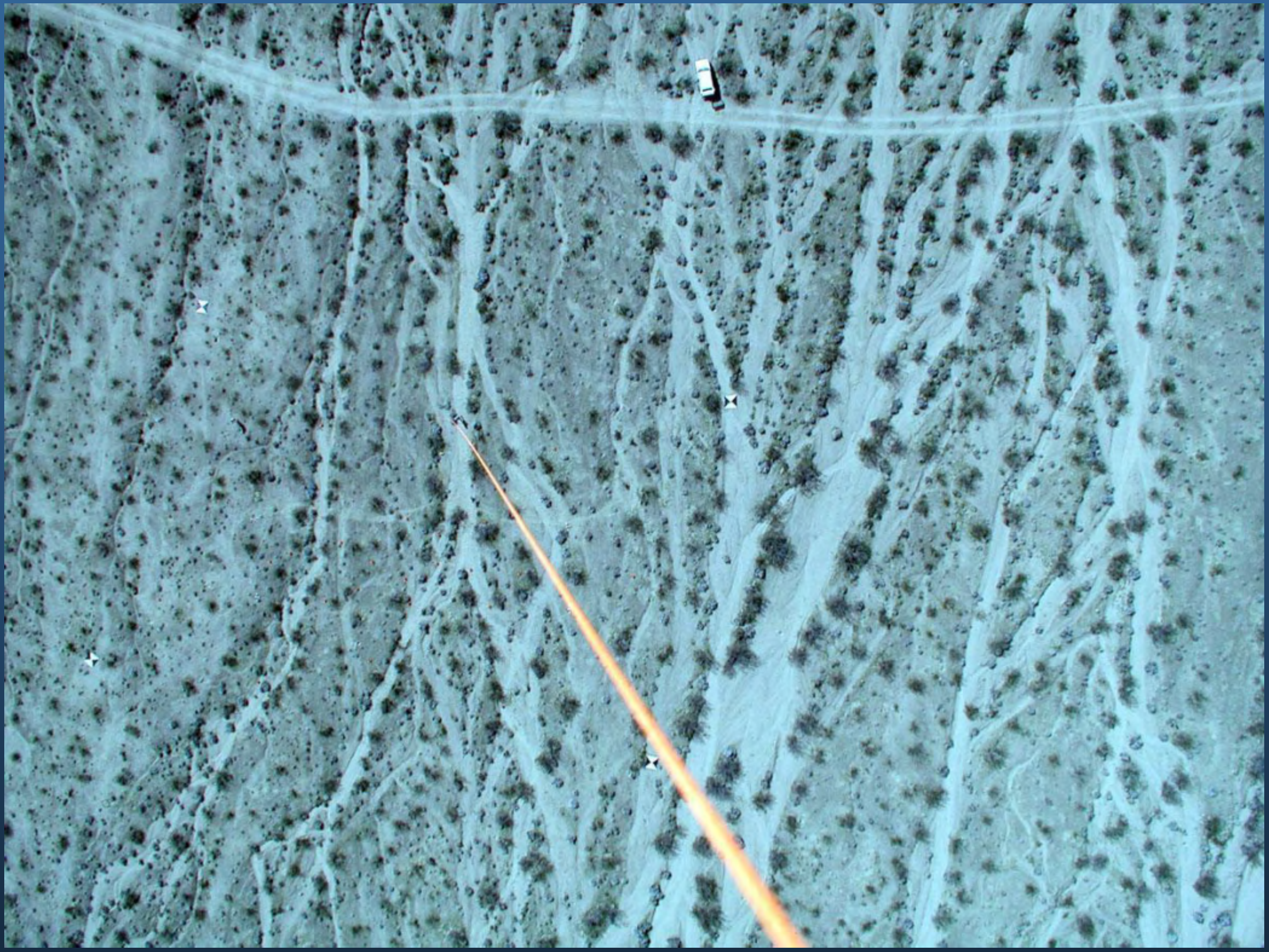
Spatial Resolution: Mojave Desert piedmont reality—Streams structure vegetation!



Stream channels viewed from a balloon camera.

Spatial Resolution: Mojave Desert Piedmont Reality—Streams are Bordered by Denser Plant Growth

Upper piedmont, channels deeply incised (note rocky banks)

Lower piedmont, channels shallowly incised

In both cases, channels are lined with many small gray shrubs and fewer large green shrubs.

