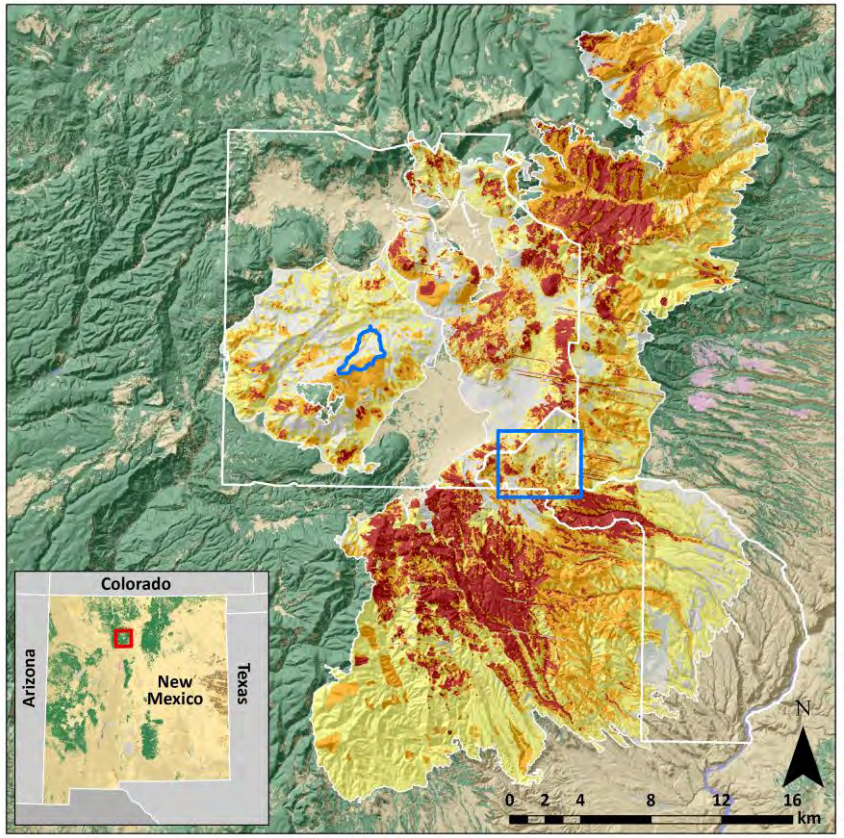
Climate Change: Understanding the Impact of Drought, Wildfire, and Infestation

Richard S. Middleton
Earth and Environmental Sciences
Los Alamos National Laboratory
rsm@lanl.gov






Multidisciplinary Problem, Multidisciplinary Team

LANL Investigators

- Adam Atchley, Katrina Bennett, Michel Brown, Ethan Coon, Kristen Honig, Dan Johnson, Alex Jonko, Eugene Kikinzon, Eunmo Koo, Rod Linn, Nate McDowell, Jordan Muss, Isabelle Runde, Alexei Skurikhin, Scott Speckart, Melissa Teter, Nathan Urban, Jorge Urrego-Blanco, Liang Wei, Judy White, Chonggang Xu

External collaborators

- Craig Allen (USGS)
- Ted Bohn (Arizona State University)
- Paul Brooks (University of Utah)
- Scott Goodrick (USDA-FS)
- Ben Livneh (University of Colorado, Boulder)
- Scott Painter (Oak Ridge National Laboratory)
- Bob Parmenter, John Swigart (Valles Caldera National Preserve)
- Roy Rasmussen (National Center for Atmospheric Research)
- Tom Swetnam (University of Arizona)
- Laura Trader (Bandelier National Monument)

Critical Watersheds

Climate, ecosystem change, and hydrology

Extreme events: drought/floods, heat waves, cold

No analog future: novel combinations of temperature and precipitation, unknown ecological response

Disruptive events: temperature-drought stress/mortality, wildfire, and infestation

Catastrophic drought, plant mortality

Impacts

- Massive impact on short- and long-term water security: quantity, quality, and timing
- Substantial implications for the energy-water nexus

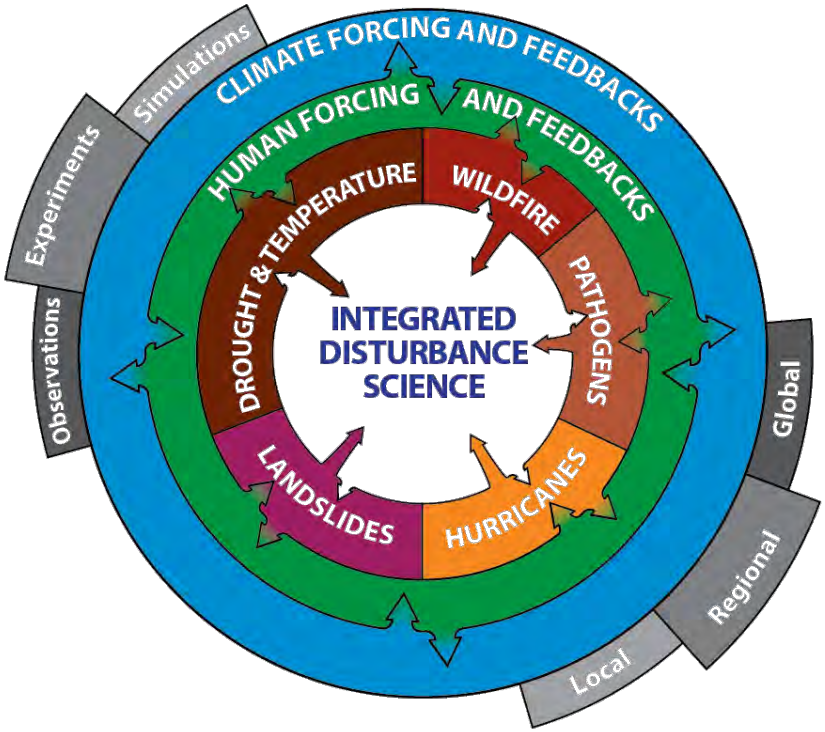
Increased frequency and intensity fires

Energy: short-term disruptions

Energy: Long-term shortages

Flood, devastating debris flows

Climate-driven Disturbances

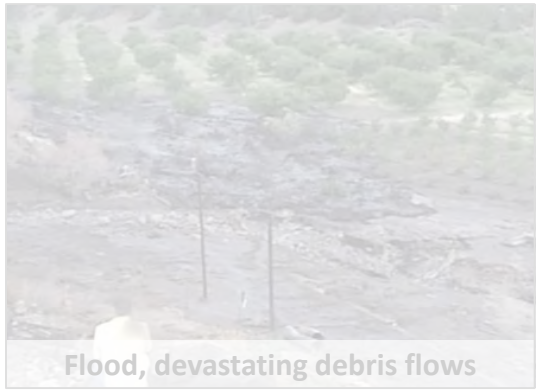


Catastrophic drought, plant mortality

Increased frequency and intensity fires

Energy: short-term disruptions

Energy: Long-term shortages



Flood, devastating debris flows

Drought/temperature-induced Stress & Mortality

Global impacts

- Carbon flux (~10 Pg C mortality)
- Carbon flux (~6 Pg C yr^{-1} growth reduction)
- Albedo

Local impacts

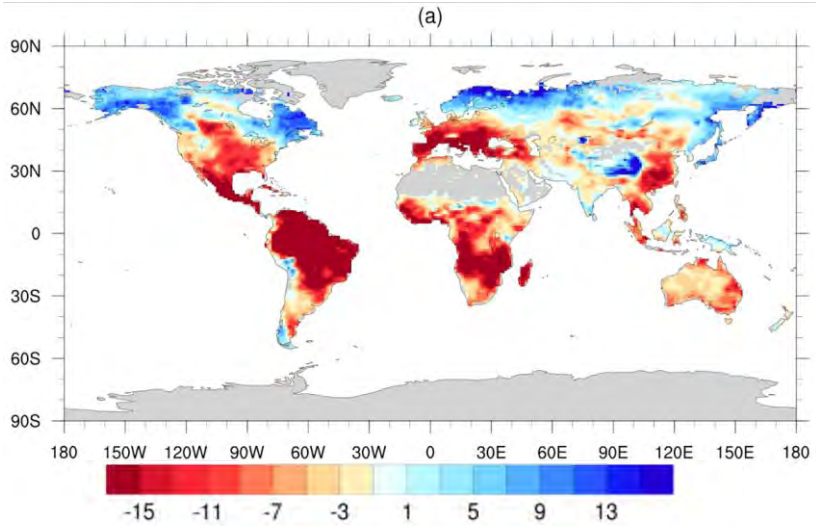
- Vegetation mortality
- Quantity, quality, and timing of water supply

Drivers

- Chronic temperature rise
- Precipitation extremes

Integrated disturbances

- Promotes fire, beetles, and erosion



Relative change in net primary production due to drought
Xu et al. in review

Wildfire

Global impacts

- Carbon flux (~2 Pg C)
- Changes in albedo and land surface coupling
- Injection of particulate into upper atmosphere

Local impacts

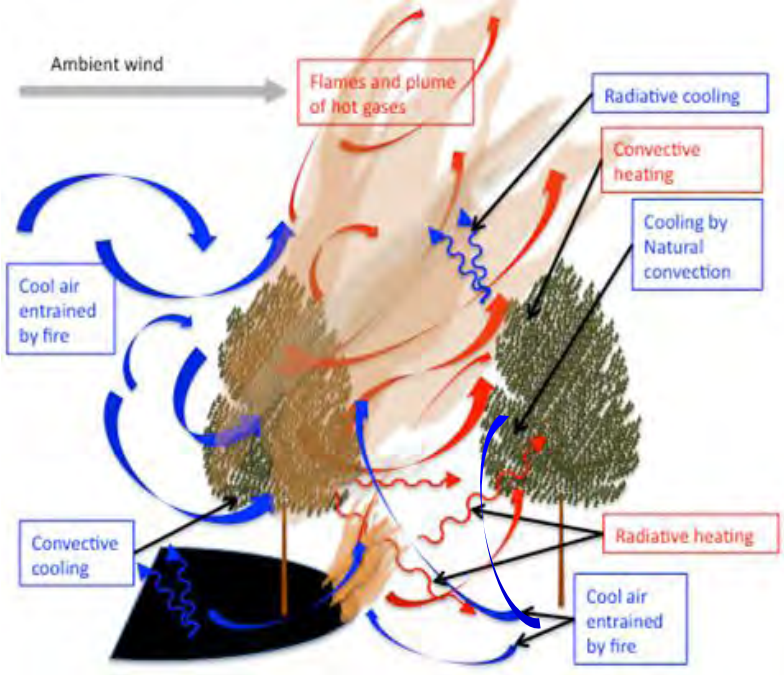
- Fast change in vegetation structure
- Surface and subsurface hydrology

Drivers

- Past disturbances (severity and frequency)
- Ecosystem productivity or fuels management
- Wind and storm events
- Seasonal/annual weather variations

Integrated disturbances

- Changes in: vegetation type and load; erosion, drought, temperature and insect resilience



Insects and Pathogens

Global impacts

- Carbon flux (large but unknown globally)
- Albedo and snow pack changes

Local impacts

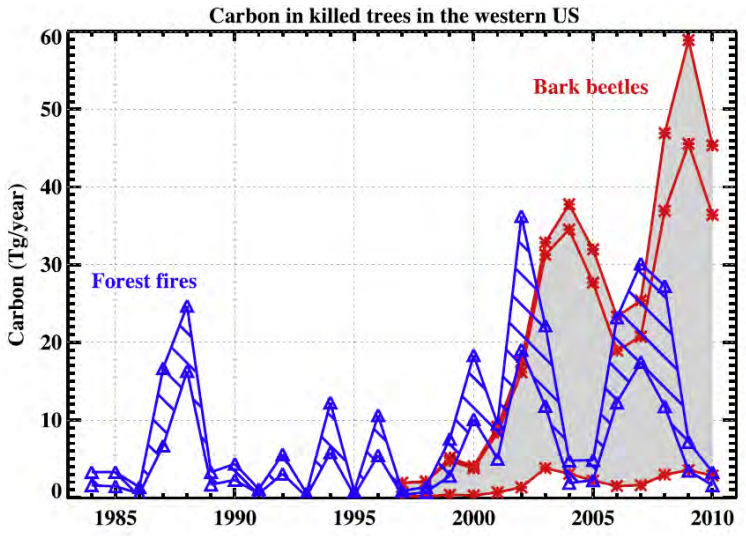
- Vegetation mortality
- Quantity, quality, and timing of water supply

