Overview of Presentation

Forest Change:

What are the issues?
Wildfire, insects, climate

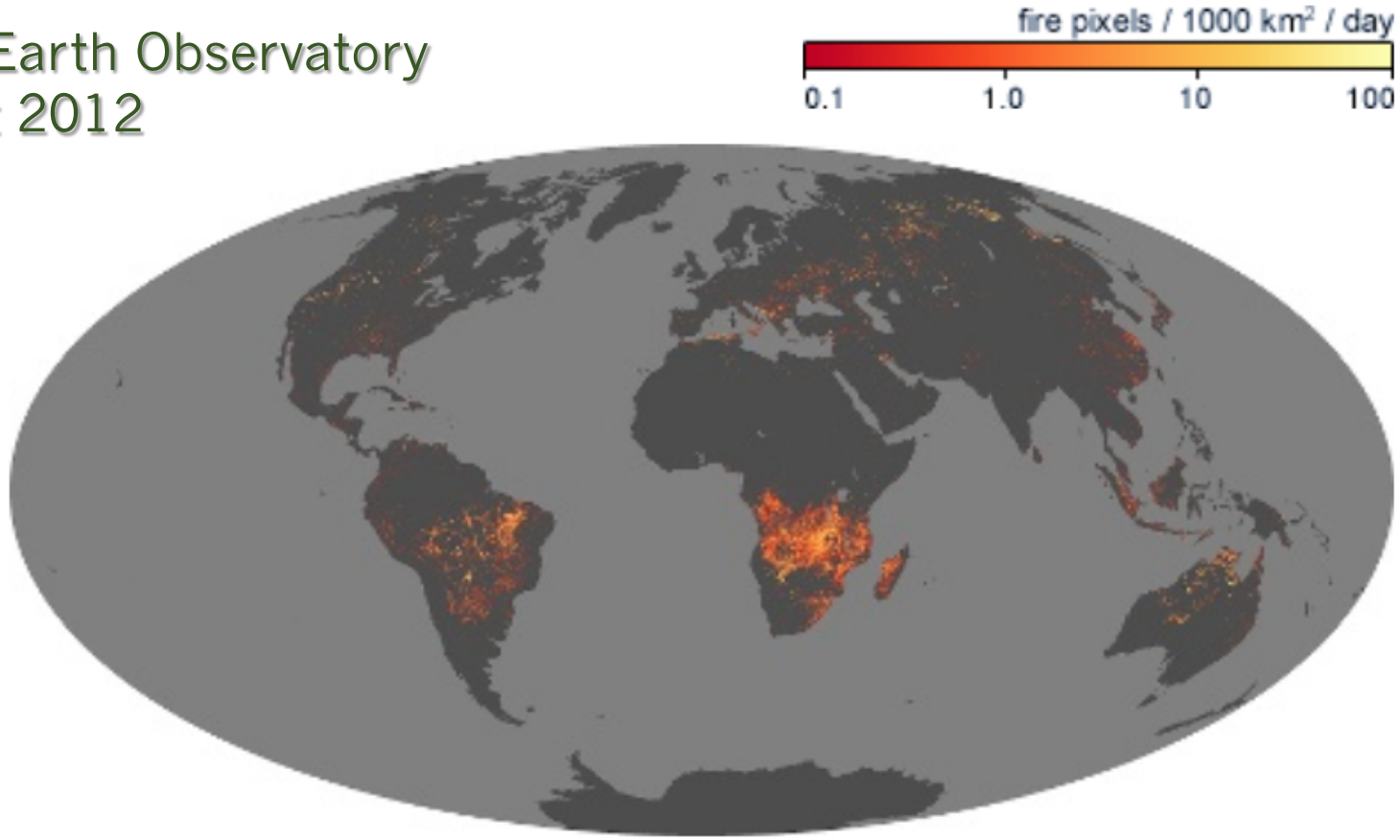
Advances in monitoring change and recovery (vegetation)

Case studies in forested regions application of remote sensing

What are the issues?

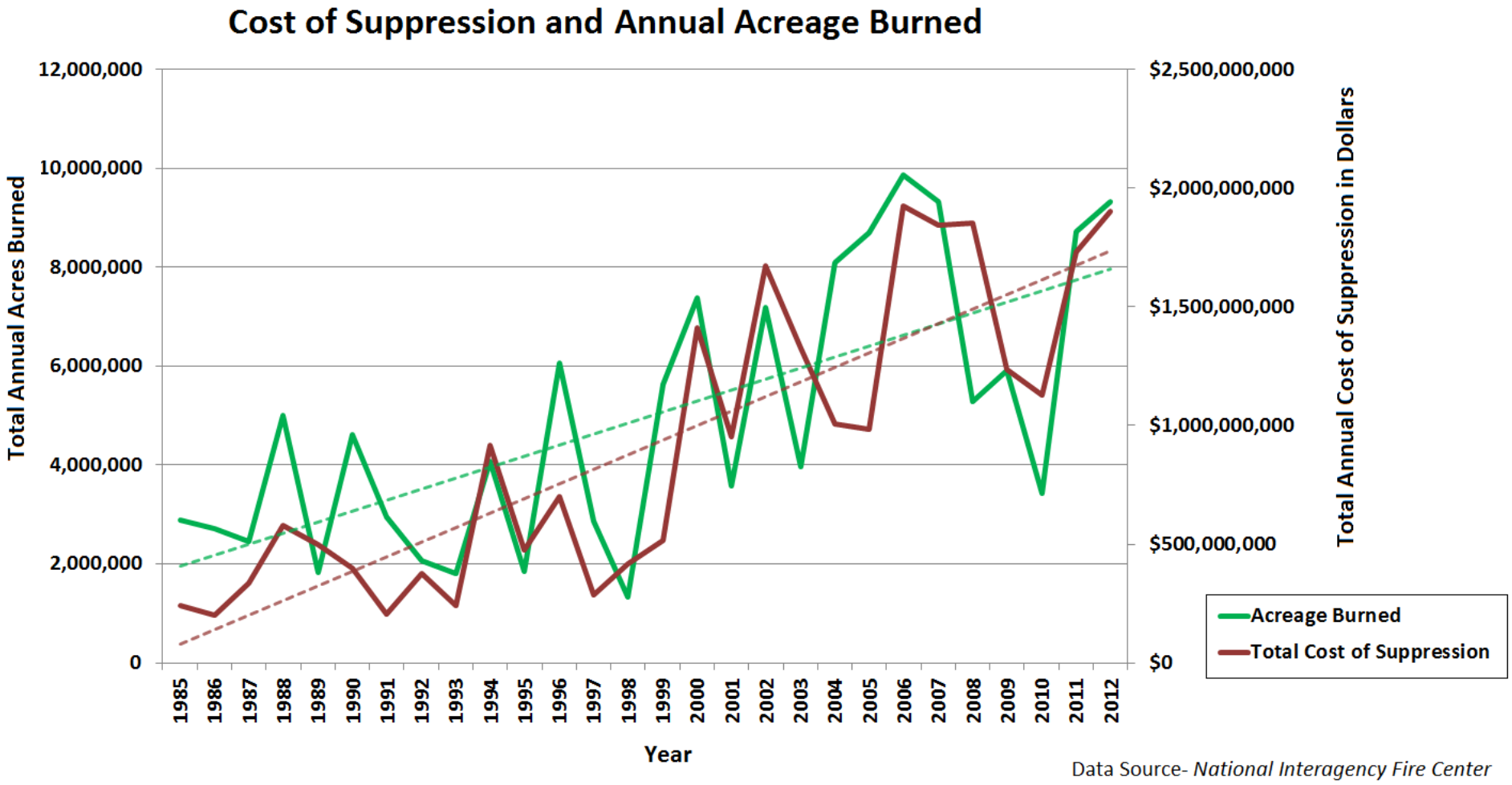
Global Fires

NASA Earth Observatory
August 2012



Natural wildfire, seasonal grass fires, agricultural burning

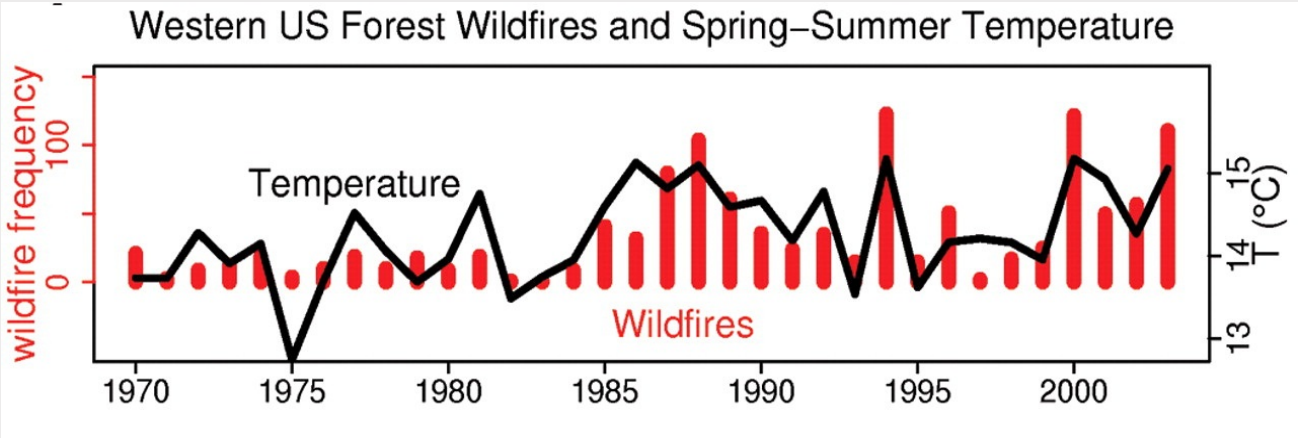
Wildfires: Western U.S.