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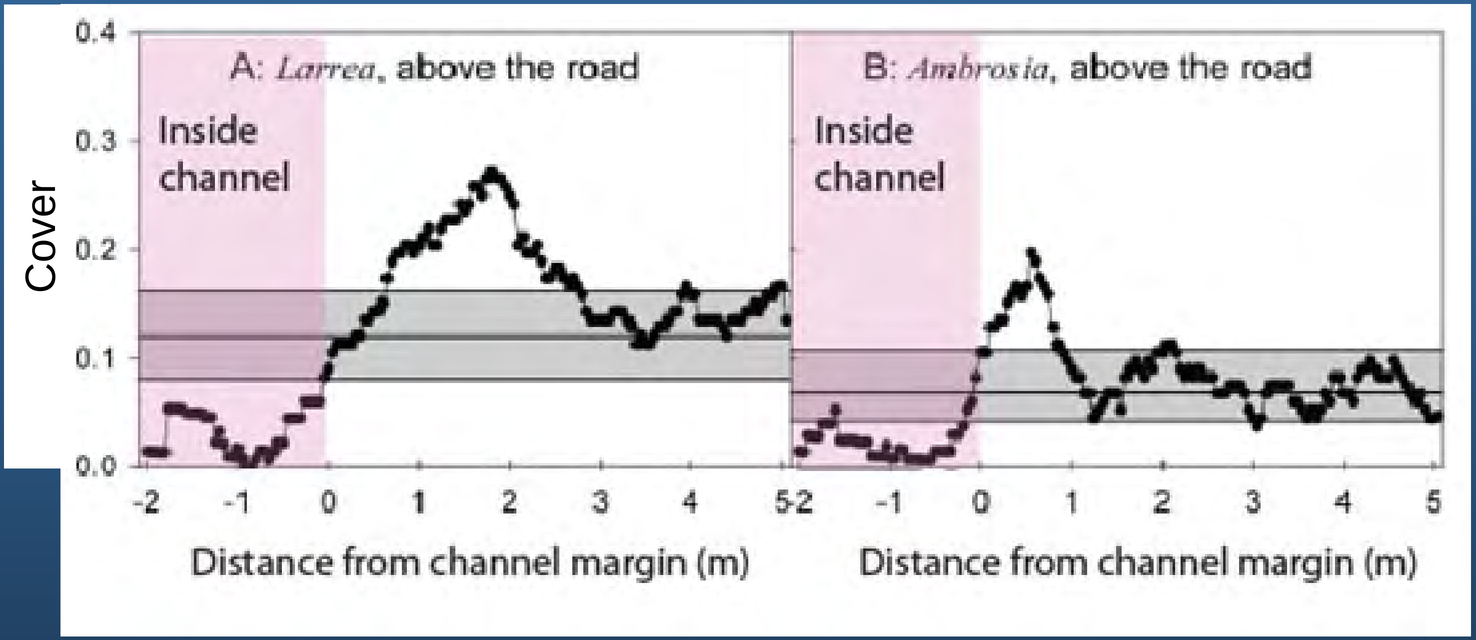
Stream Channel Effects (from Schwinning and others, 2011)



Shaded bands indicate standard error.

<u>Peak Plant Cover</u>

Larrea Tridentata (creosote bush)

1.2 – 1.6 meters (m) from wash edge

Ambrosia Dumosa (white bursage)

0.5 – 1.0 m from wash

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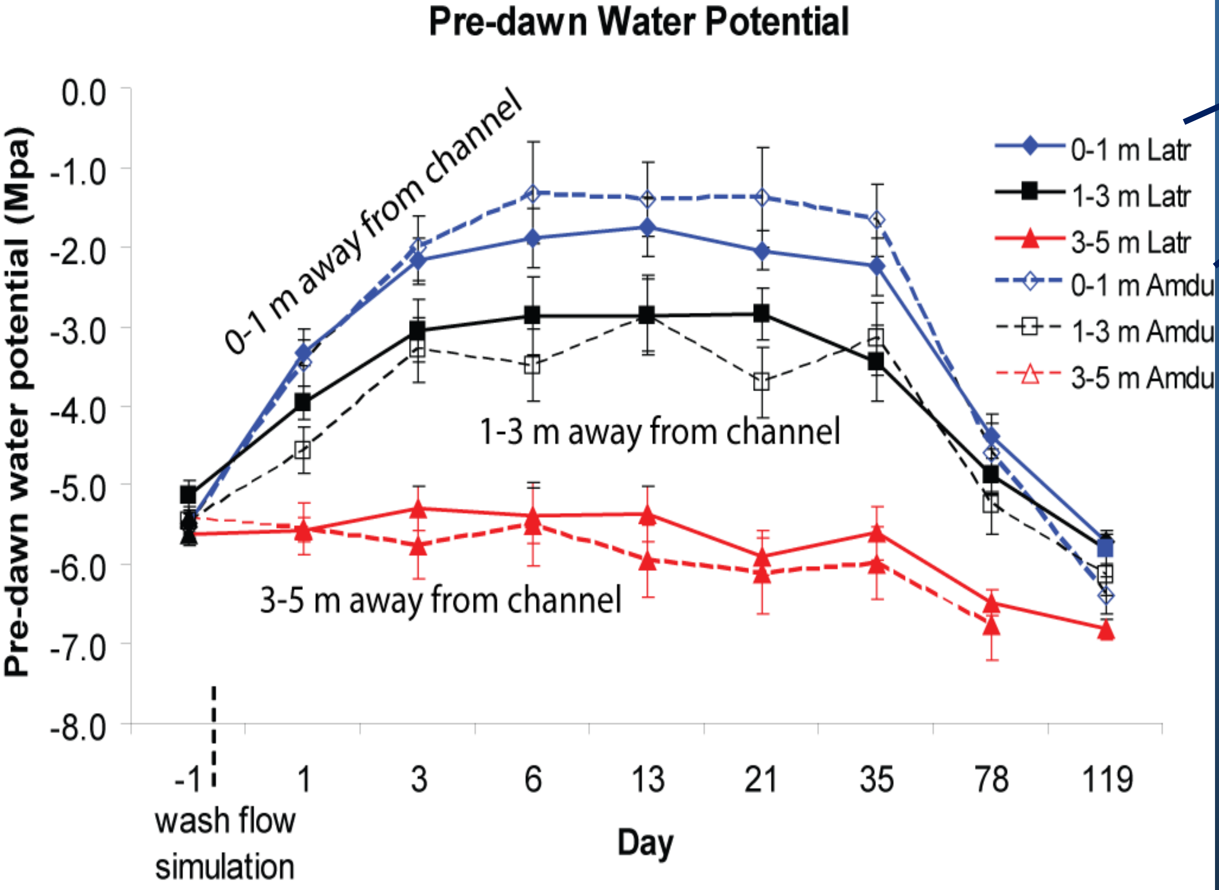
Stream Channel Effects: Watering Experiments in July (Advanced Stress)



Larrea Tridentata

Ambrosia Dumosa

before

after

Creosote bush leaves.