Drivers

- Chronic temperature rise (winter important)
- Precipitation extremes

Integrated disturbances

- Feeds back upon fire, drought, warming, erosion



Hicke et al. 2013

Abiotic Disturbances

Landscape evolution

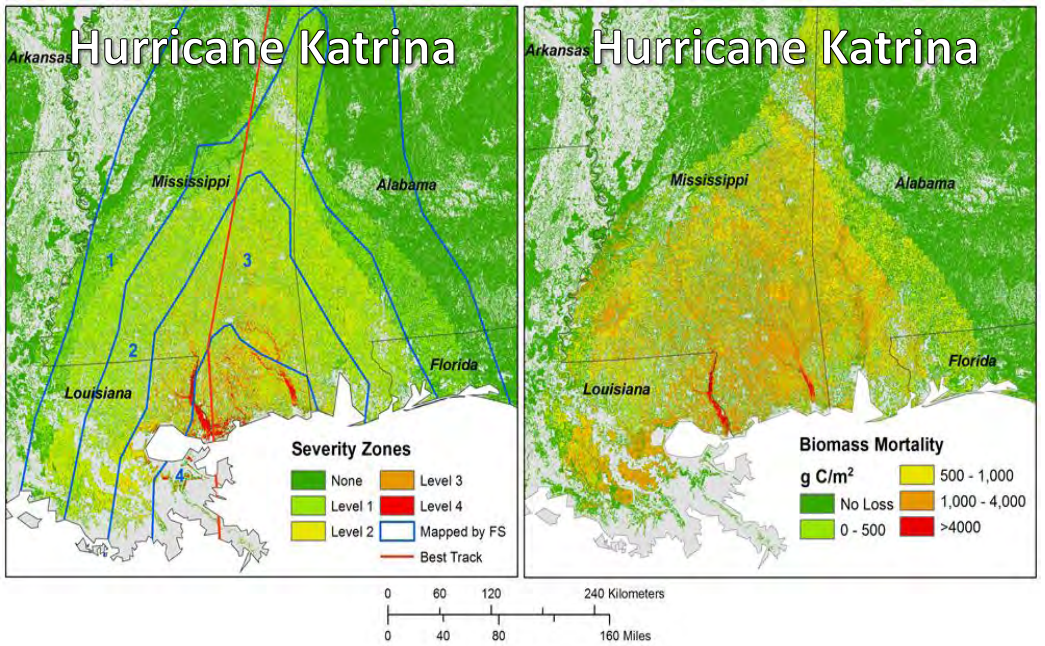
- Flooding
- Landslides

Wind

- Blow-downs
- Hurricanes

Anthropogenic

- Land use change, forest management



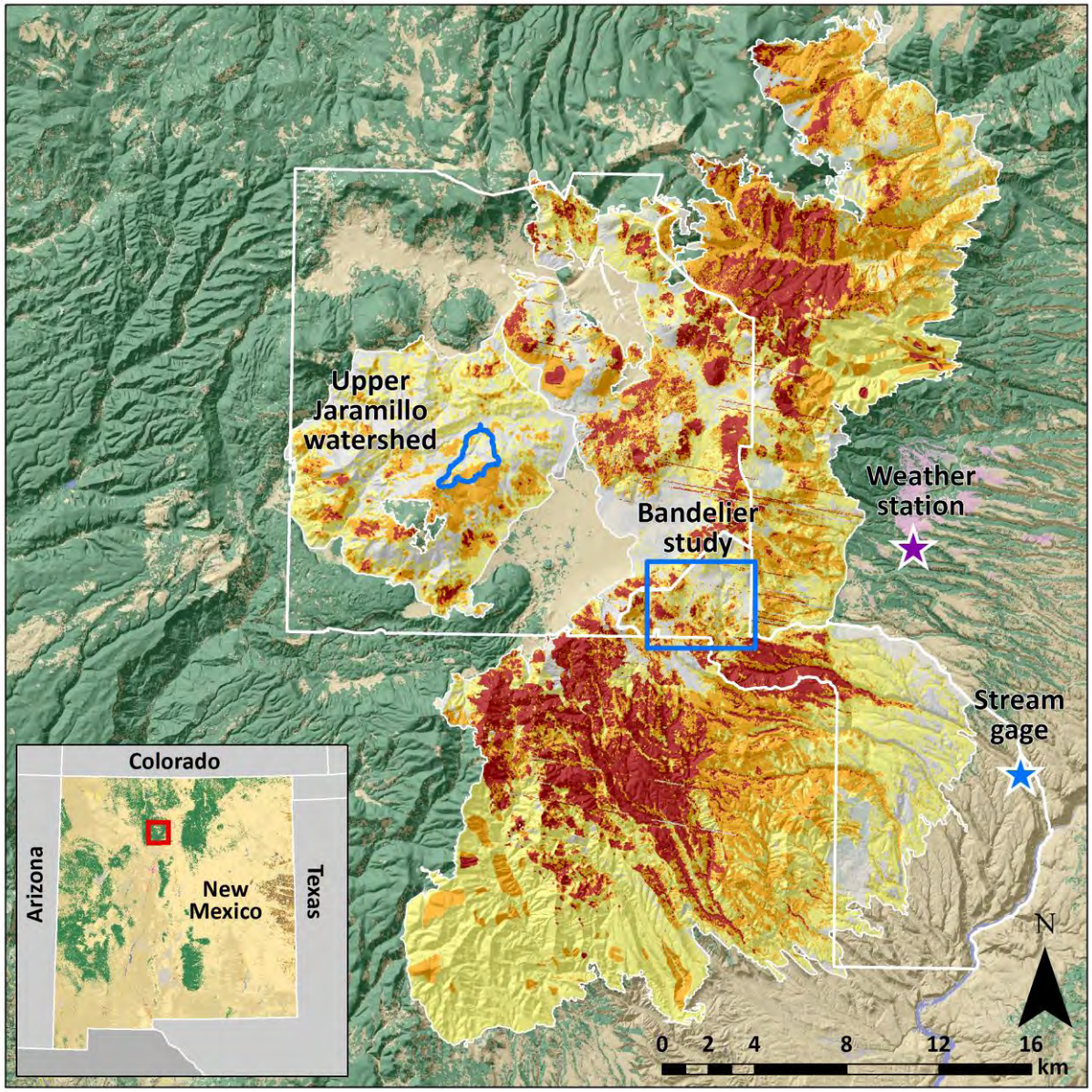
LA-UR-16-21758

Disturbance and the Southwest

History of disturbance

- Drought, temperature, wildfire, infestation, flooding/landslides, blowdown

http://www.foxnews.com/us/2013/06/02/new-mexico-fights-wildfire-blazes-calif-area-evacuated.html



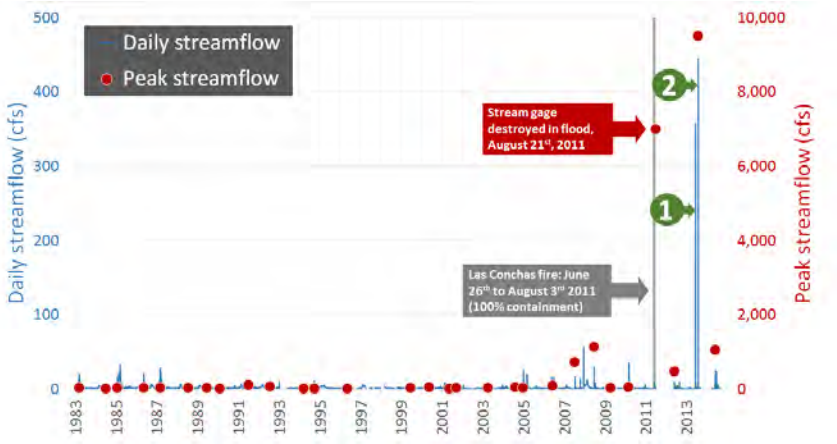
Cascading Processes and Impacts

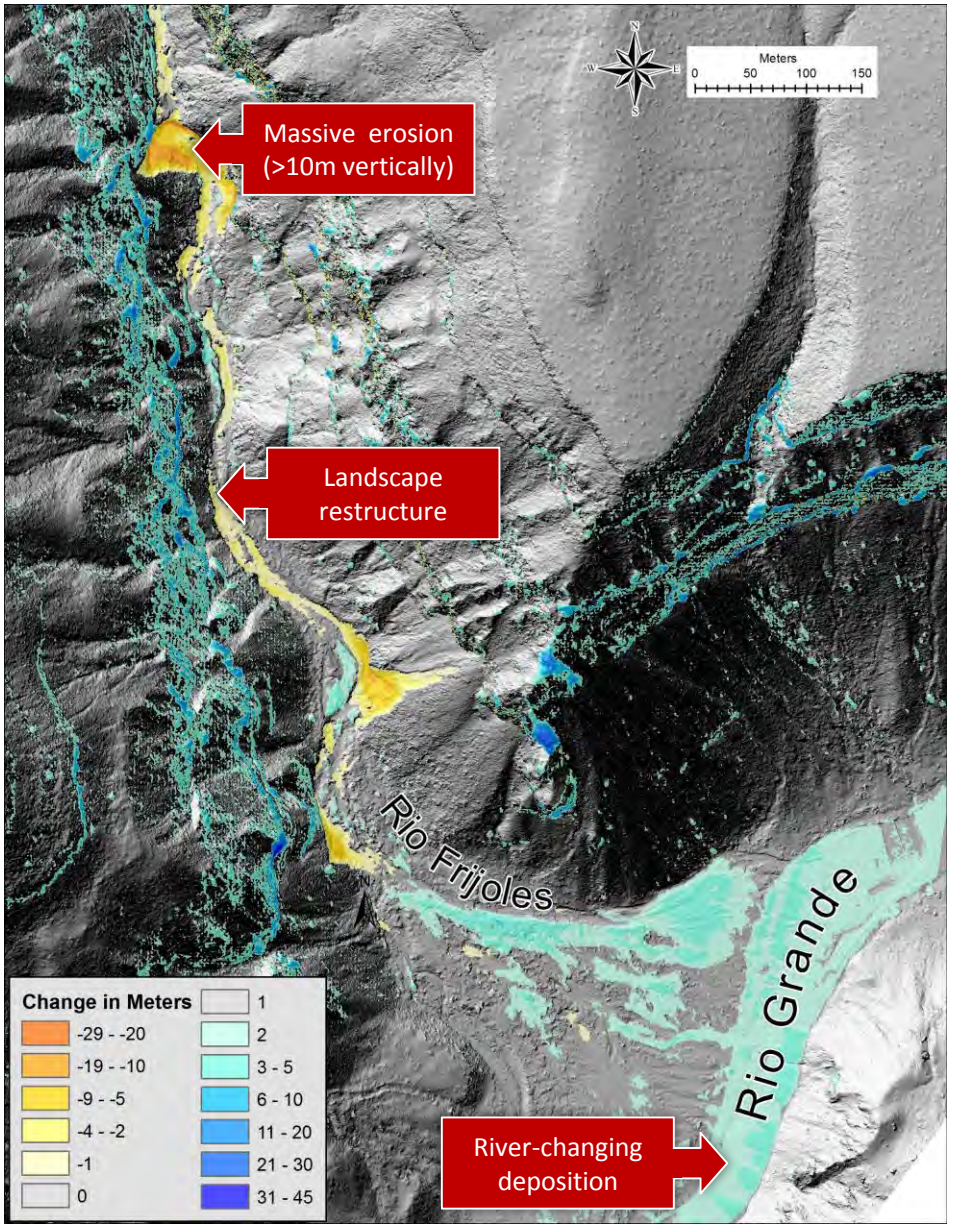
Linked, cascading events

- Drought, infestation, forest management, fire, extreme precipitation, flood
- Ecosystem tipping point: fundamental restructuring of ecology and hydrology

Impacts

- Massive erosion/deposition
- Critical infrastructure
- Future?