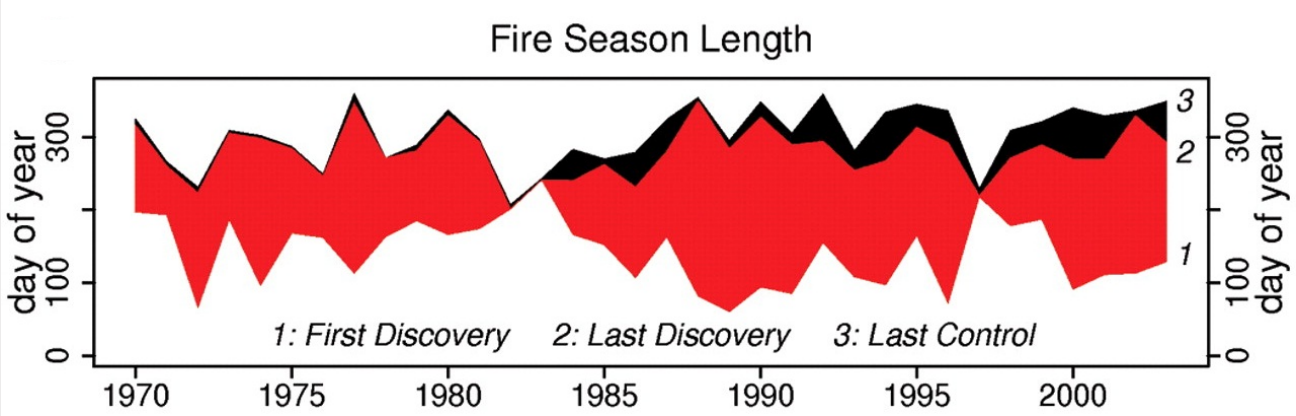
Data Source- *National Interagency Fire Center*

HOGUE HYDROLOGY GROUP

Why Increasing Fires?



- Increase in large-wildfire frequency
- Warmer temperatures and earlier spring melt → increased wildfire activity



Longer fire durations and longer fire seasons since mid-1980's

Westerling et al., 2009

Hydrologic Impacts

Physical/Chemical Changes

Acute loss of vegetation, decreased soil cohesion, ash layer deposition, hydrophobic layer formation.

Hydrologic Consequences

Decreased: infiltration, ET demand, water quality

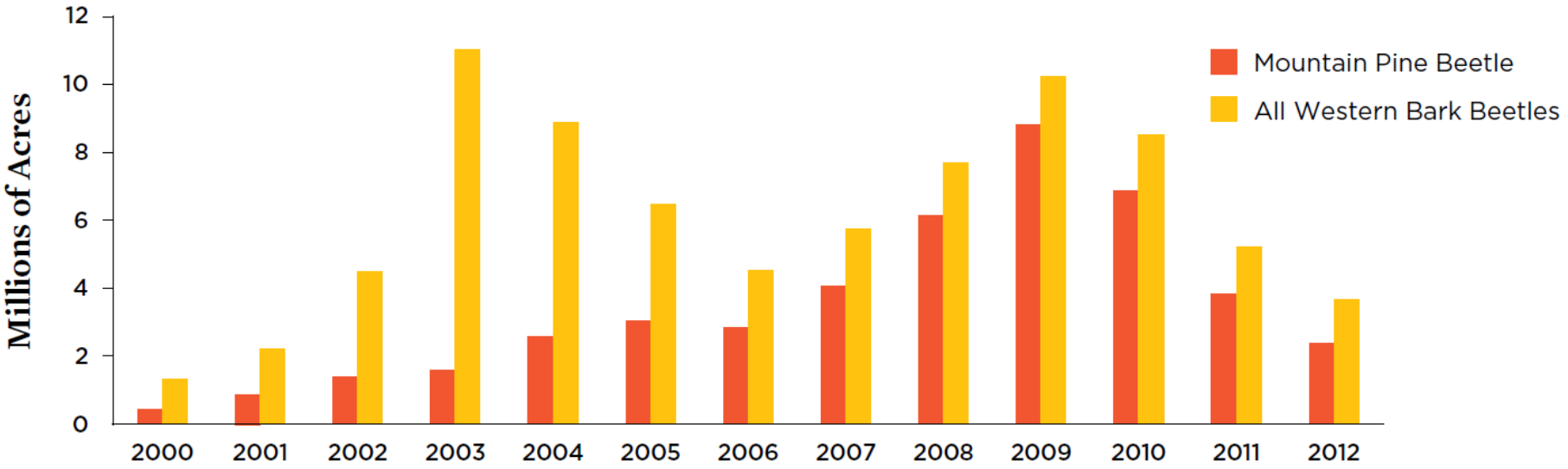
Increased: floods, erosion, sediment laden and debris flow occurrence, dry season flow.

Mountain Pine Beetle: Western U.S.

- The current MPB outbreak has impacted more than **4 million acres** in western North America since its start in 1996.
- More than 1.5 million acres impacted in Colorado and southern Wyoming.
- **Essential water supplies are at risk:** the heart of the epidemic in Colorado and Wyoming contains the headwaters for rivers that supply water to 13 western states.

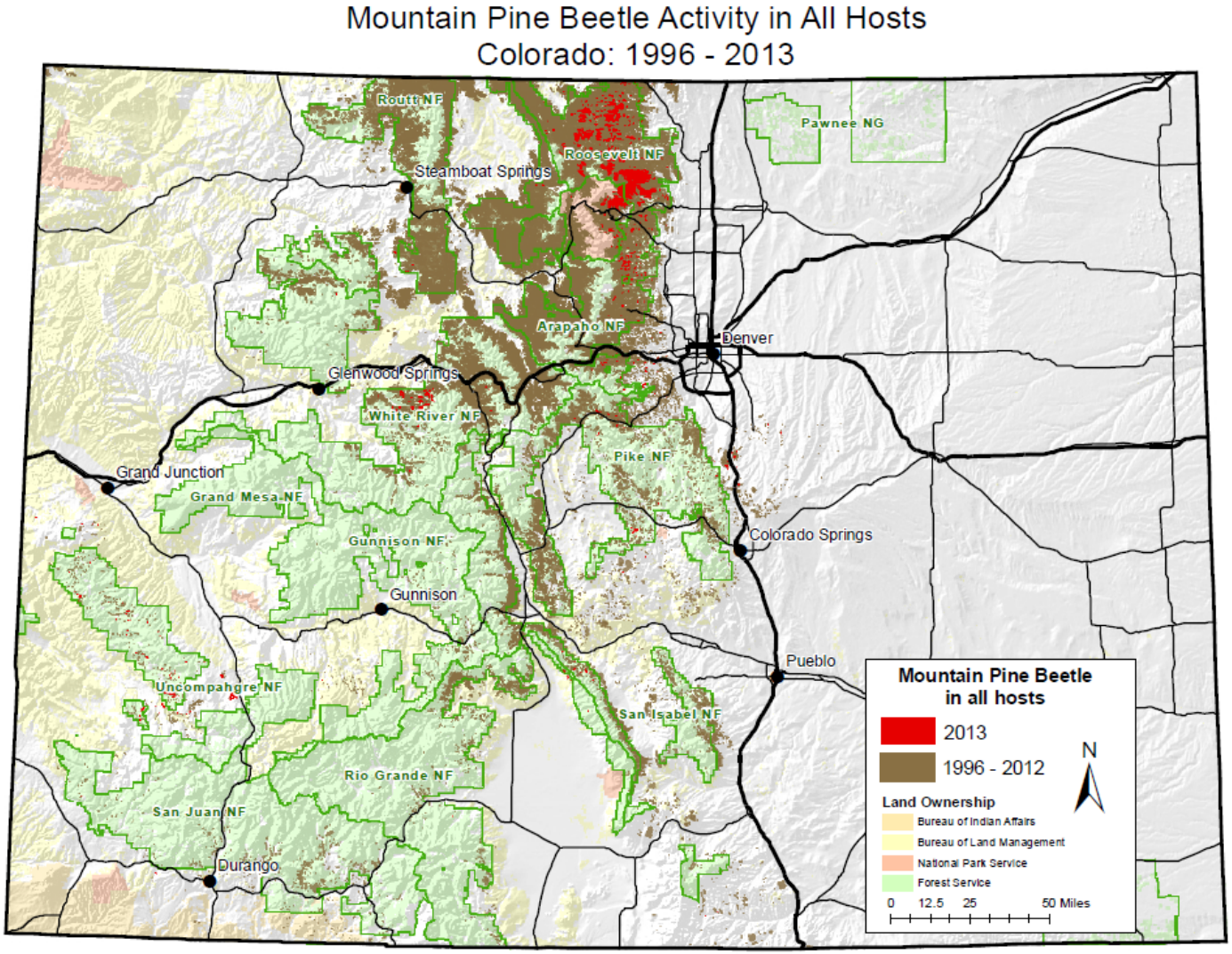
(source: US Forest Service http://www.fs.usda.gov/main/barkbeetle/aboutepidemic,)