- Sustained increase in water availability >75 days
- Visual “greening” for >6 months
- No change >3 meters (m) from channel

(Data from Newlander and others, 2009; Sandquist and others, 2011; Bedford and others, 2011)

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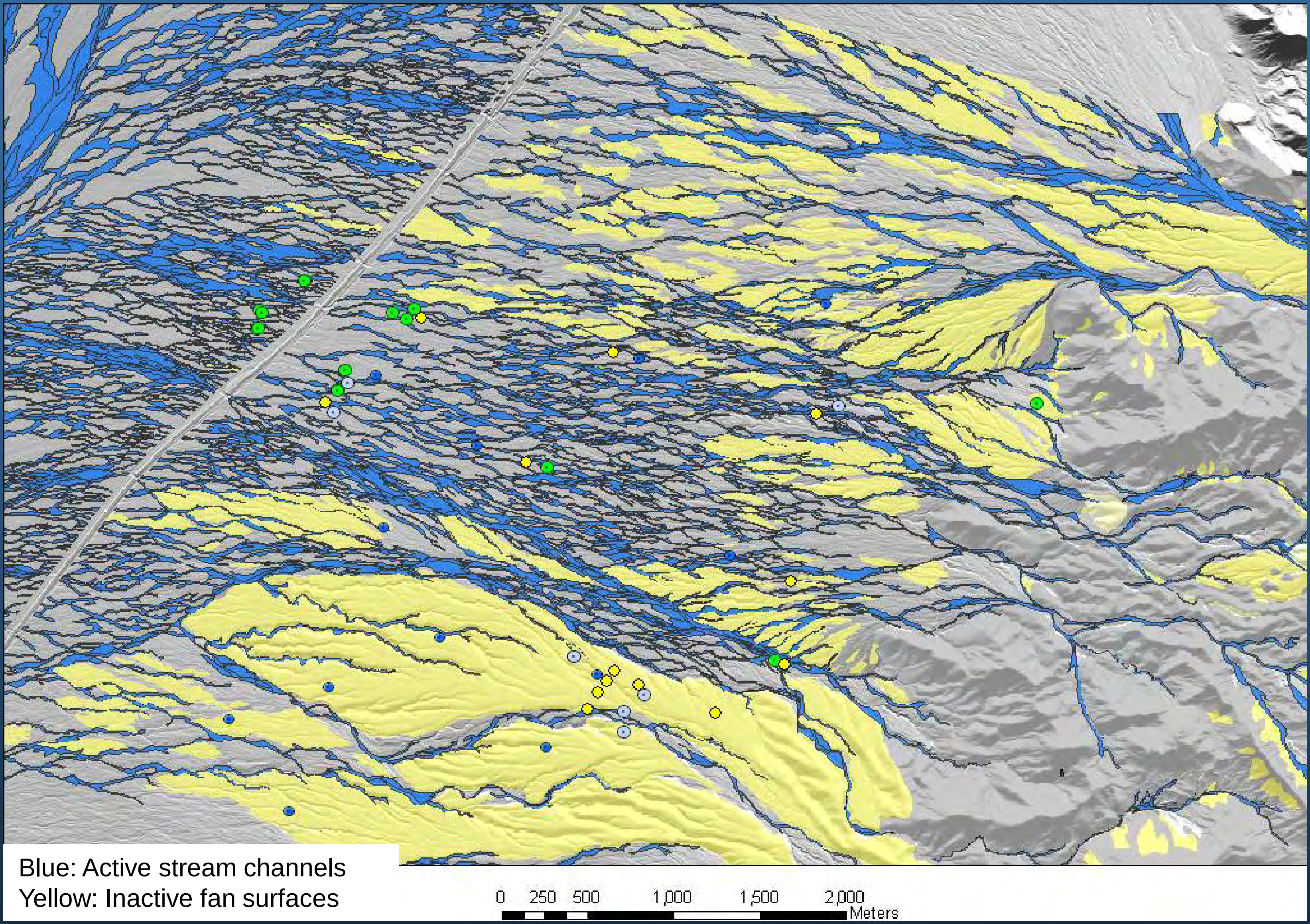

How much of the piedmont is influenced by runoff?

What is the result of increased or decreased discharge? Altered frequency?

How will monsoon changes affect stream flow?