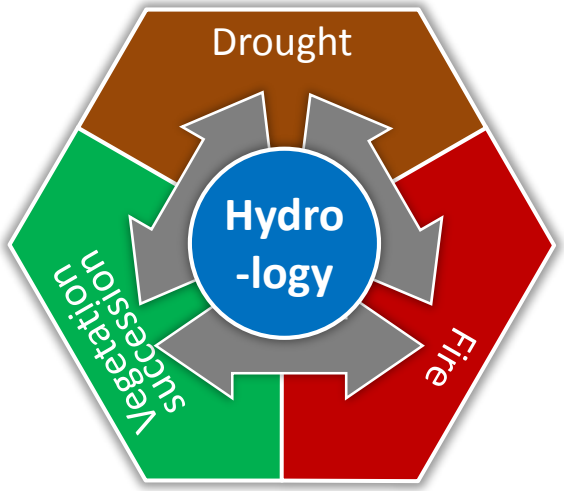


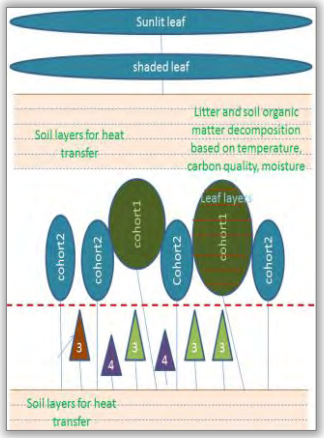
Why LANL?

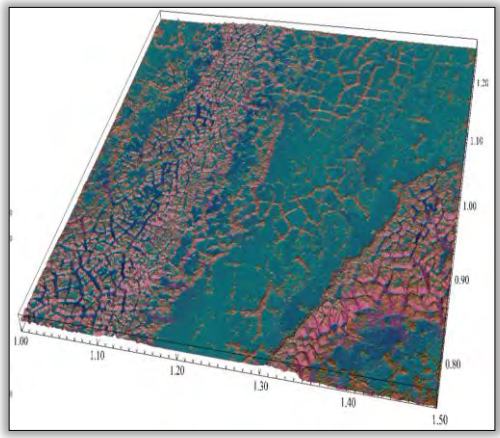
Integrate high-impact capabilities in drought, plant mortality, fire, vegetation succession within the hydrologic cycle to assess water supply impacts

Key project components – LANL capabilities

1. Coupled hydrology-ecosystem framework
2. Plant mortality and drought ecology
3. Vegetation succession
4. Fire behavior
5. Extreme climate projections
6. Remote sensing and algorithms

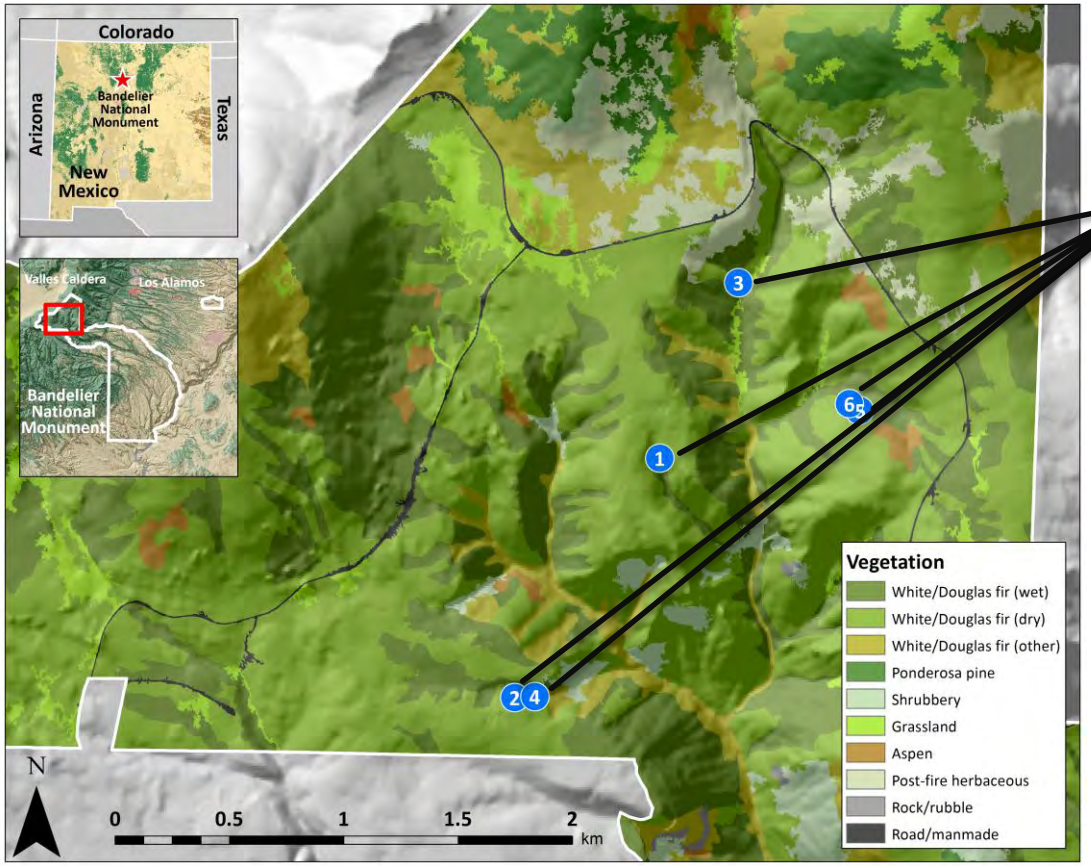


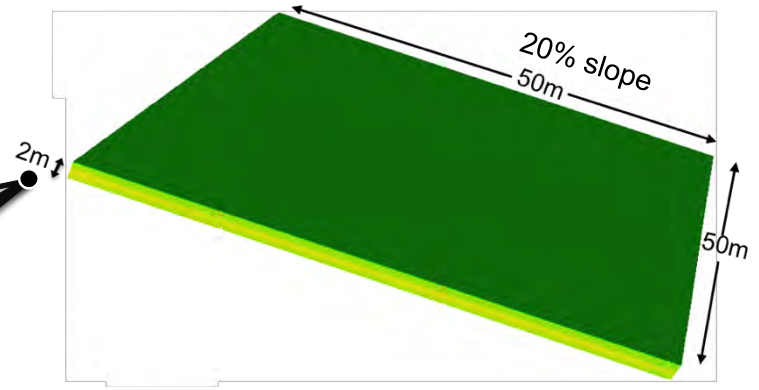




Las Conchas Fire, Upper Frijoles Canyon

- Incorporating field data from Bandelier National Monument in to fine scale surface-subsurface hydrologic model



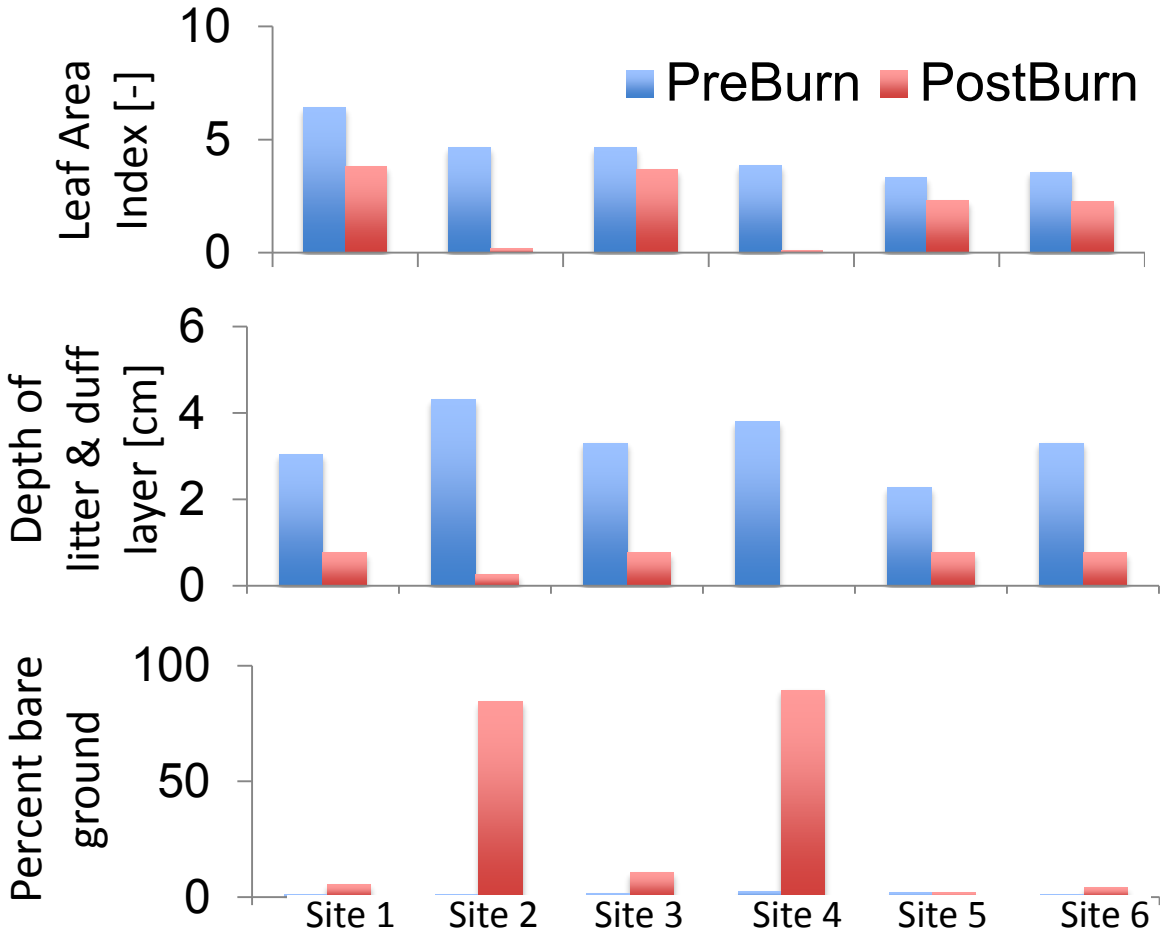


Simulating before and after fire vegetation conditions

- Resolving 3D Richards equation, surface flow, and evapotranspiration for a full water budget estimation.
- Parflow-CLM