Mountain Pine Beetle
(actual size:1/8 to 1/3 inch
Source: CSU Extension



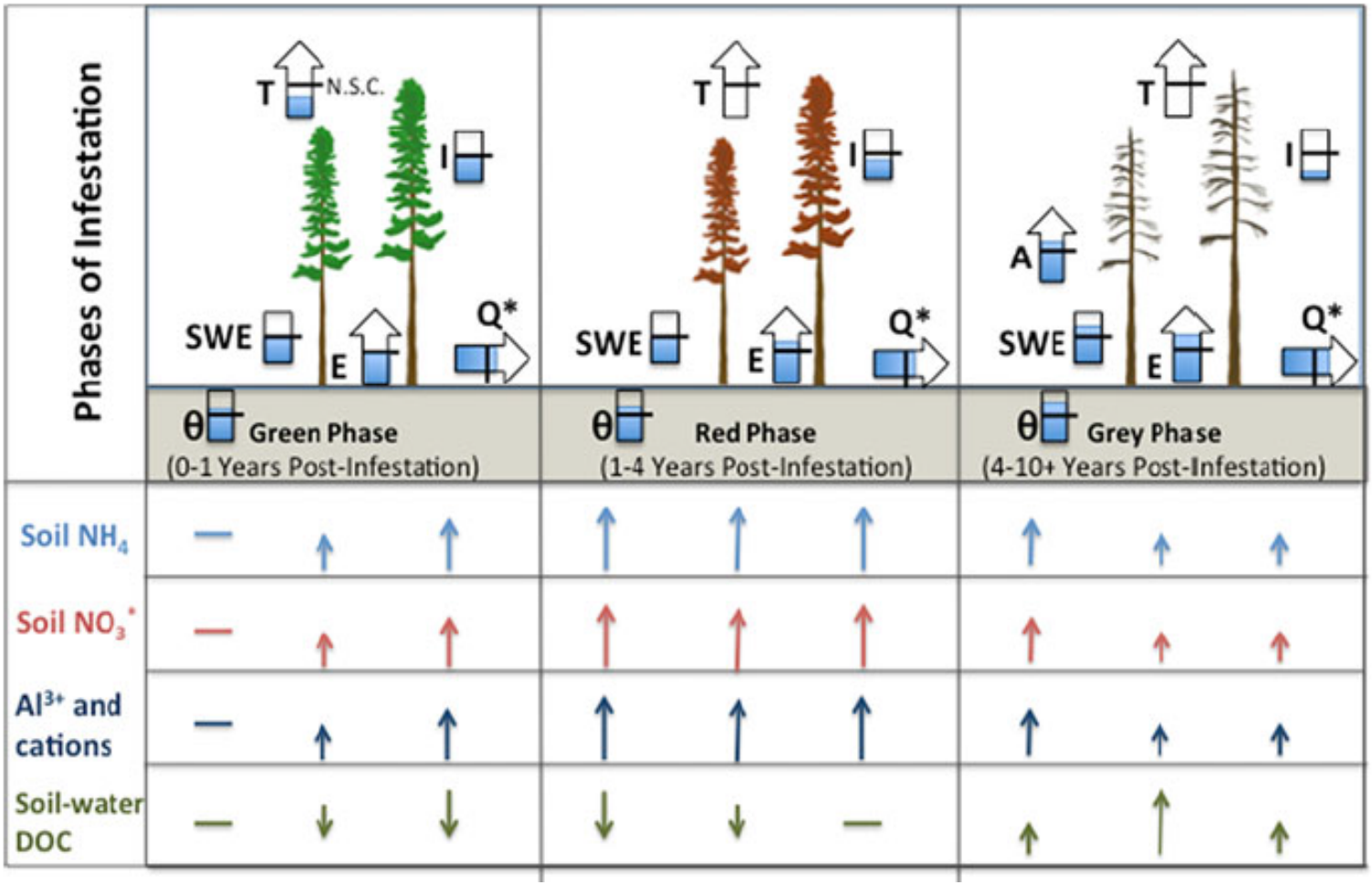
HOGUE HYDROLOGY GROUP

Mountain Pine Beetle: Colorado



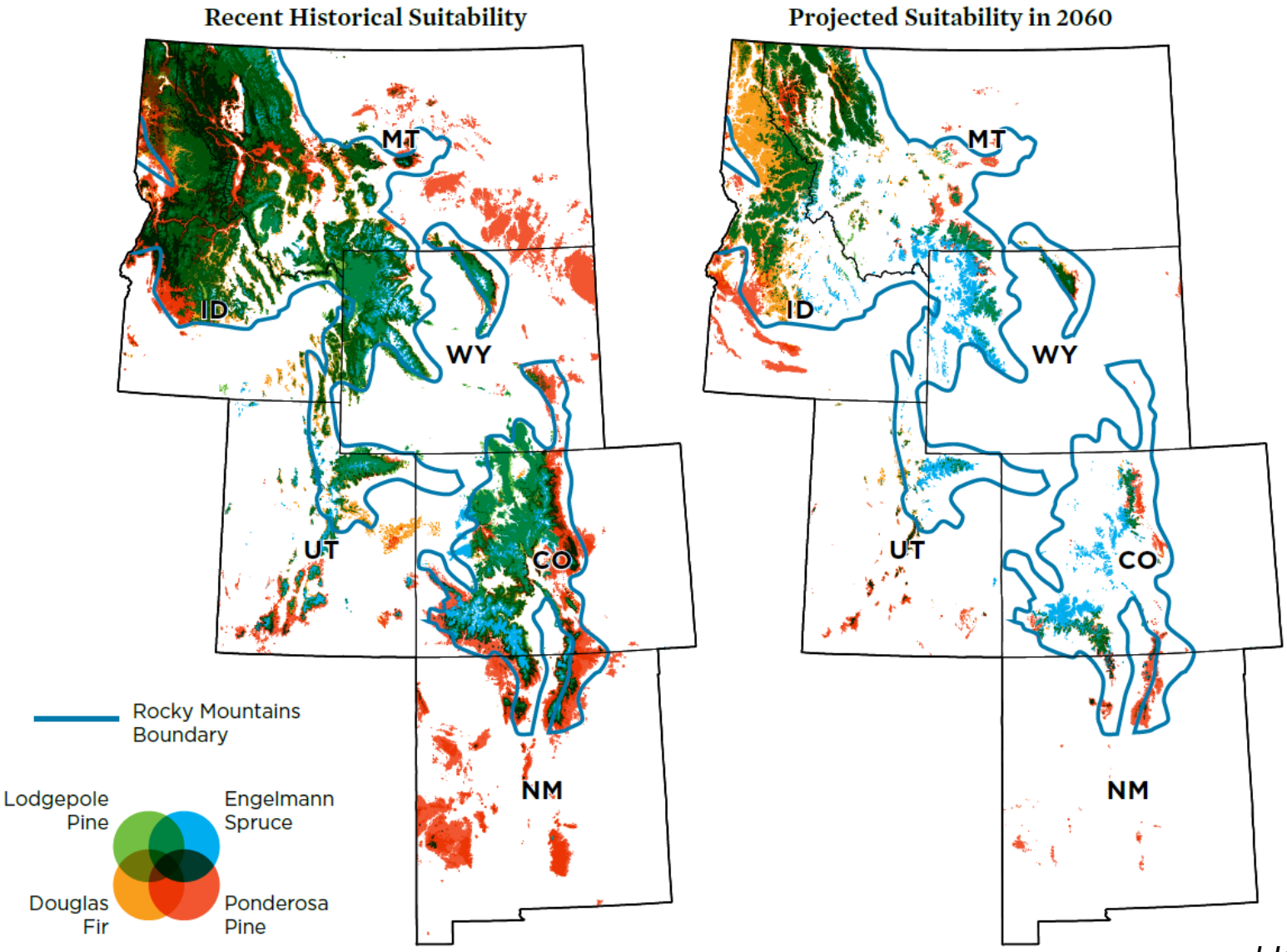
HOGUE HYDROLOGY GROUP

Mountain Pine Beetle: Hydrologic Impact



Mikkelson et al., 2013

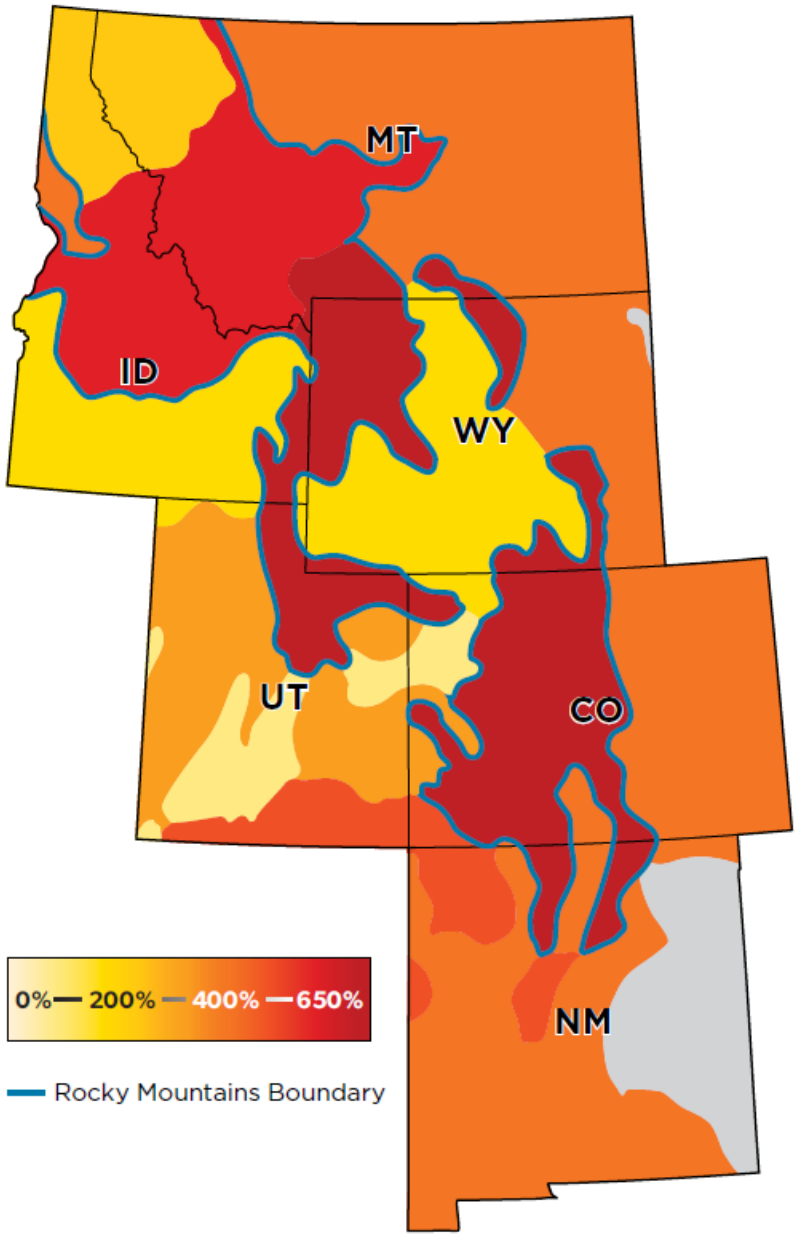
Predicted Change in Rocky Mtn. Forests



UCS, 2014

Predicted Change in Wildfires

Increase in burn area (relative to 1950-2003) with 1.8°F temperature increase



UCS, 2014

Gaps in our Understanding

- Long-term “hydrologic” behavior after disturbance
- Seasonal variability in discharge, water quality and snow
- Efficacy of pre-disturbance management strategies

What do we need?

- Improved spatial data and temporal data
  - ungauged basins
- Model parameterization for disturbance regimes
- Long-term monitoring and data collection
- Work with water resource and forest managers

Remote sensing products for monitoring hydrologic change

REMOTE SENSING OF FOREST HEALTH