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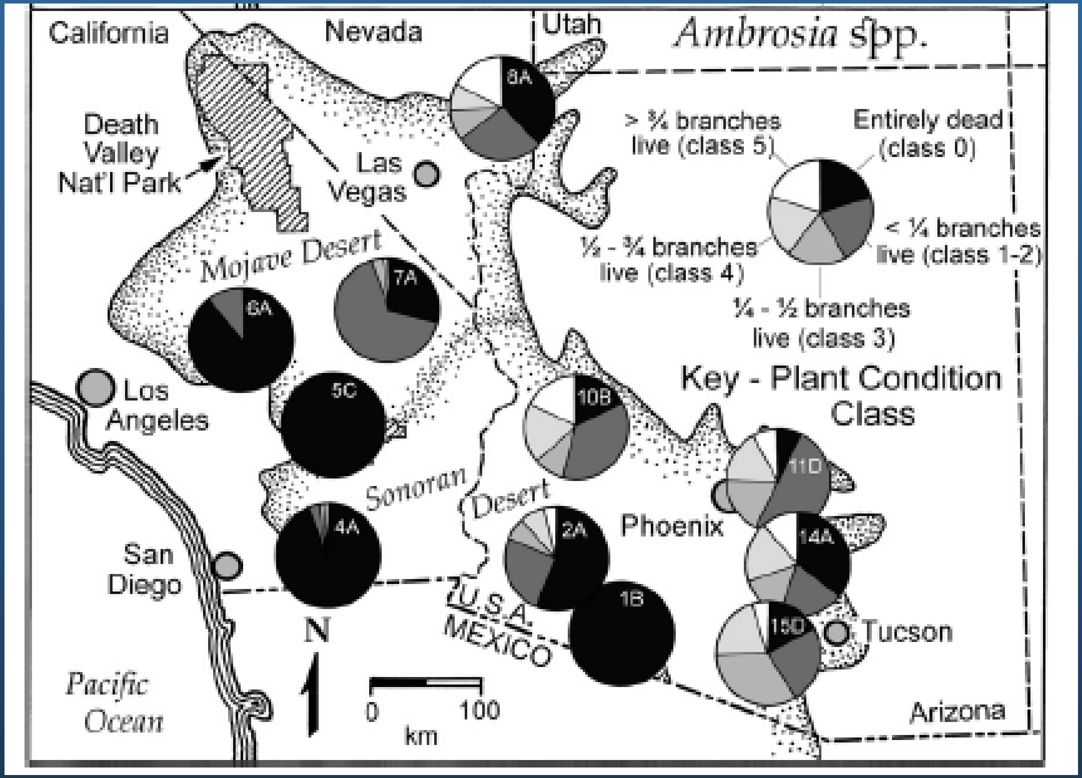
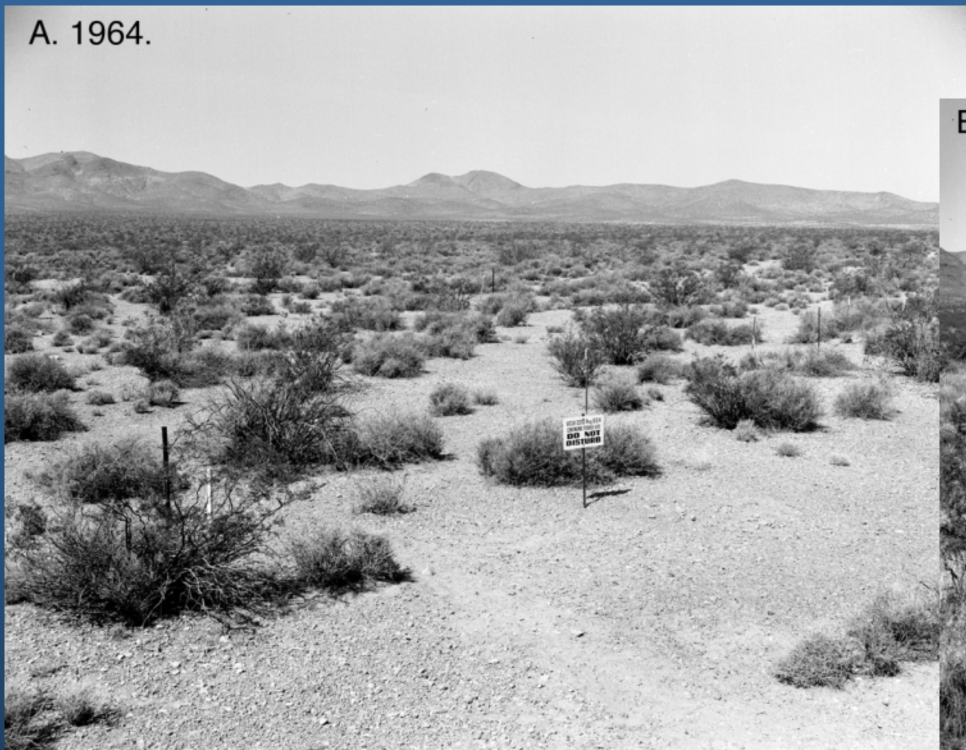
Temporal Resolution: Mojave Desert Piedmonts—Drought Mortality 1998–2002



- Drought mortality is plant-function specific
- Shows strongest correlation with 5-year aridity (cool season)

(From McAuliffe and Hamerlynck, 2010)

Temporal Resolution: Mojave Desert Piedmonts—Recruitment



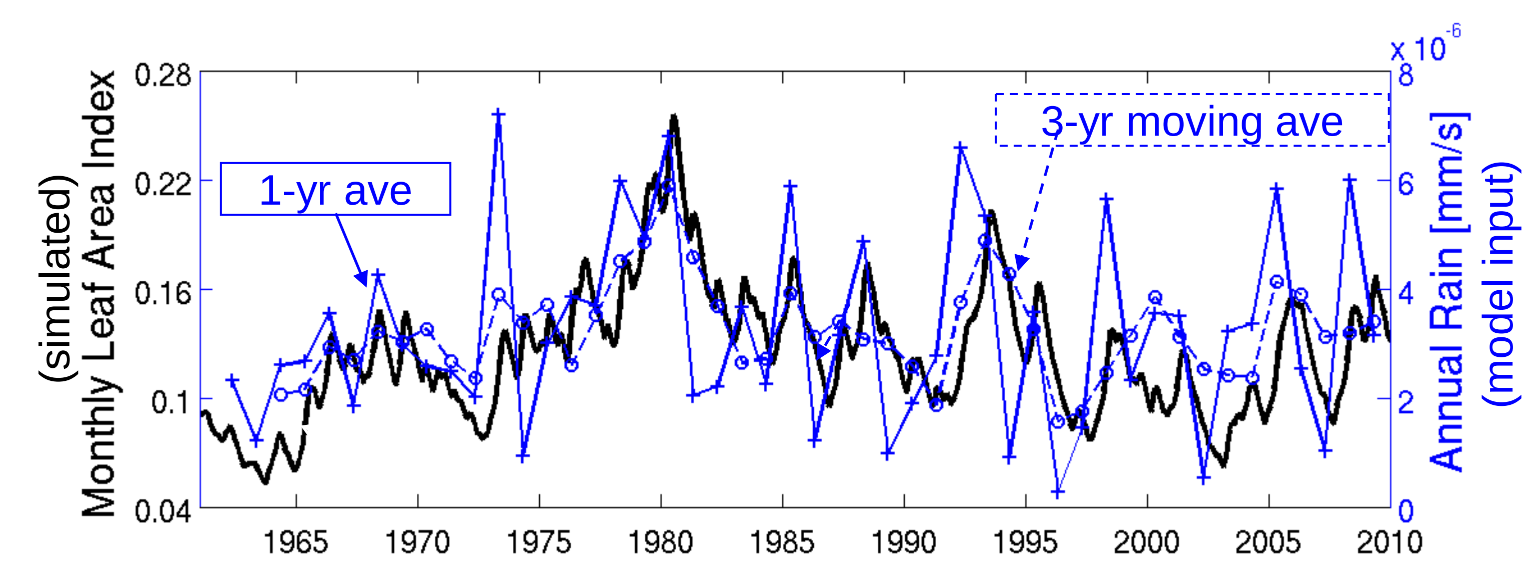
Long-term plot studies, Nevada Test Site (From Webb and others, 2003).