Bandelier National Monument Data

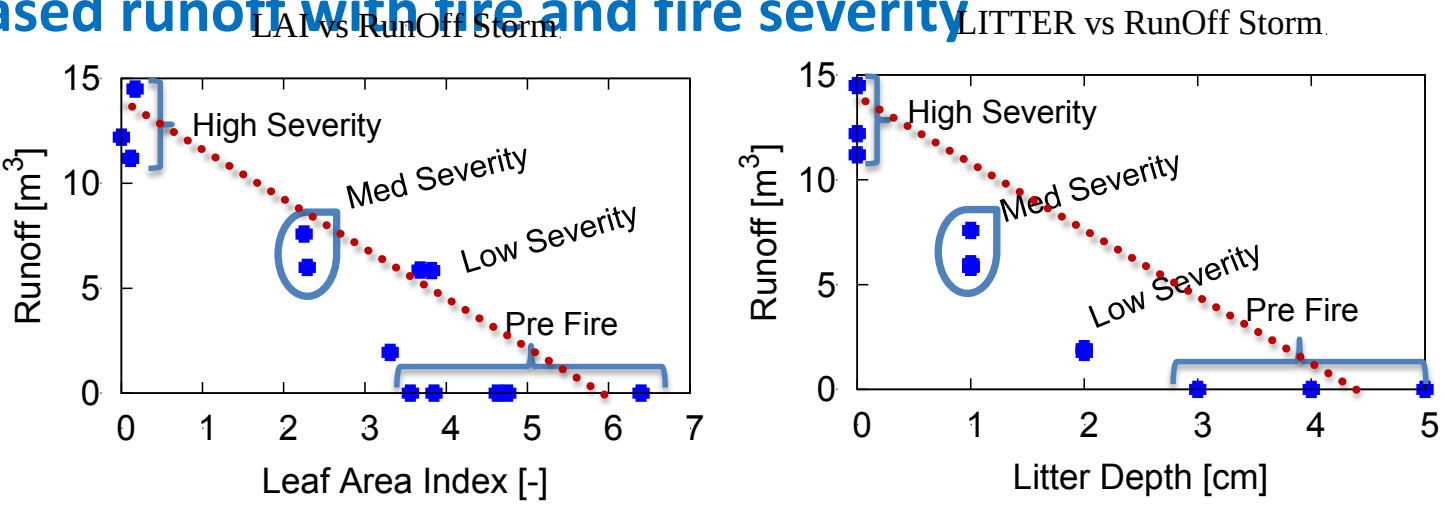
Vegetation & Surface Characterization



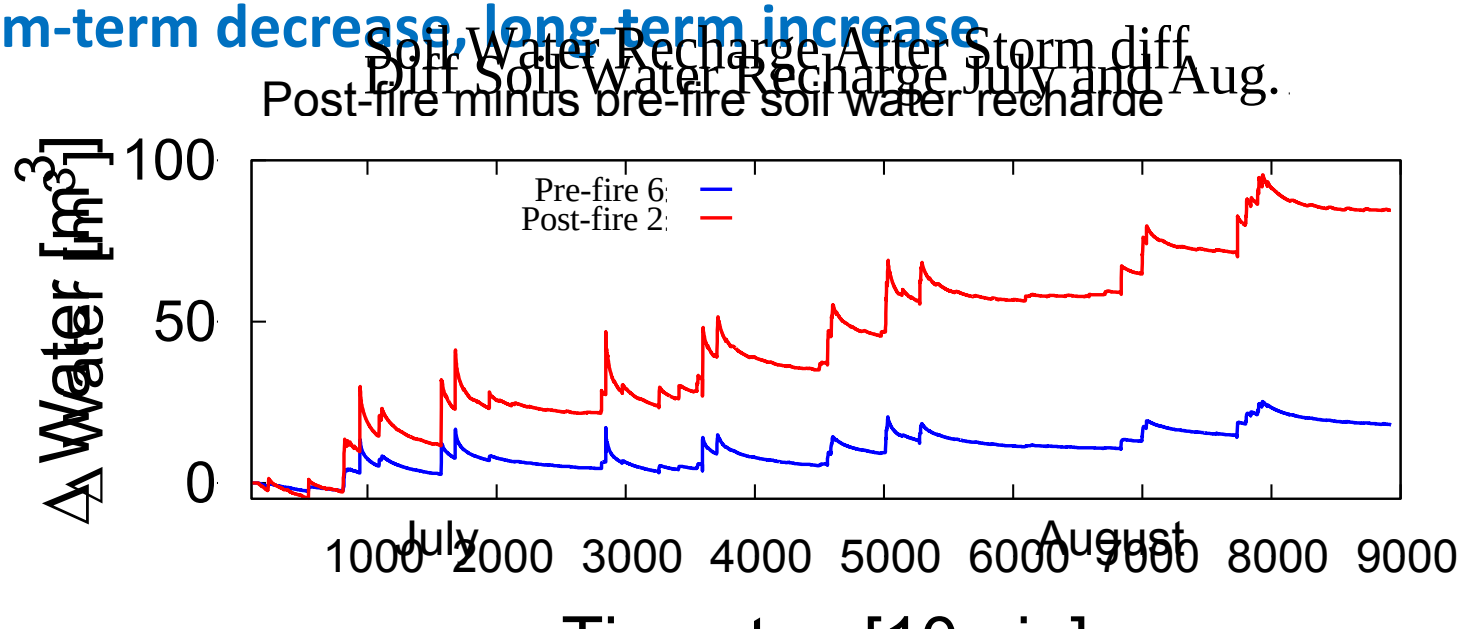
LA-UR-16-21758

Results

Increased runoff with fire and fire severity

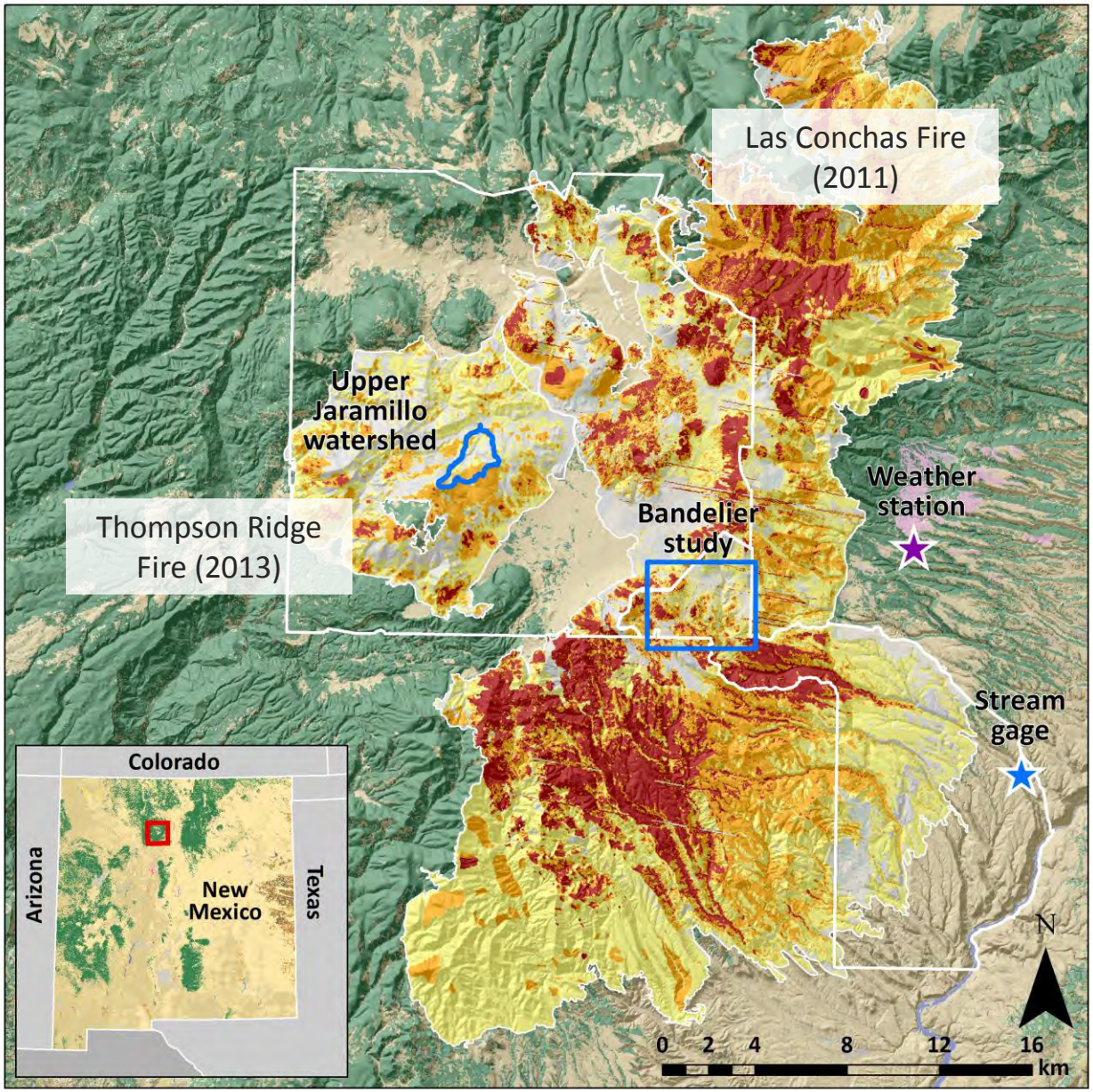


Medium-term decrease, long-term increase



LA-UR-16-21758

Upper Jaramillo Demonstration

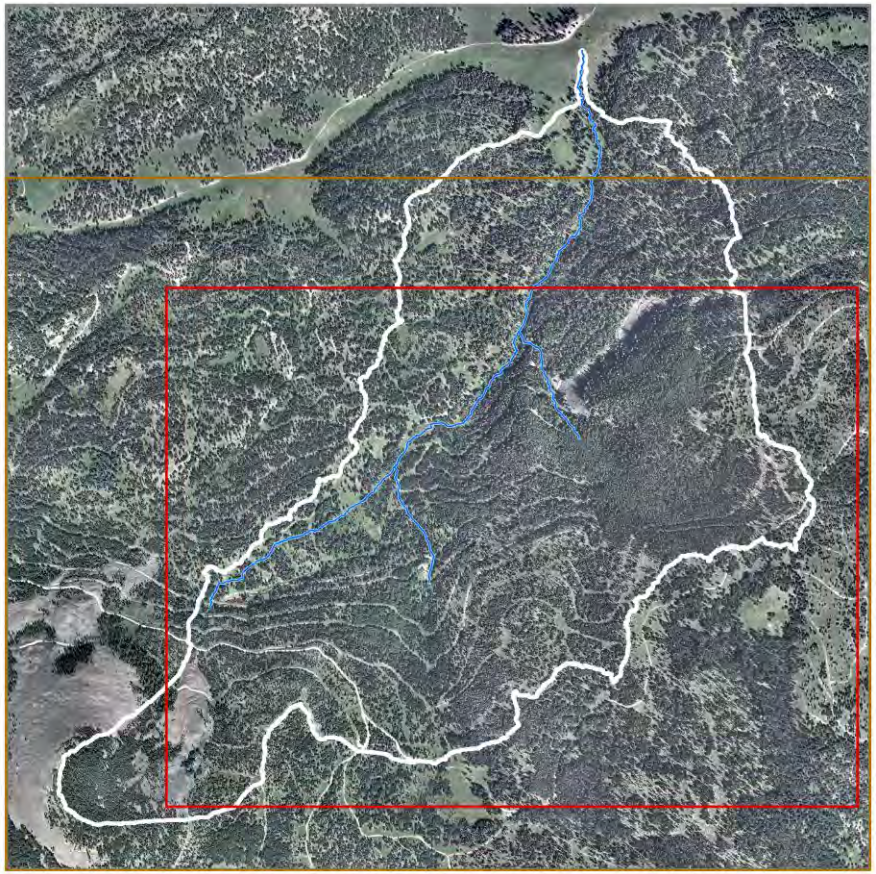


Upper Jaramillo Watershed

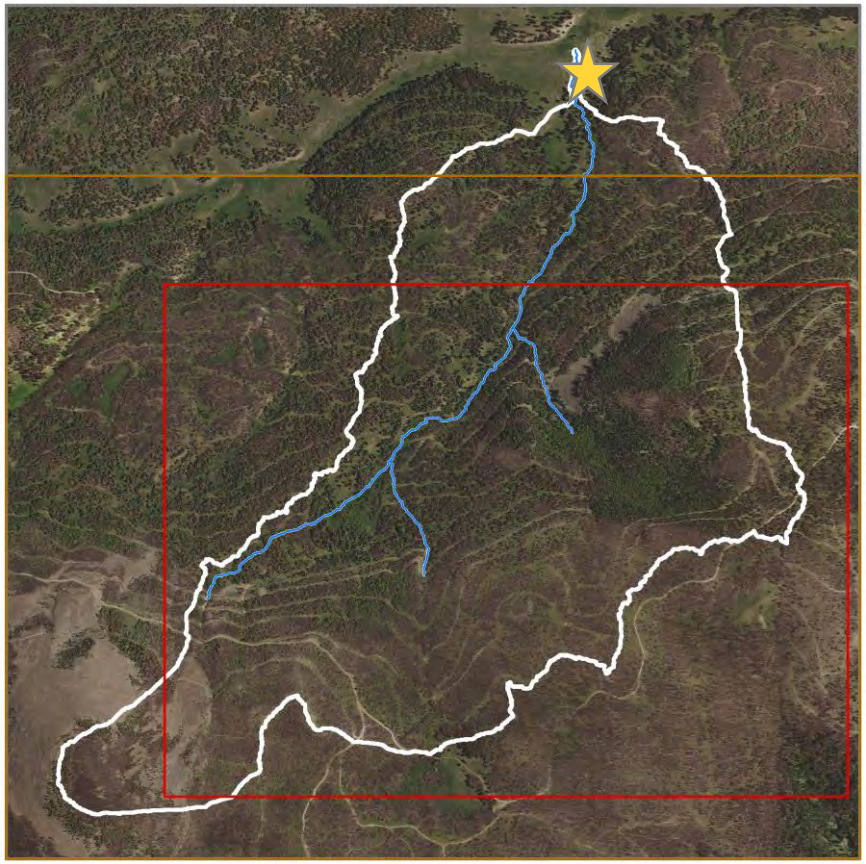
- Primary watershed
- Variably burned in the Thompson Ridge Fire
- NSF-CZO partners
- Well-instrumented and surveyed
- LIDAR data
- Stream gauge (survived fire), nearby Meteorology stations