Land Cover Classification

NDVI / EVI

(Normalized Difference Vegetation Index / Enhanced Vegetation Index)

PET

(Potential Evapotranspiration)

AET

(Actual Evapotranspiration)

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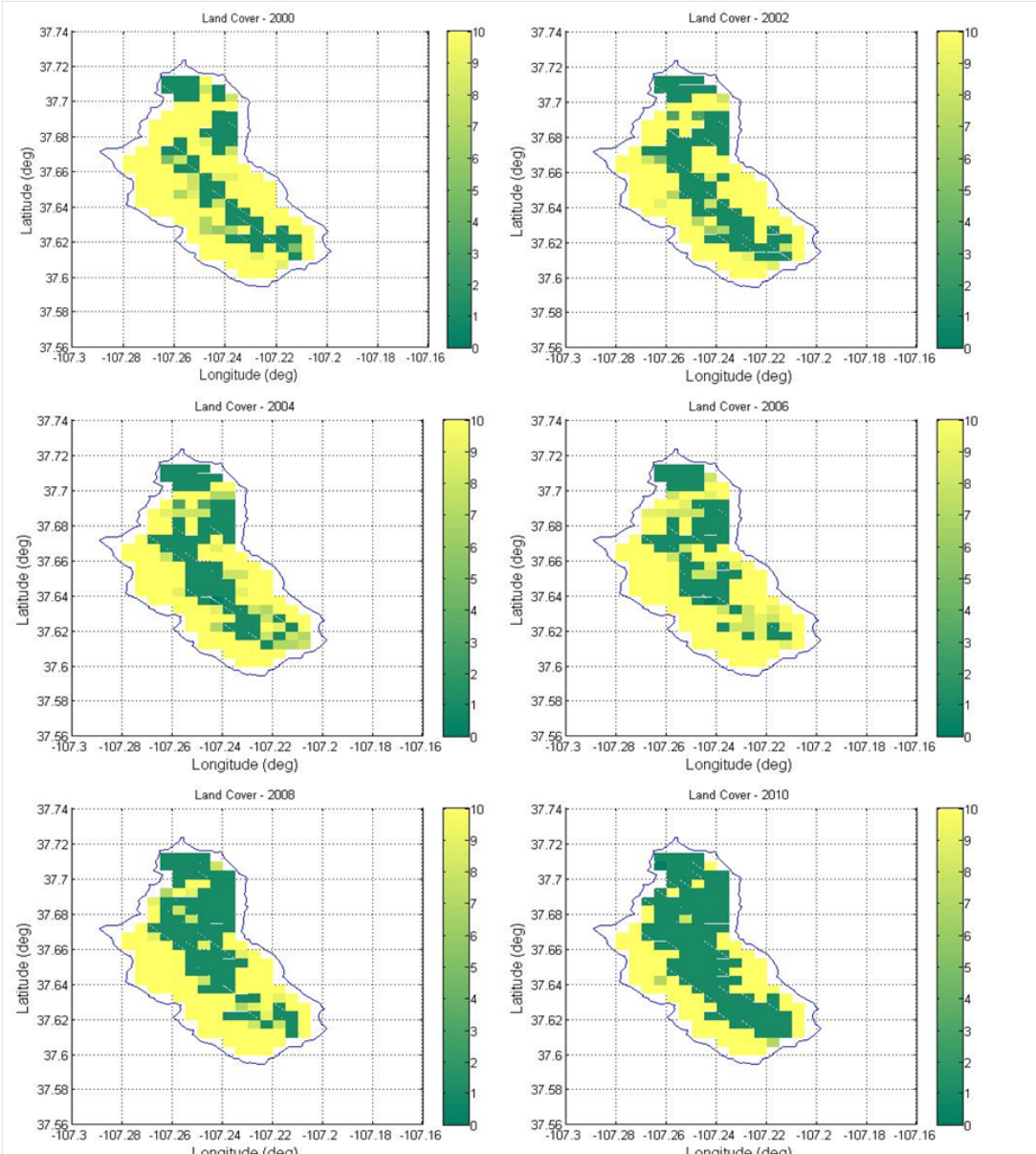
MODIS

Product: MCD12Q1
Platform: Combined Terra &
Grid Resolution: 500x500 m
Temporal Resolution: Yearly

IGBP land cover types found in MCD12Q1 MODIS product.

Class	IGBP (Type 1)
0	Water
1	Evergreen Needleleaf Forest
2	Evergreen Broadleaf Forest
3	Deciduous Needleleaf Forest
4	Deciduous Broadleaf Forest
5	Mixed Forest
6	Closed Shrublands
7	Open Shrublands
8	Woody Savannas
9	Savannas
10	Grasslands
11	Permanent Wetlands
12	Croplands
13	Urban and Built-up
14	Cropland/Natural Vegetation Mosiac
15	Snow and Ice
16	Barren or Sparsely Vegetated
254	Unclassified
255	Fill Value

Global Land Cover as defined by MODIS MCD12Q1 for even years between 2000 and 2010. Greens indicate areas of forest canopy cover and yellows indicate areas of grassland type vegetation.