Periods of recruitment and drought strongly affect plant cover and species composition.

Temporal Resolution: Mojave Desert Model—Vegetation Response to Climate

Data assimilation modeling: (Ng and others, unpublished data)

- Numerical ecohydrological model (hourly time step) combined with monitoring data
- Reveals prolonged impact of climate on creosote bush over a range of time scales



Greater than 1-year (yr) rainfall totals appear to drive trends in creosote bush leaf area index (LAI). ave, average; mm/s, millimeters per second.

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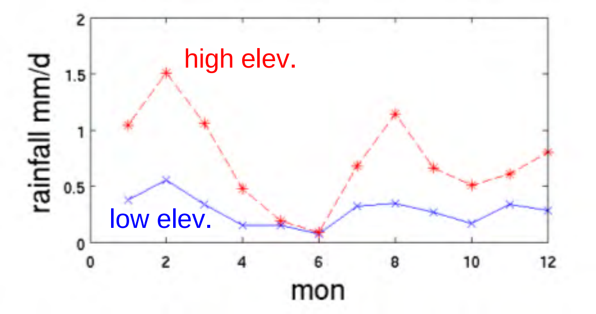
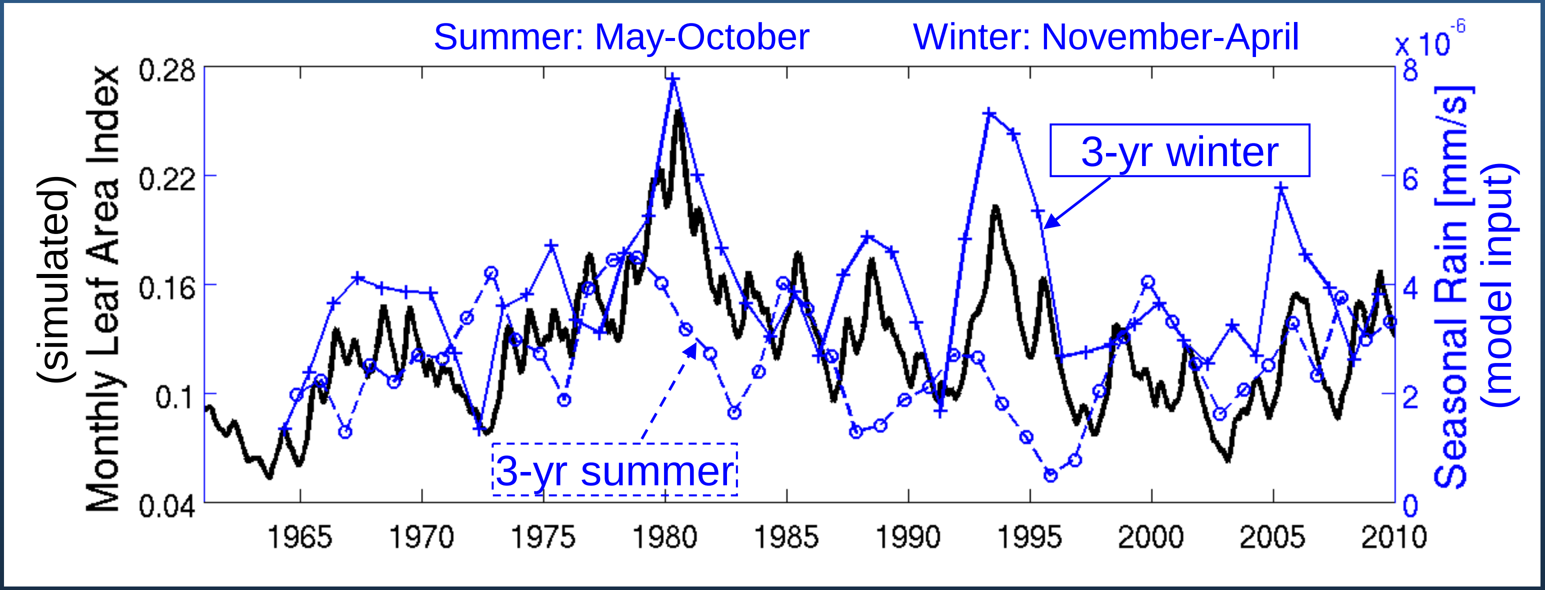
Temporal Resolution: Mojave Desert Model—Seasonal Effects



Bimodal rainfall (intense, short summer rains, steadier winter rains)



Winter rains seem more important than summer rains for creosote. yr, year; mm/s, millimeters per second.