LA-UR-16-21758

Upper Jaramillo: Fire History

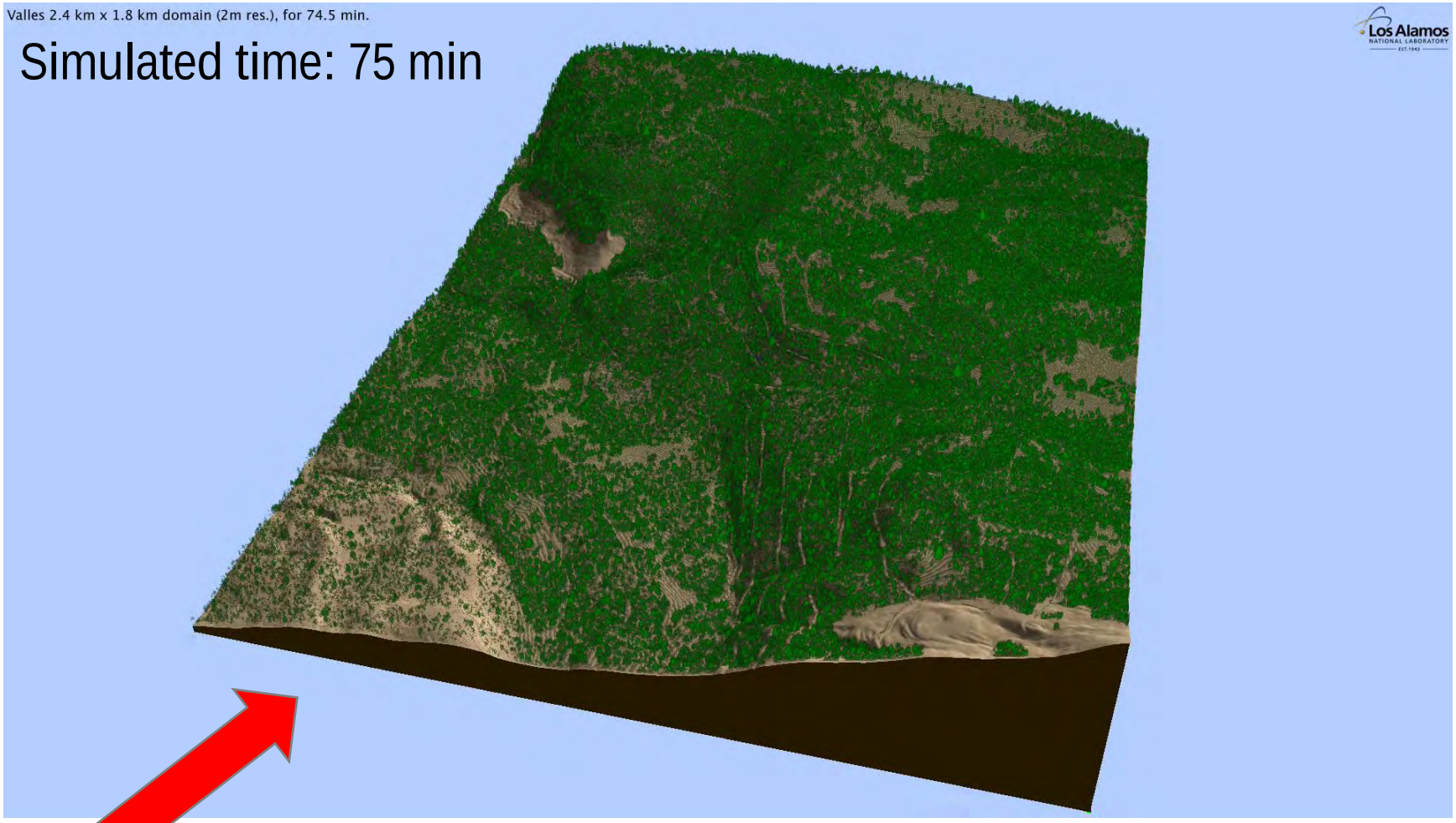


pre-fire



post-fire

FIRETEC: Upper Jaramillo



Ambient wind

10 m/s at z=10 m

(similar to Las Conchas Fire conditions on first afternoon)

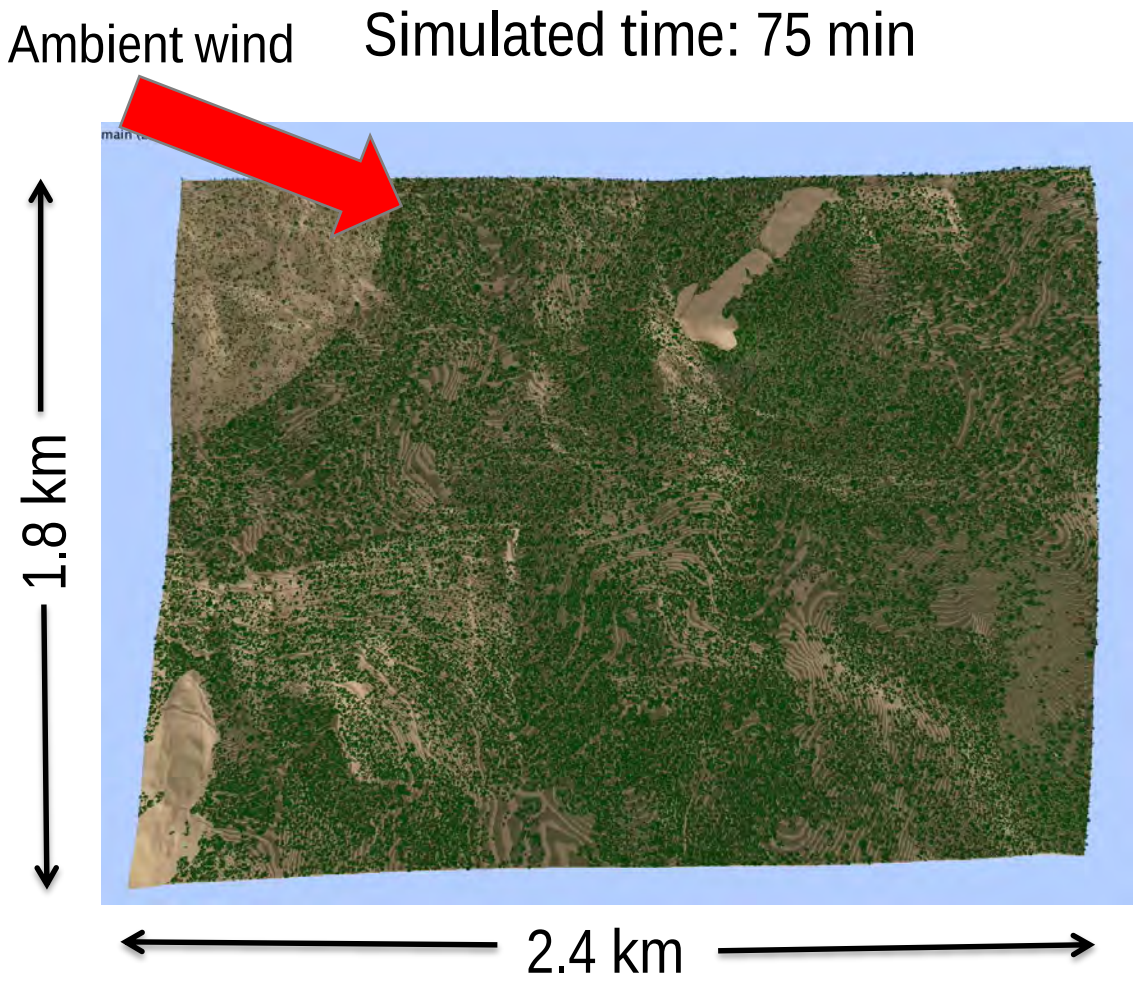
FIRETEC: Upper Jaramillo

Simulations capture

- Heterogeneous burn patterns and fuel consumption
- Influences of topography
- Influences of vegetation patterns

Significant cost

- 3M CPU hours for this 75 minute simulation (~24 days on 5000 processors)
- Unrealistic computational cost for performing ensembles of calculations



LA-UR-16-21758

QUICFire Development

Fast-running diagnostic wind model

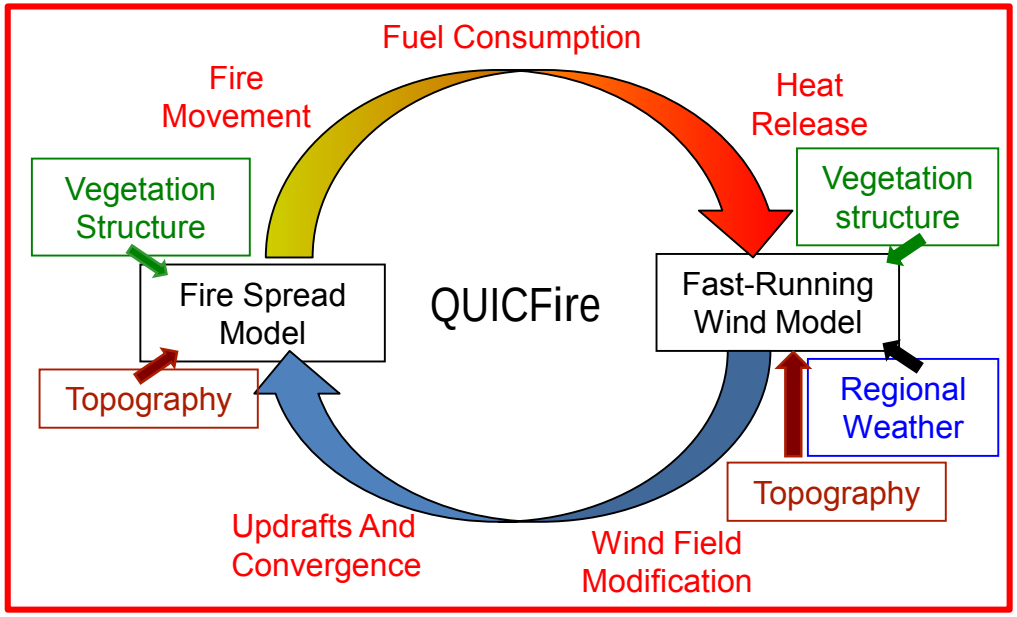
- Combines influences of ambient wind and fire influences
- Influenced by vegetation structure and topography

Reduced-order fire spread model

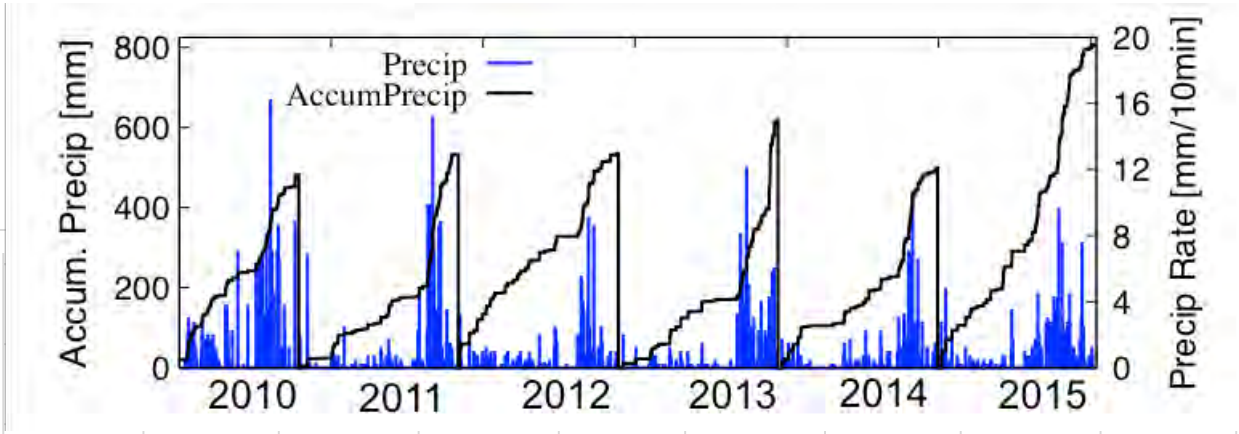
- Based on Cellular Automata (CA) framework
- Fire spread and intensity
- Fuel consumption consistent with burning conditions
- Impact on local wind field