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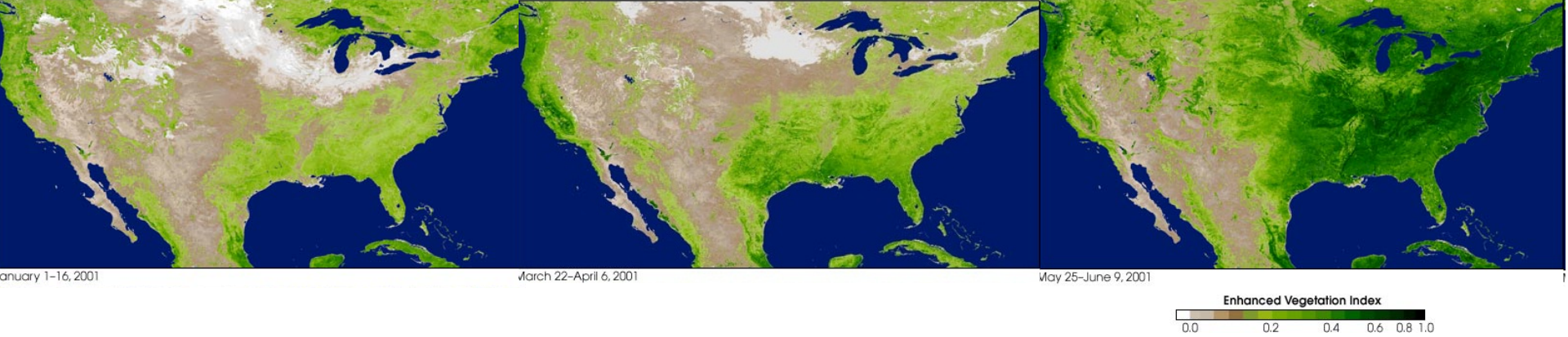
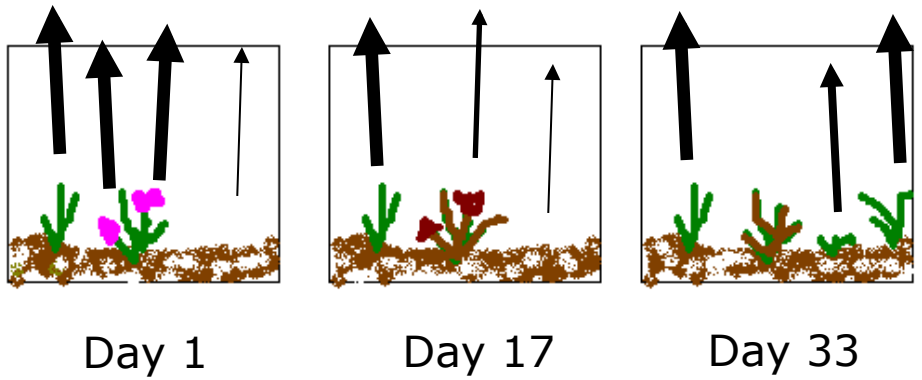
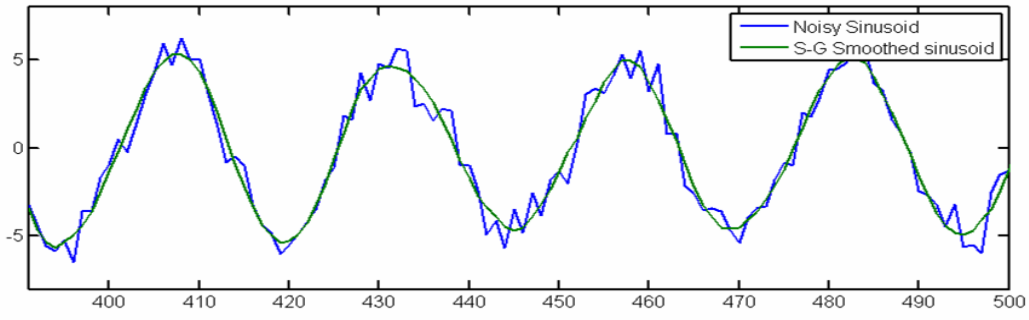


MODIS Enhanced Vegetation Indices (EVI)

$$EVI = 2.5\left[\frac{\rho^*_{NIR} - \rho^*_{RED}}{\rho^*_{NIR} + C_1\rho^*_{NIR} - C_2\rho^*_{BLUE} + L}\right]$$

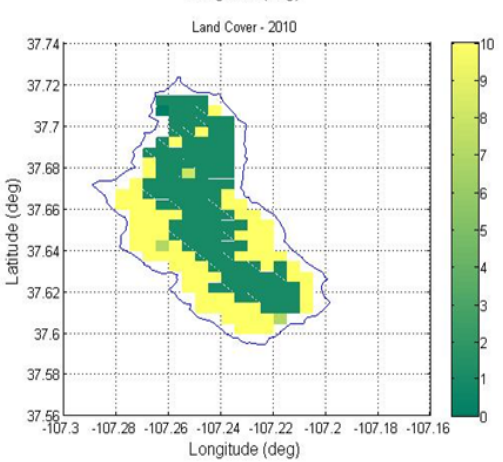
- Reduced soil and atmospheric interference (compared to NDVI, LAI)
- 16 day series
- 250 m resolution
- Savitzky-Golay Filter (Jonsson and Eklundh,2004)

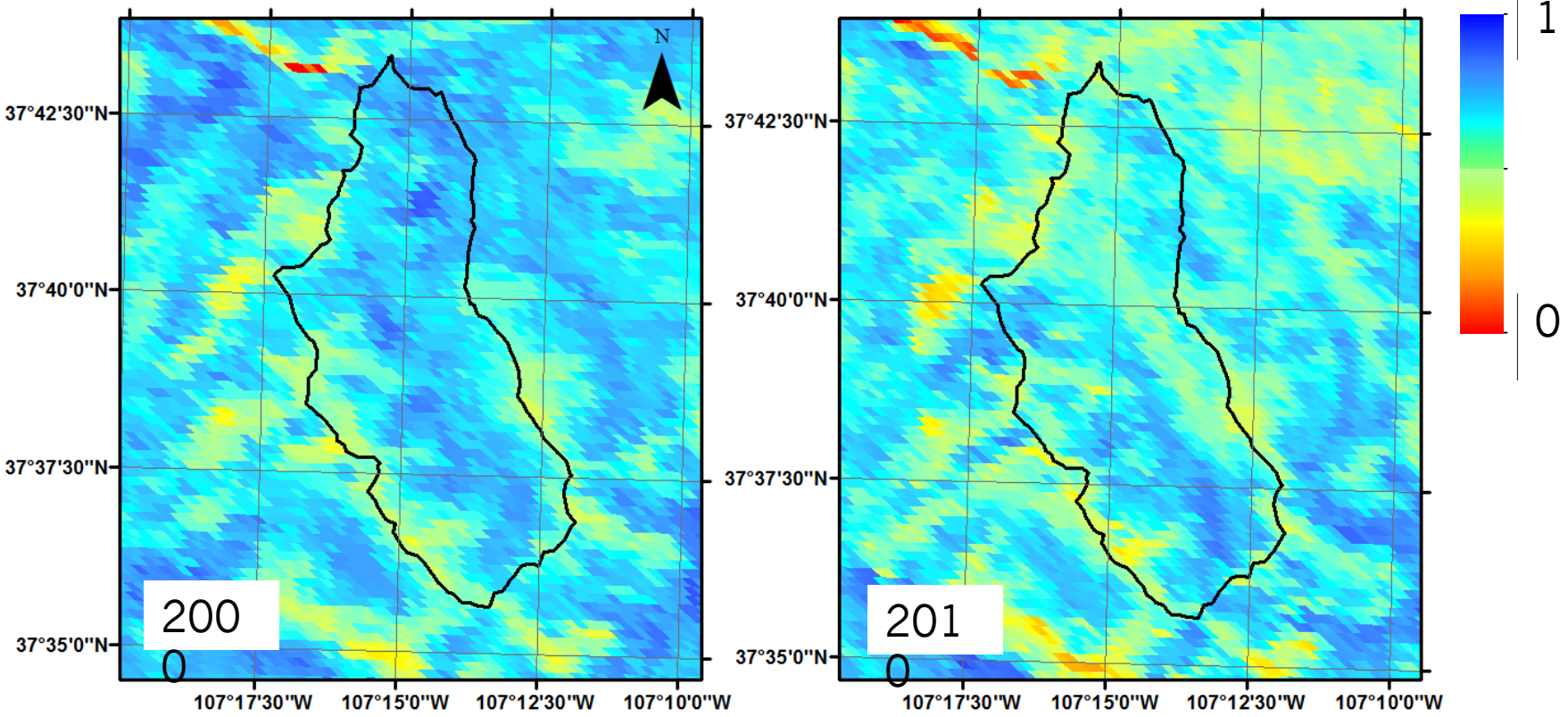




MODIS

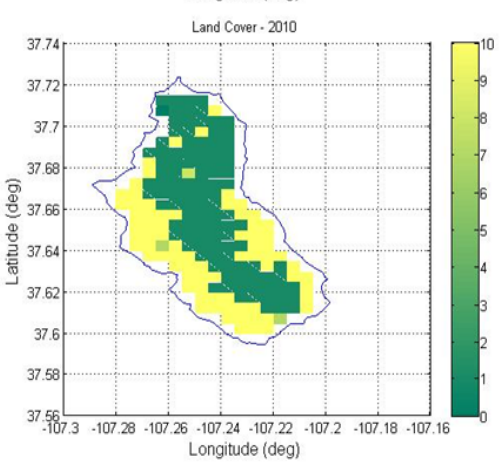
Product: MOD13A1 / MYD13A1
Platform: Terra & Aqua
Grid Resolution: 250x250 m
Temporal Resolution: daily (2001-present)