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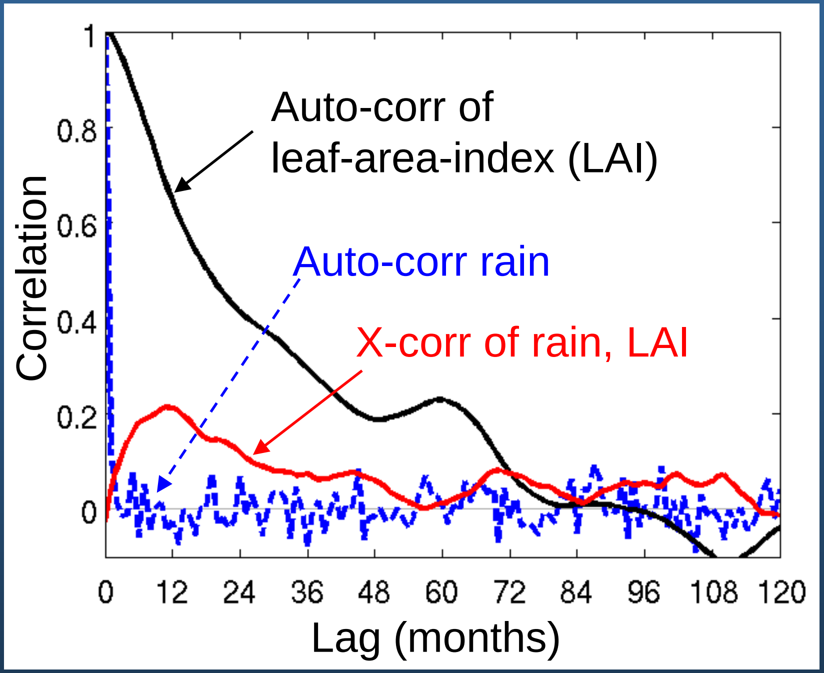
Temporal Resolution: Mojave Desert Model—Plant Persistence

Correlation (corr) calculated with rainfall input data and calibrated leaf area index (LAI) simulations



- Vegetation trends persist ~5–6 years
- Vegetation dynamics lag rainfall ~1 year

DIVERSE relevant time scales in climate and vegetation:

2–3+ year **winter** rains drive vegetation (creosote) dynamics.

Vegetation trends lag rains by a year and then persist for as much as 5 years.

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Temporal Resolution: Mojave Desert Piedmonts

Extreme events are very important:

- Subhourly (to predict rainfall runoff in stream channels)
- Seasonal (heat wave, drought)
- Multiseasonal (drought, winter wet, freezing roles in recruitment)

We depend on datasets that honor the extreme values.

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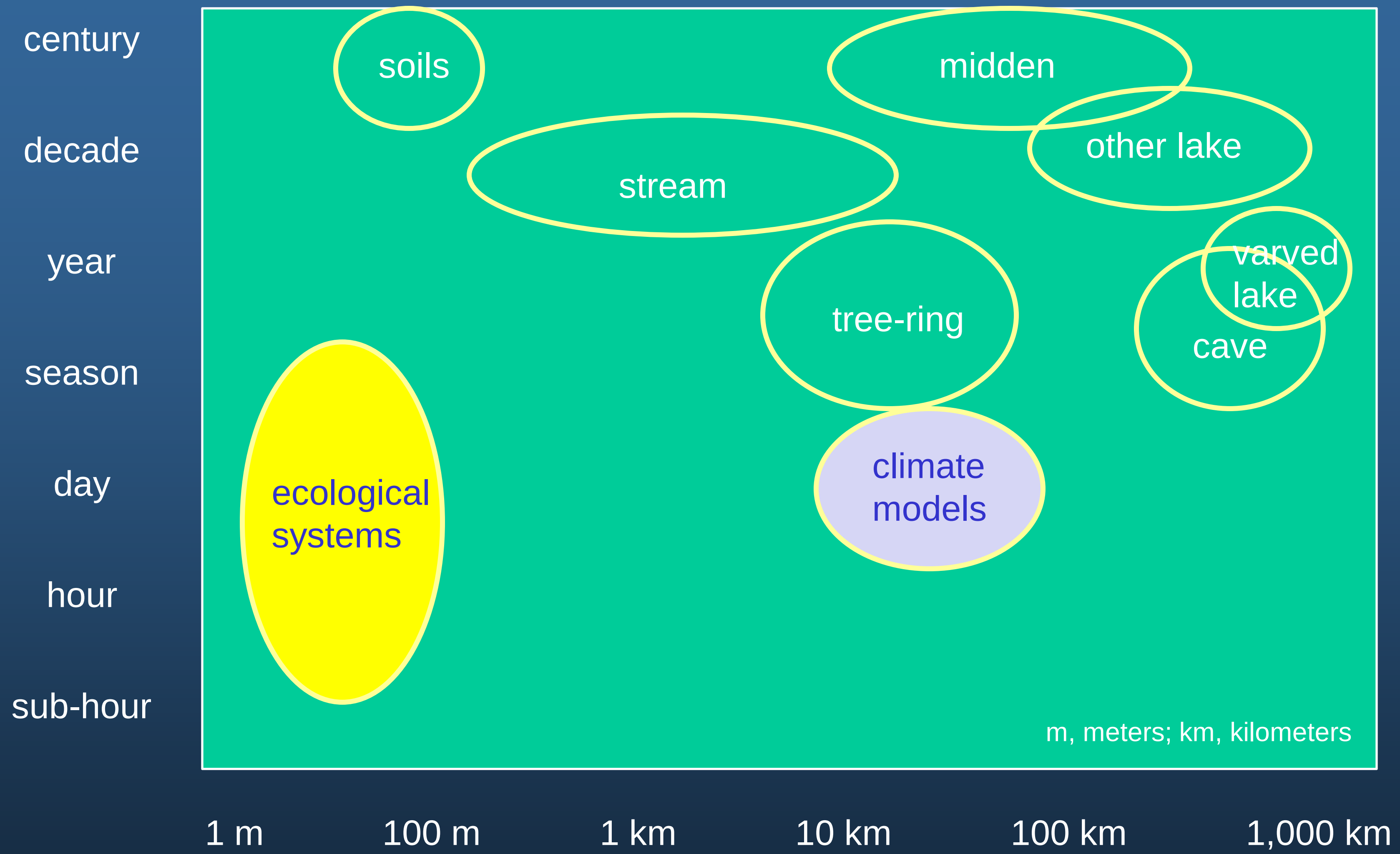
Temporal and Spatial Scales

Paleoecology records: Various kinds of records offer varying scales of temporal and spatial data.