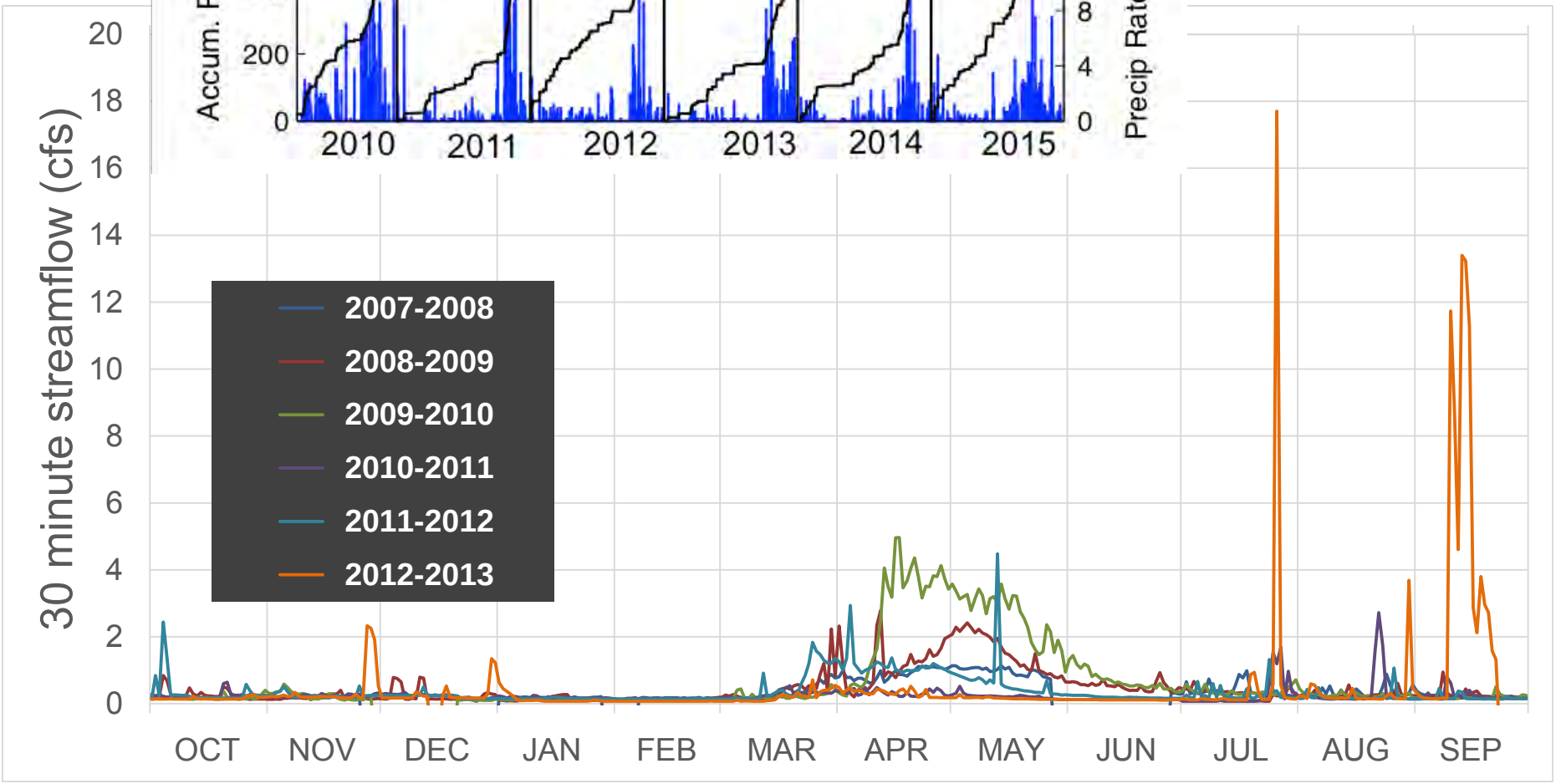
Spin off

- Funded for urban wildfire
- National security applications



Upper Jaramillo: Streamflow

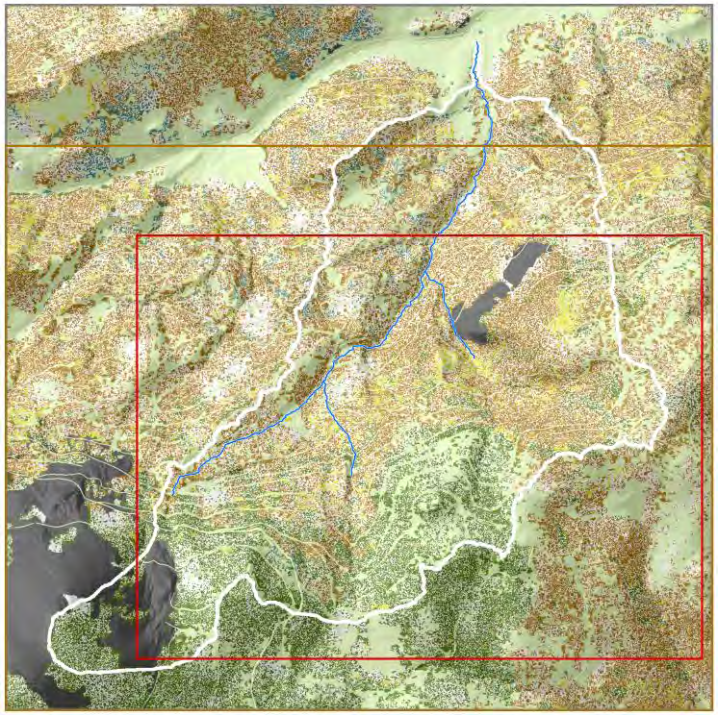




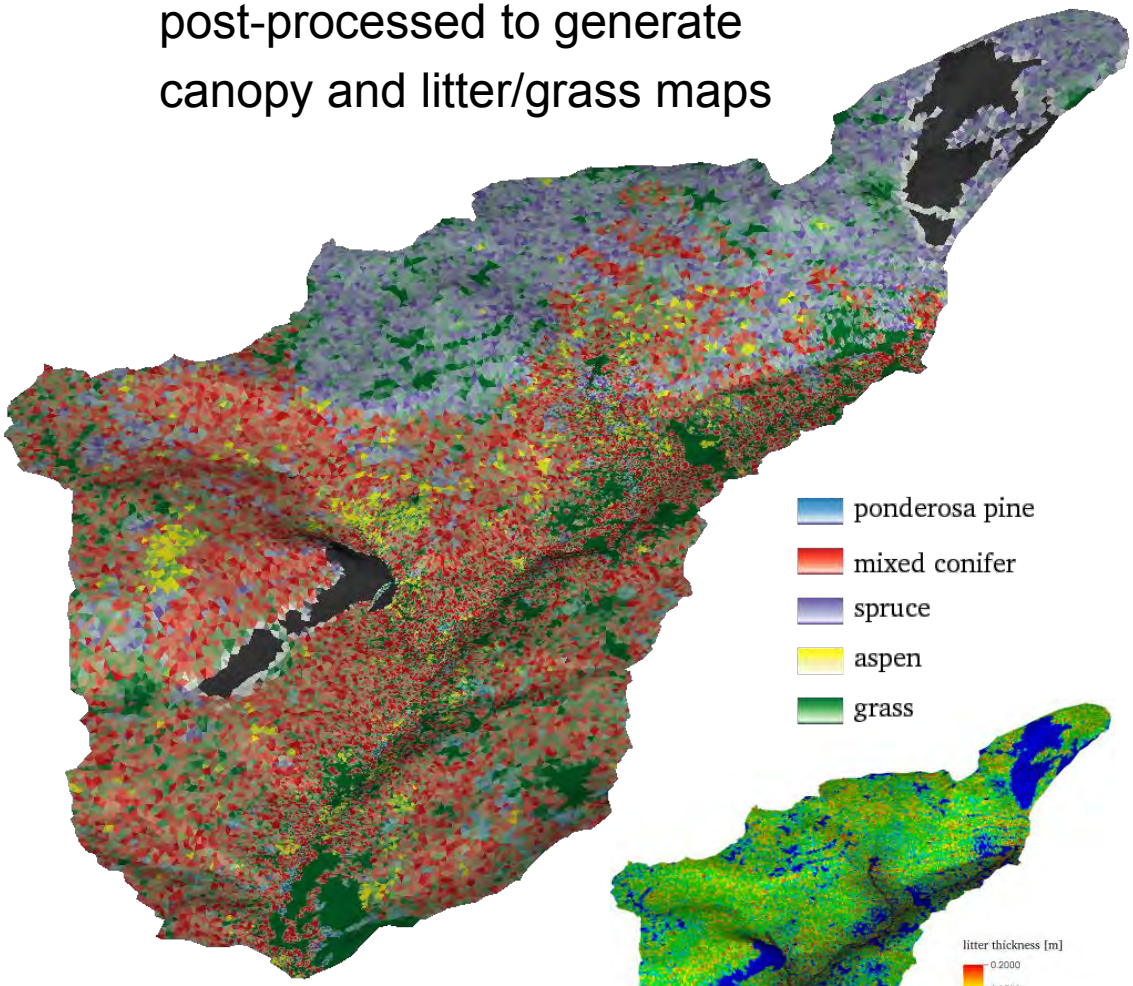
LA-UR-16-21758

Upper Jaramillo: Model Setup

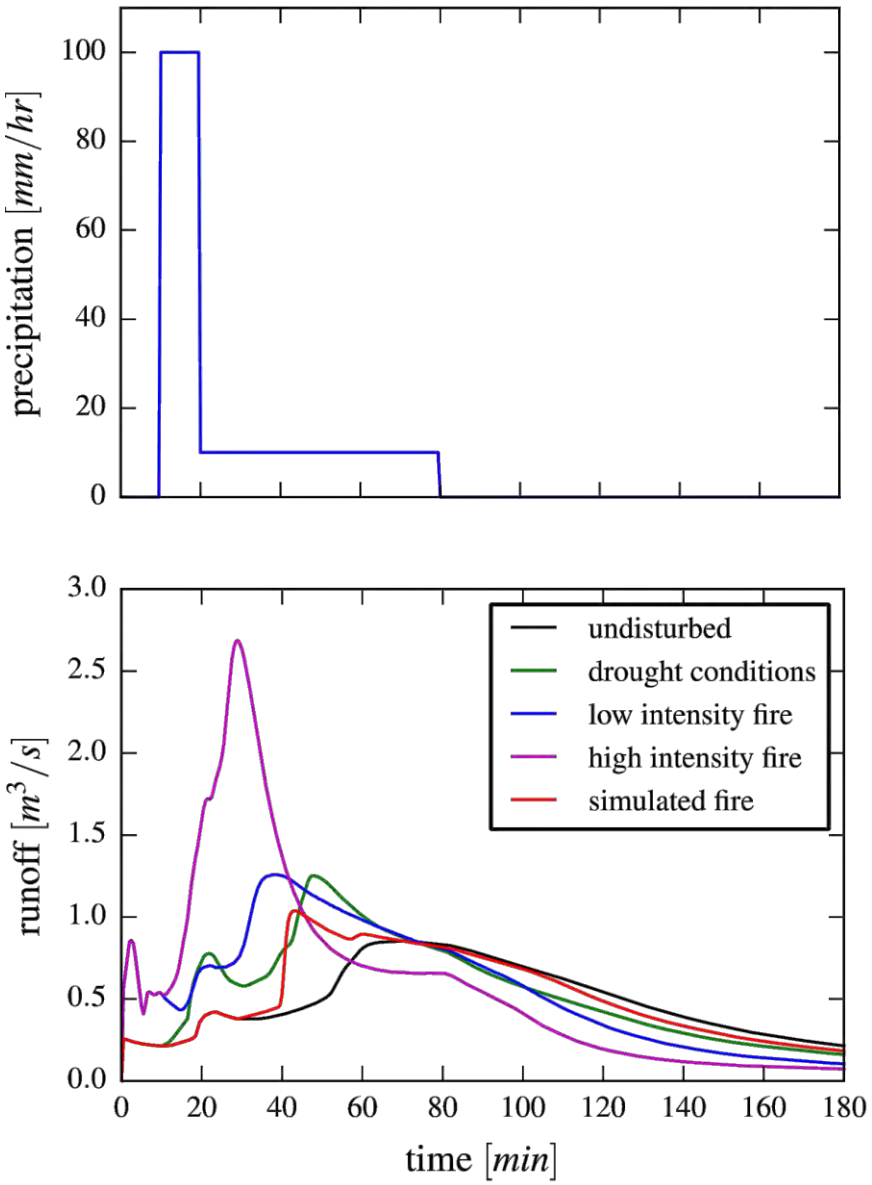
DisTreebutor: trees planted to generate fuel loads