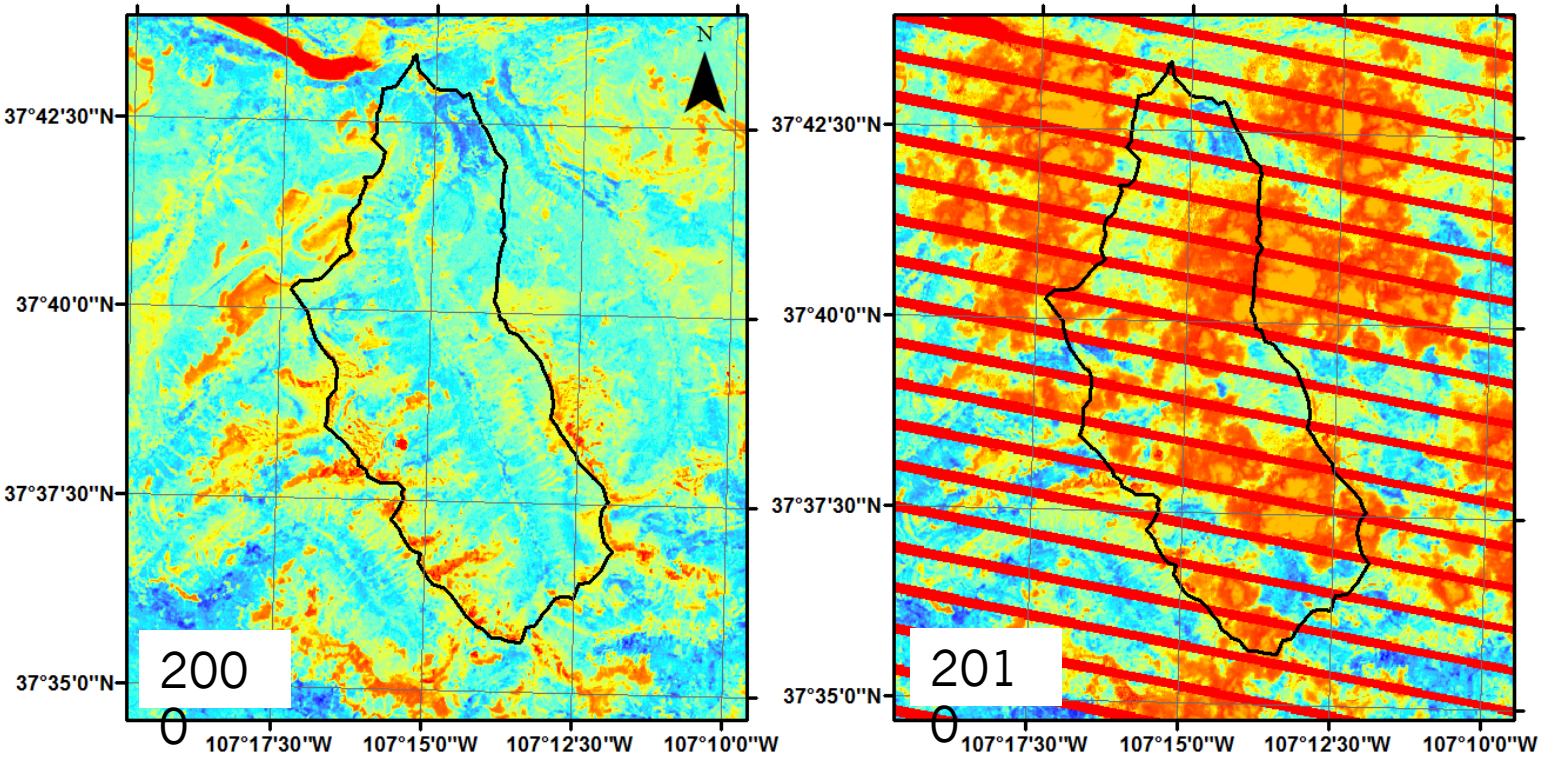


HOGUE HYDROLOGY GROUP

LANDSAT



Product: Landsat 7 ETM+
Platform: Na
Grid Resolution: 30x30 m
Temporal Resolution: 16 days (1999-present)

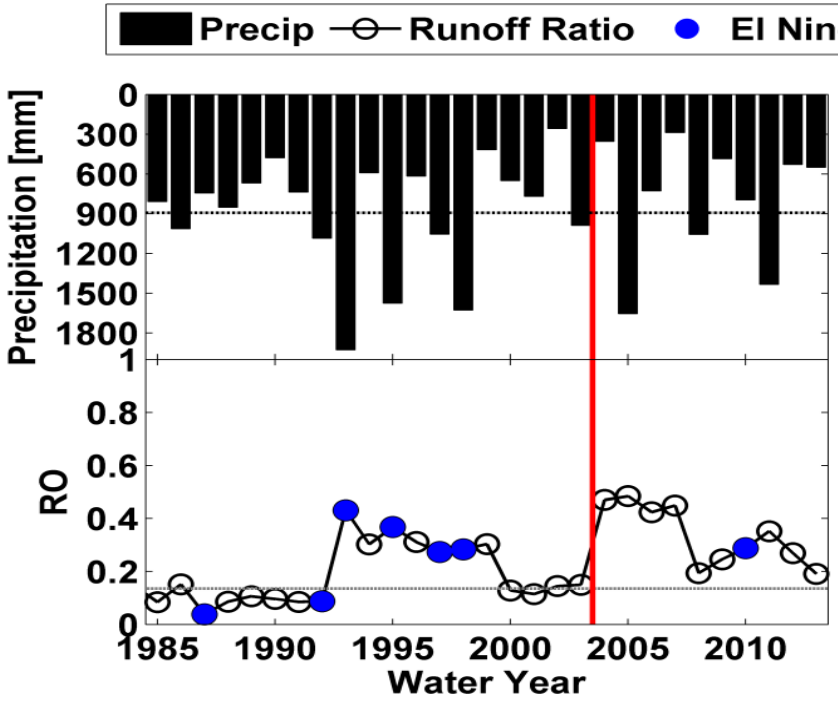


HOGUE HYDROLOGY GROUP

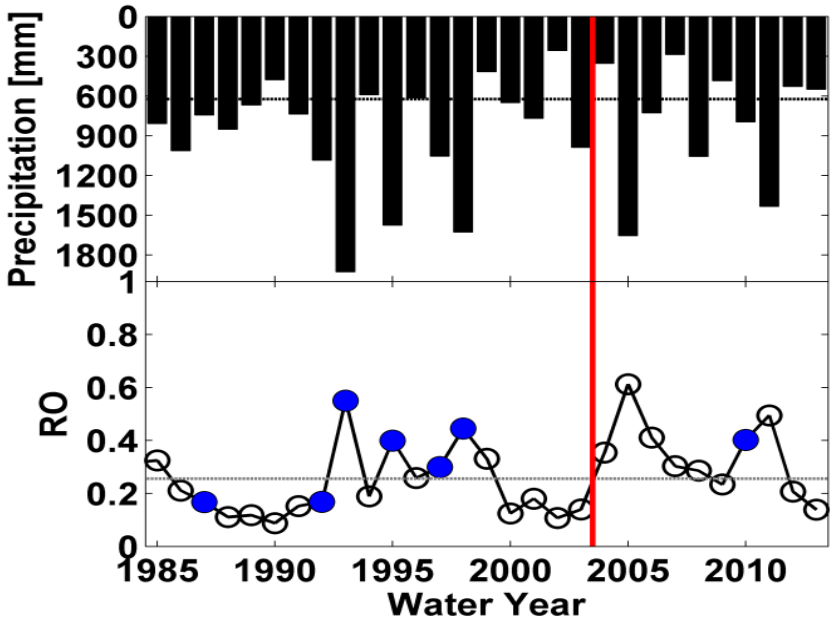
2003 Old Fire - San Bernardino Mts.