Temporal and Spatial Scales



Needs for ecology do not match much of the data available. Paleo-records that offer temporal resolution come from unusual places (caves, lakes, springs, forests)!

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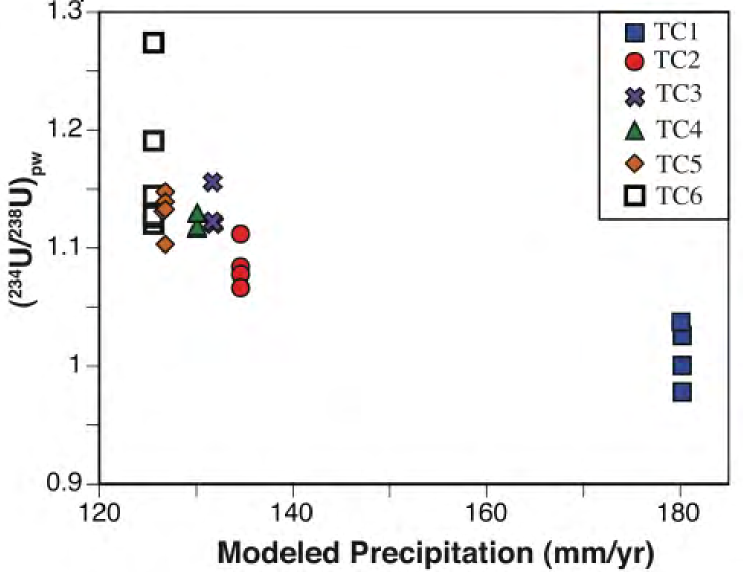
High Spatial Resolution: Can We Get Smart About Soils in Typical Lowland Settings?

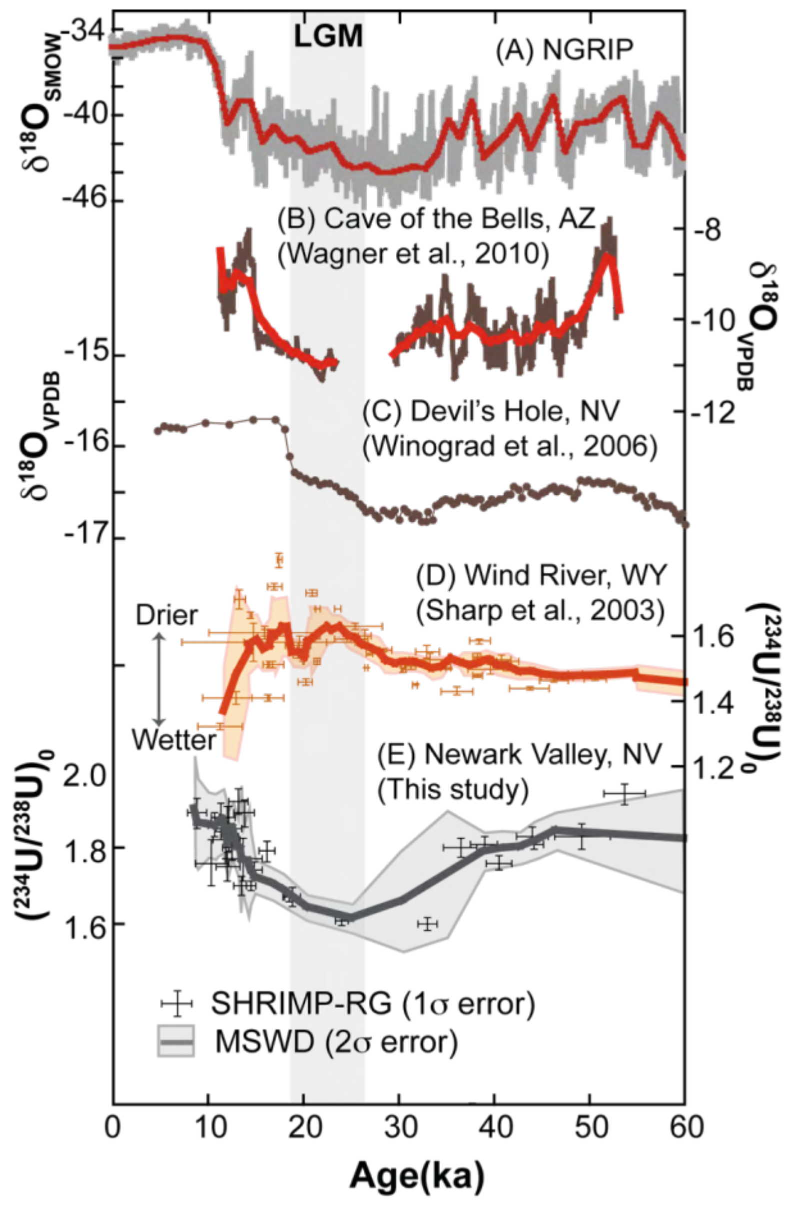
An Example: Microbeam Technology to Explore Uranium (U) Isotopes in Soil Opal

Uranium-234/238 ($U^{234/238}$) ratio is a measure of residence time of soil water and shows climatic correlations.

Modern soil-water U isotopes, Fish Lake Valley, Nevada, correspond to modern rainfall.



mm/yr, millimeters per year. From Oster and others, 2012.