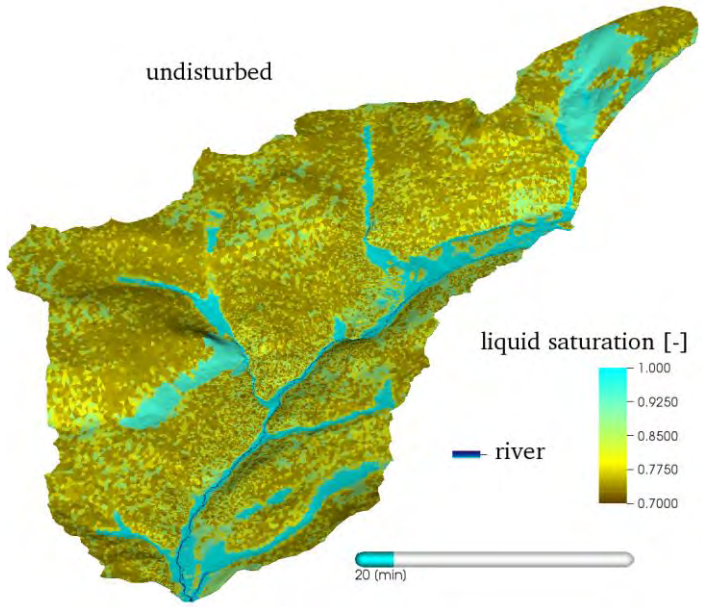


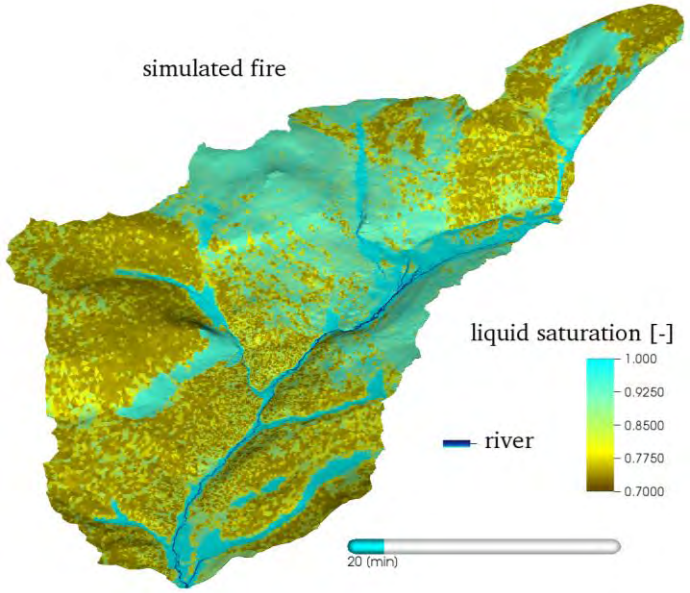
post-processed to generate canopy and litter/grass maps



Upper Jaramillo: Disturbed Hydrology



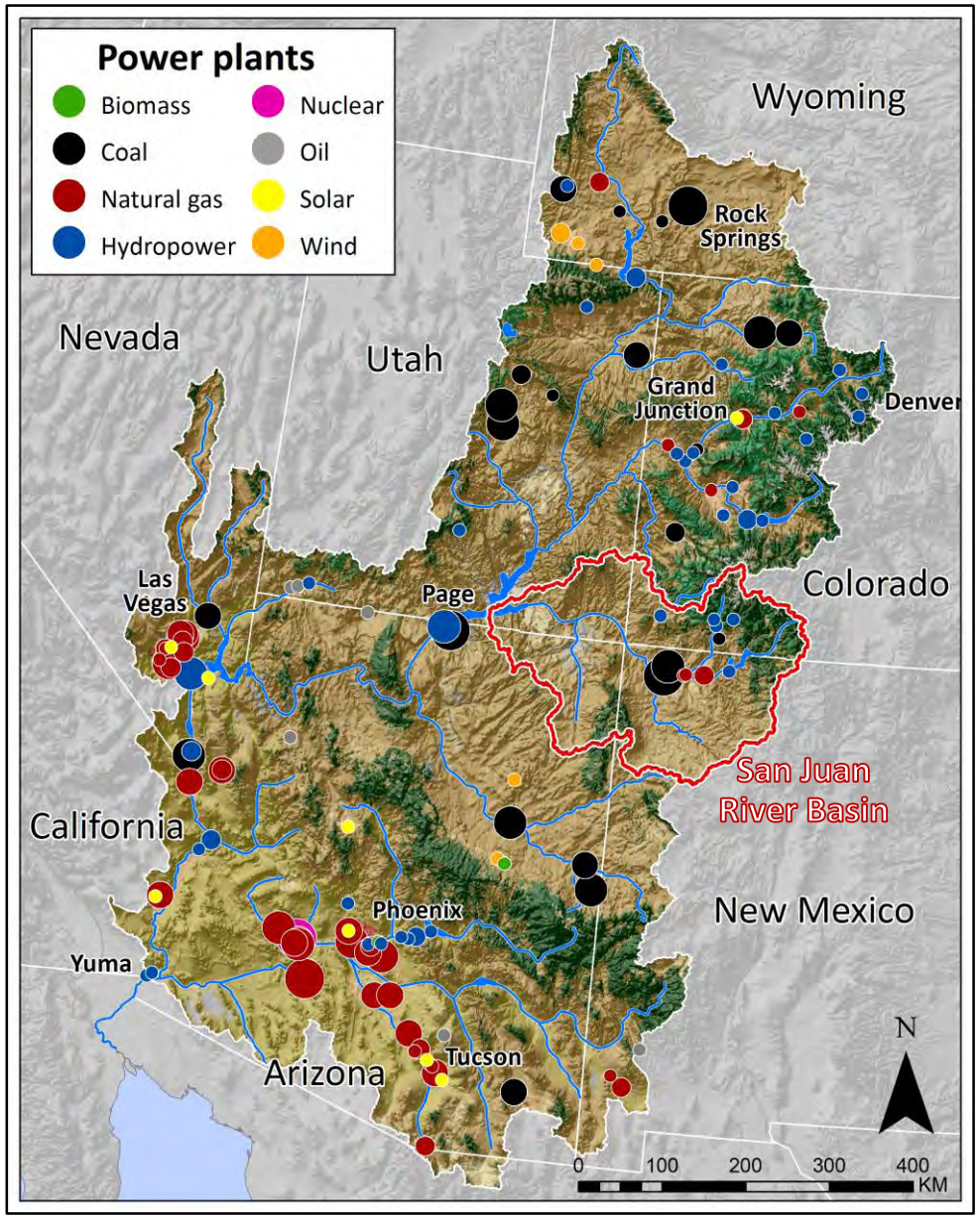




Study Area: San Juan River

Colorado River Basin

- Colorado River basin 634,150 km^2
- San Juan 61,560 km^2
- Piedra 1,700 km^2
- 9.2C annual average mean T
- 382 mm annual average P
- Snow melt driven



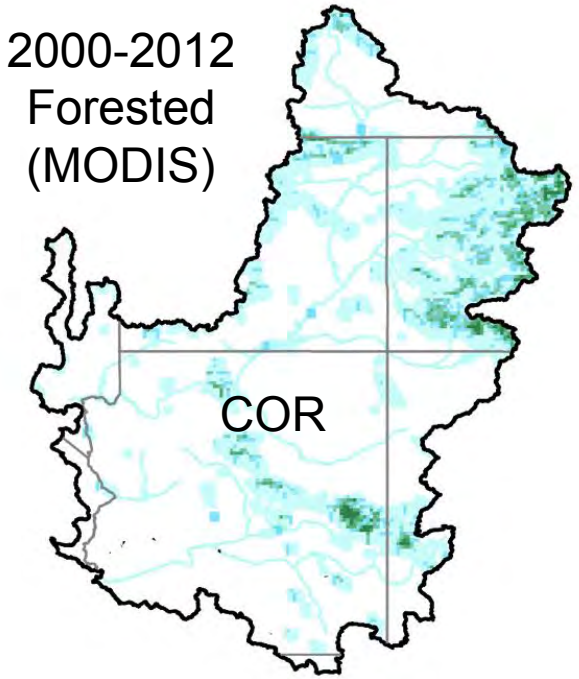
LA-UR-16-21758

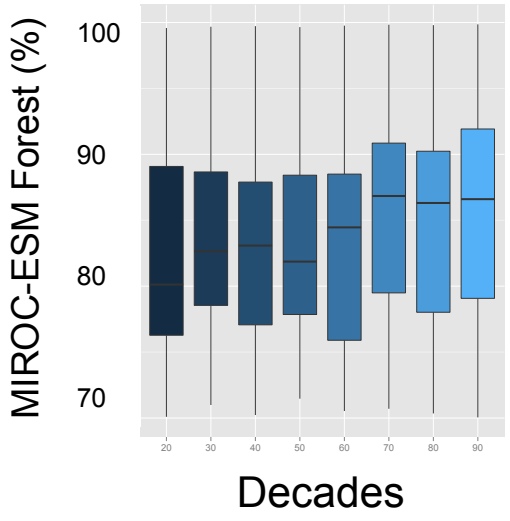
Methods

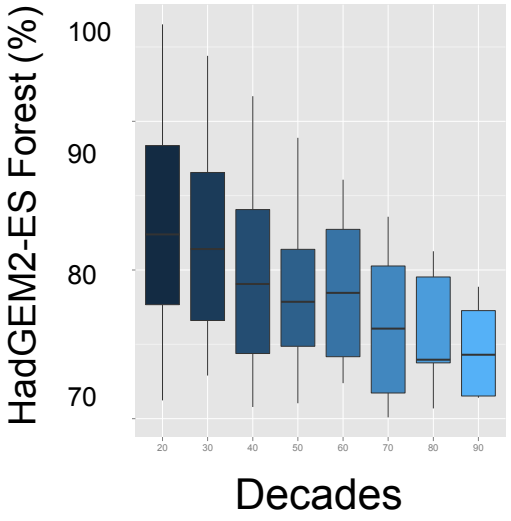
CMIP5 global climate models (GCMs) with dynamic vegetation (RCP 8.5)