- Eastern Los Angeles Basin
- >90,000 acres (~360 km^2)
- 993 homes lost and 6 deaths

Devil Canyon (14km^2)



City Creek (51 km^2)

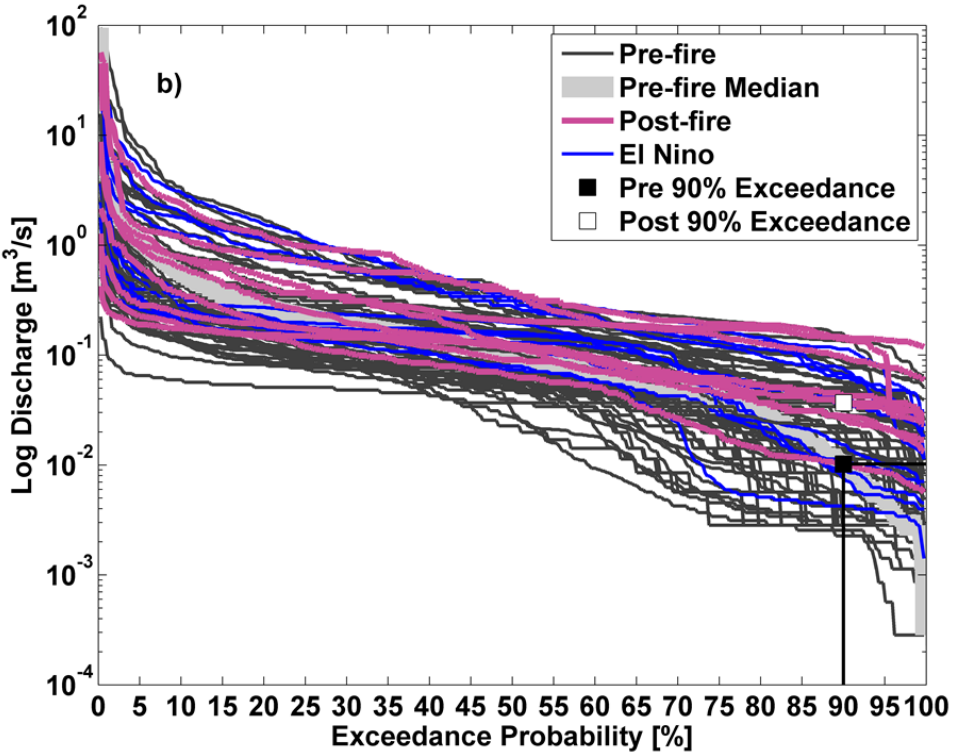


Post-fire: Low Flow Change

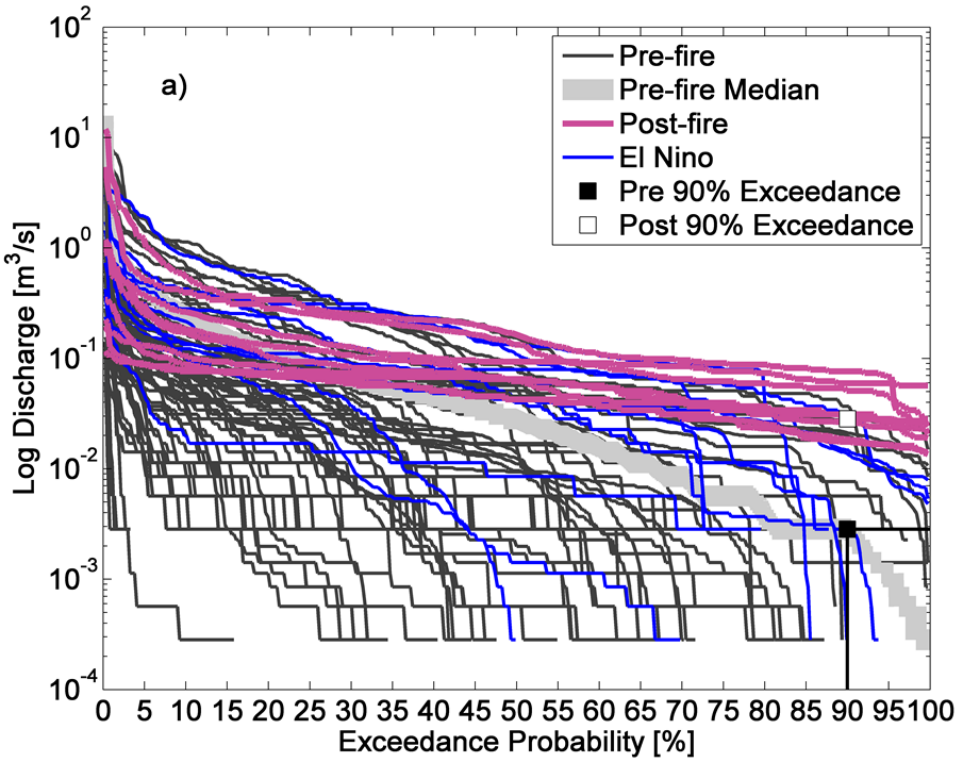
Kinoshita and Hogue, 2014

Dry season flow increase: ~1000% (Devil Canyon) and ~120% (City Creek)

Devil Canyon (14km^2)

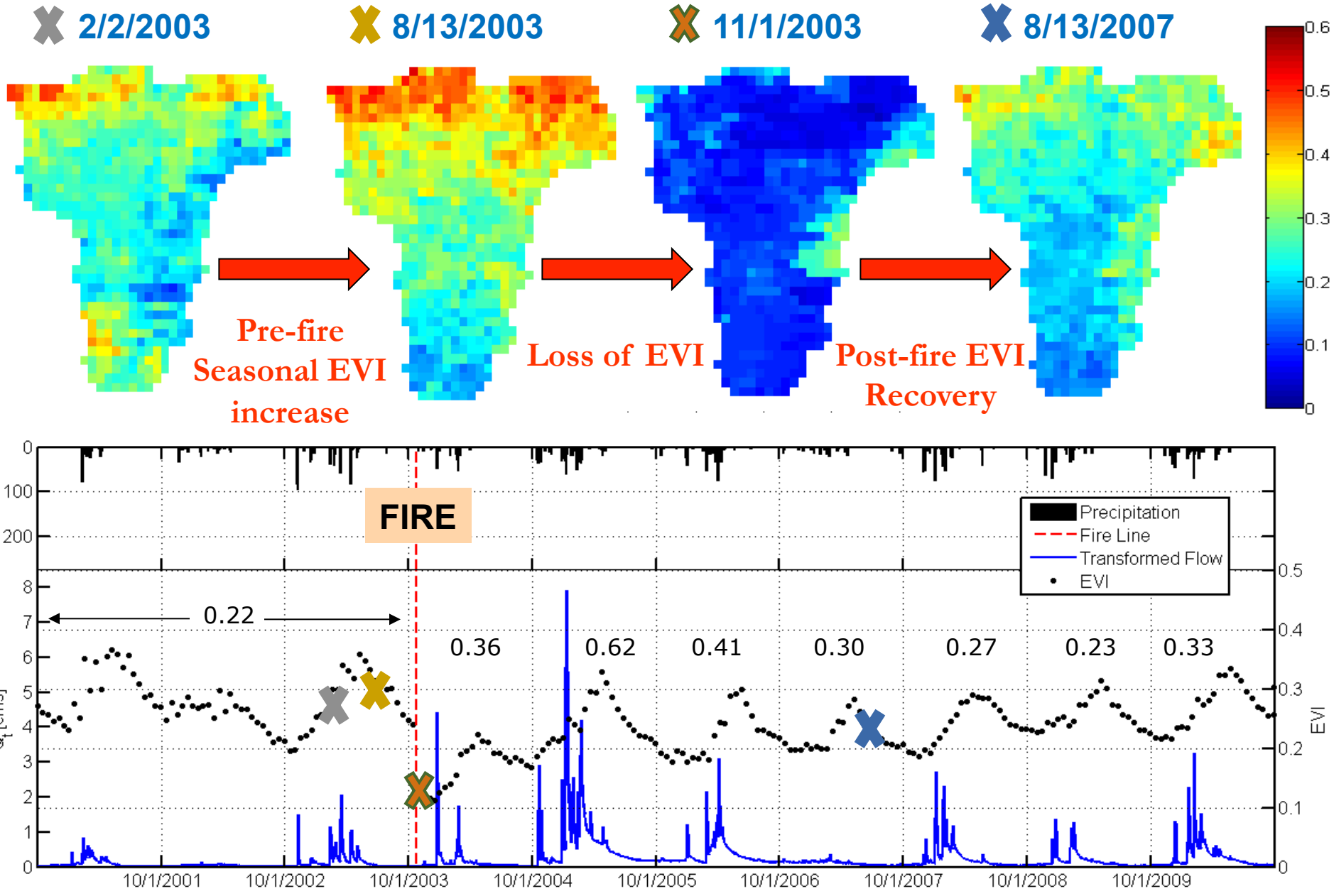


City Creek (51 km^2)