Paleo soil-water U isotopes from Arizona (AZ), Nevada (NV), and Wyoming (WY) over the past glacial cycle compared to Oxygen (O) isotopes and Greenland ice sheet (North Greenland Ice Core Project, NGRIP) data. LGM, Last Glacial Maximum; SHRIMP-RG, Sensitive High Resolution Microprobe-Reverse Geometry; MSWD, mean square weighted deviation; ka, kilo-annum.

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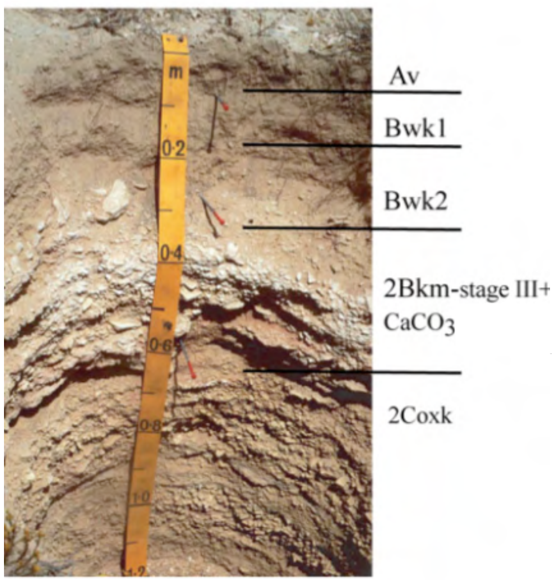
High Spatial Resolution: Can We Get Smart About Soils in Typical Lowland Settings?

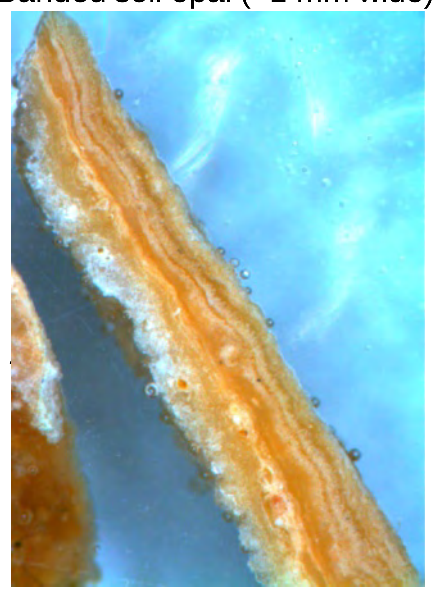
Can we use phytoliths in soil to create dated high-resolution proxies for soil properties and plant communities?
What other informative objects persist in soil?

Soil profile



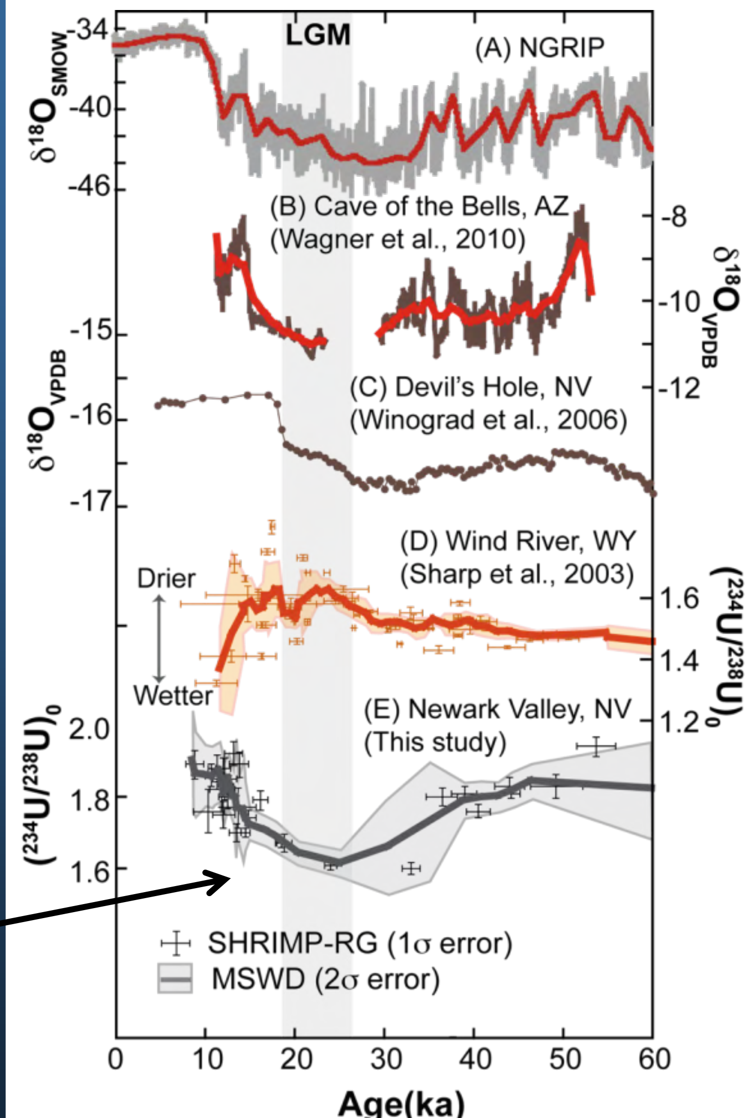
Newark Valley, Nevada

Banded soil opal (~1 mm wide)



Pedogenic $CaCO_3$ and SiO_2(am)

mm, millimeter; $CaCO_3$, calcium carbonate; SiO_2(am), silicon dioxide (amorphous).



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Solutions for The Resolution Gap

- Use mechanistic and assimilation models to generalize spatially and temporally without(?) loss of content
- Use climate models and climate dynamics to identify proxies for high temporal resolution events in lower resolution data
- Improve paleoecologic and paleoclimate data for targeted species, time periods, and processes
- Use assimilation models to simulate landscape processes, validate with paleoecologic data, and then forward model the future

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