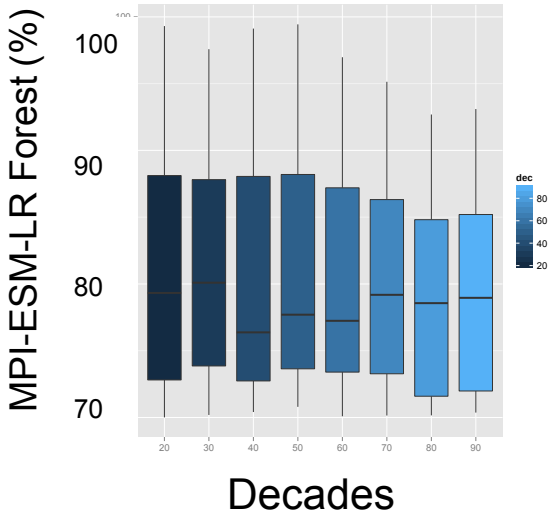
- HadGEM2-ES
- MPI-ESM-LR
- MIROC-ESM

Downscaling "delta" change







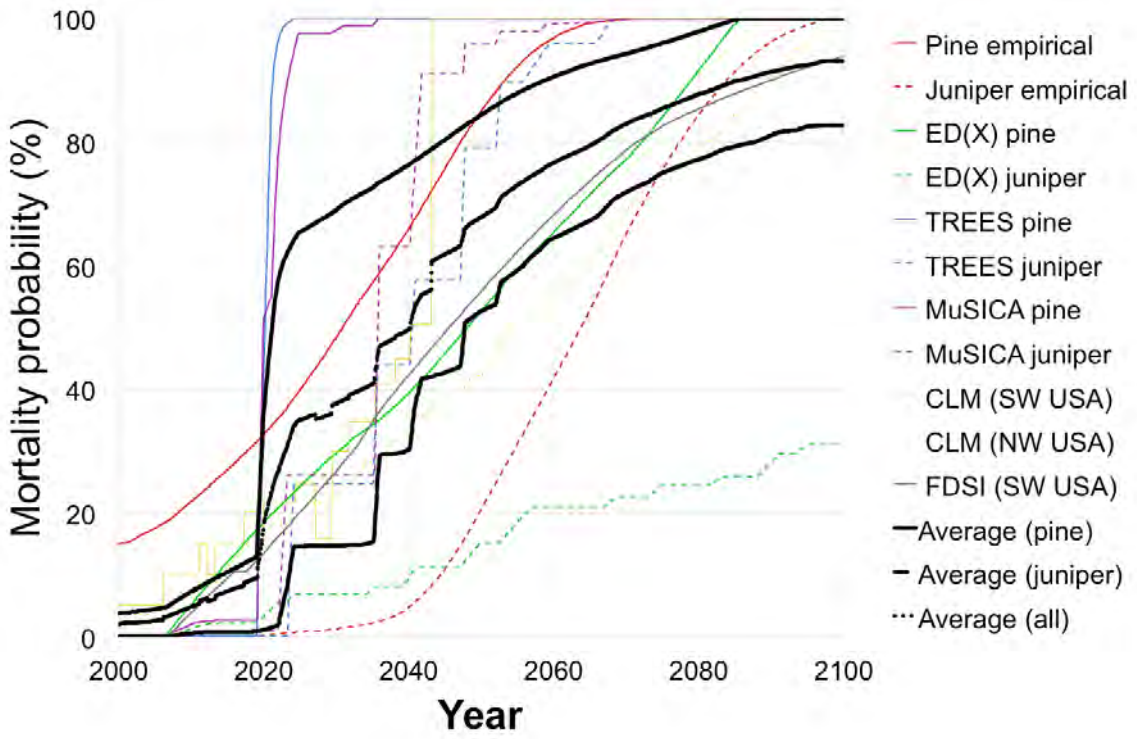


LA-UR-16-21758

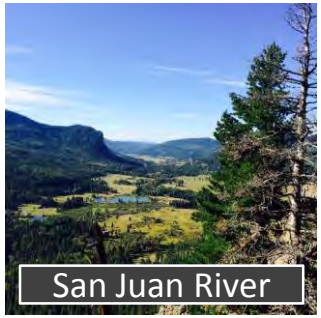
Methods

Dynamic vegetation models

- Statistical and physically-based models
- Mortality probability
- Simulated for the SW region
- Increasing and severe mortality projected by 2100
- Shrub replacement used for trees



McDowell et al. Convergent predictions of massive conifer mortality due to chronic temperature rise. *Nature Climate Change* 2015.



Results: Streamflow

Average streamflow changes

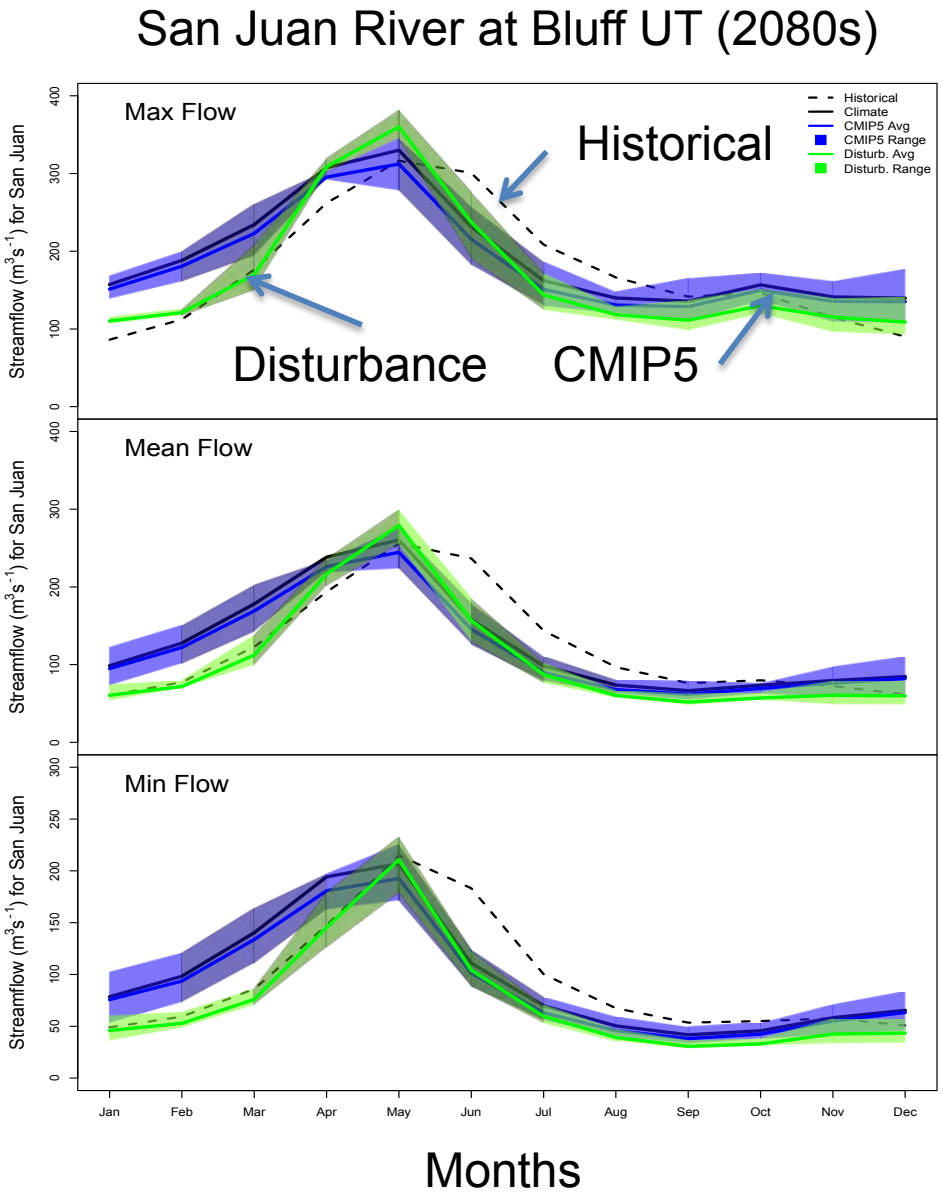
- Just climate:
  6% *increase*
- Climate + dynamic vegetation:
  4% *decrease*
- Climate + disturbance:
  14-18% *decrease*

Disturbance scenario

- Significantly reduced flows
- Lower base flows
- Increased spring runoff

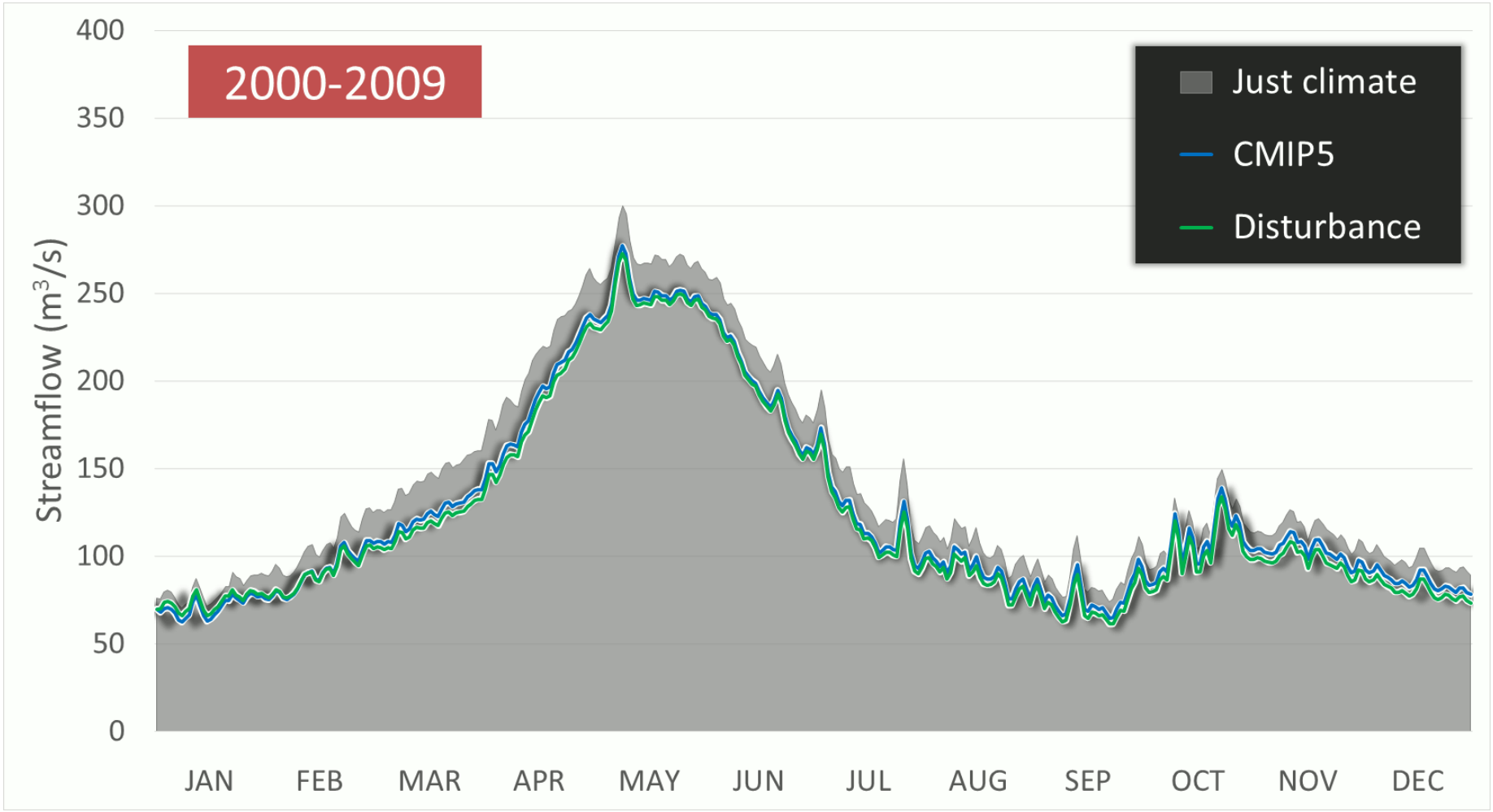
Drivers

- Changes in evapotranspiration (incoming shrubs), snowpack formation



LA-UR-16-21758

Results: Streamflow Time Series



LA-UR-16-21758

Take Home Message

Climate-driven disturbances

- Massive impact on ecosystems and hydrology → local-to-global scale
- Massive impact on climate → local-to-global scale (beyond project scope)
- Poorly understood and modeled processes, poorly understood impacts