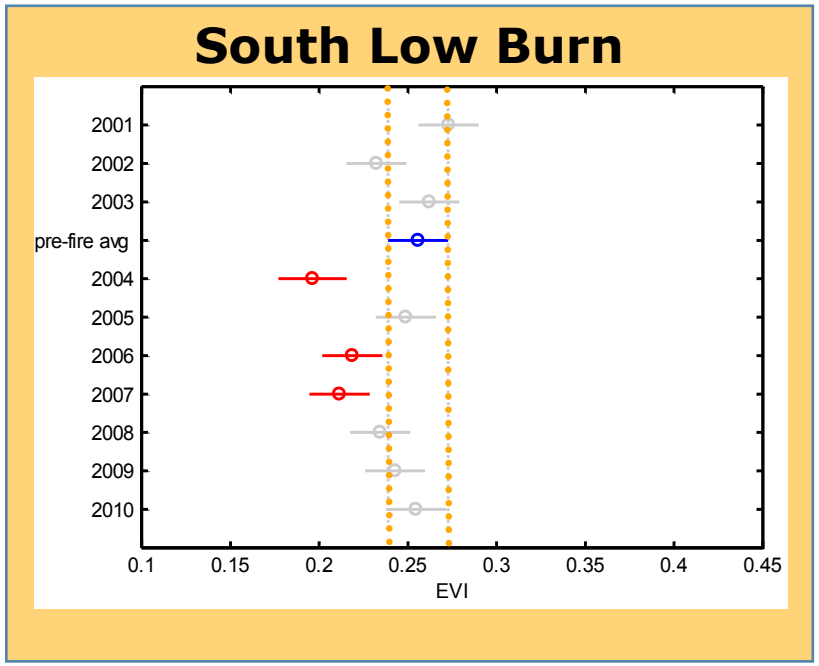
Vegetation and Discharge

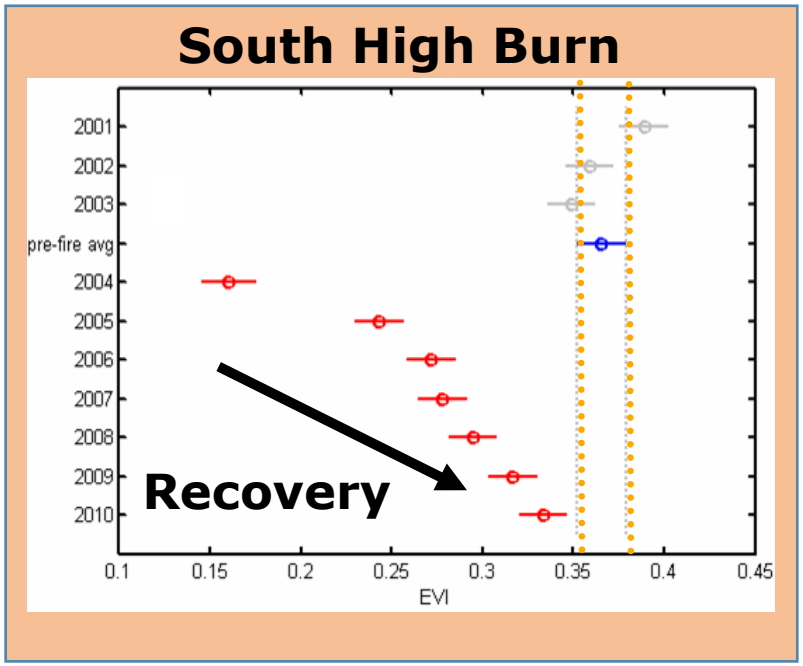
Kinoshita and Hogue, 2011

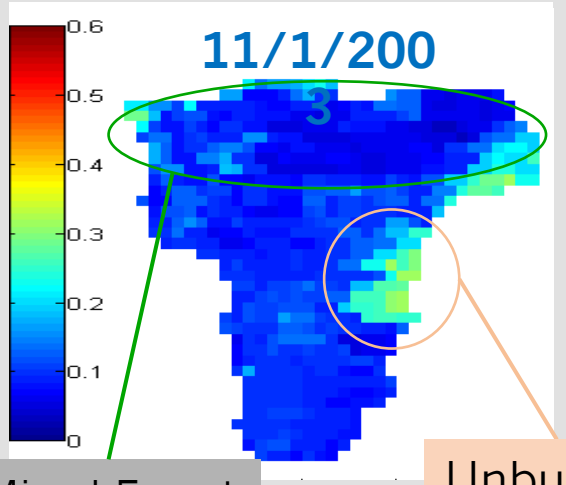


Post-fire Recovery

Kinoshita and Hogue, 201





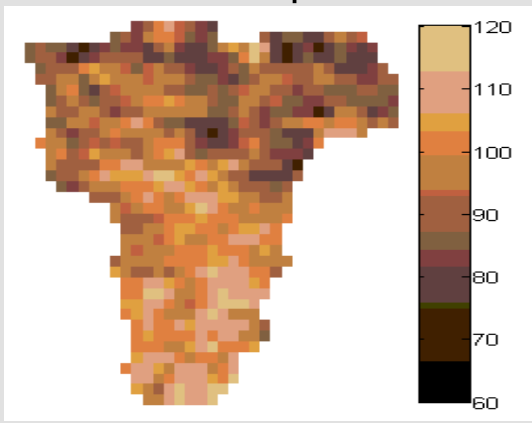


Mixed Forest

Unburned

Recovery of EVI relative to pre-fire

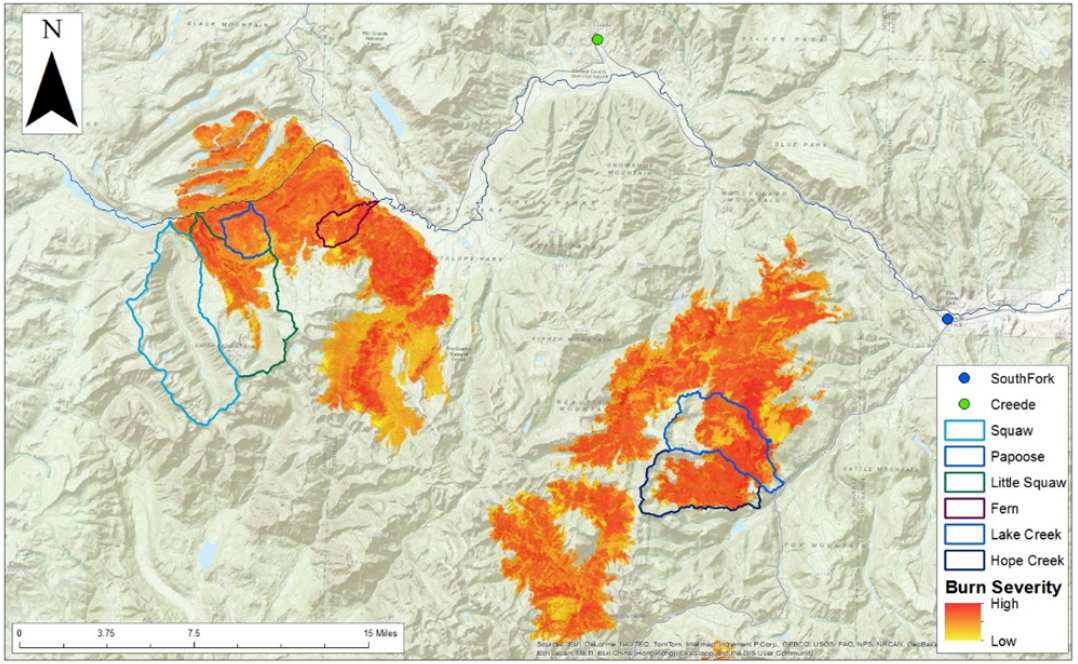
% Recovery 2007



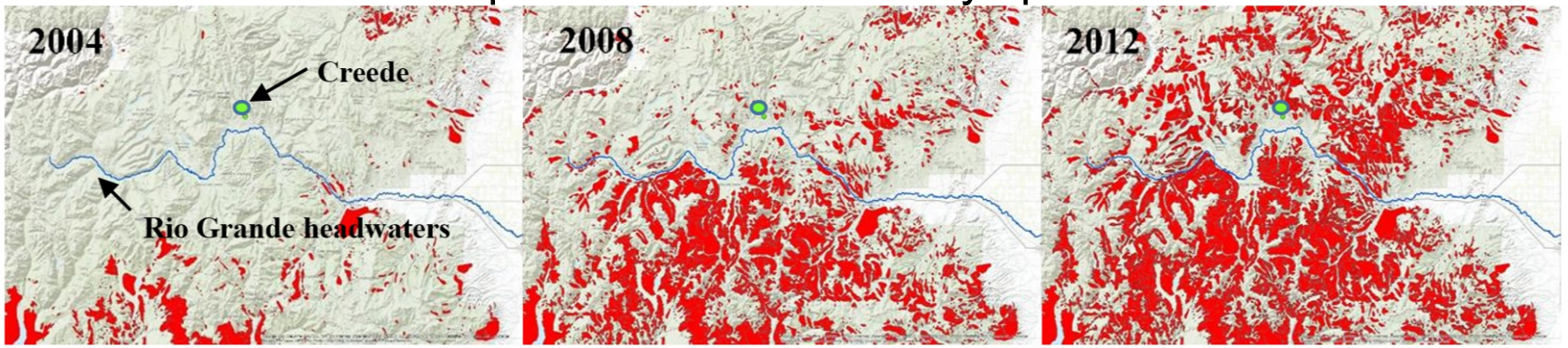
% Recovery

2013 West Fork Complex Fire (450km^2)

Rio Grande Headwaters

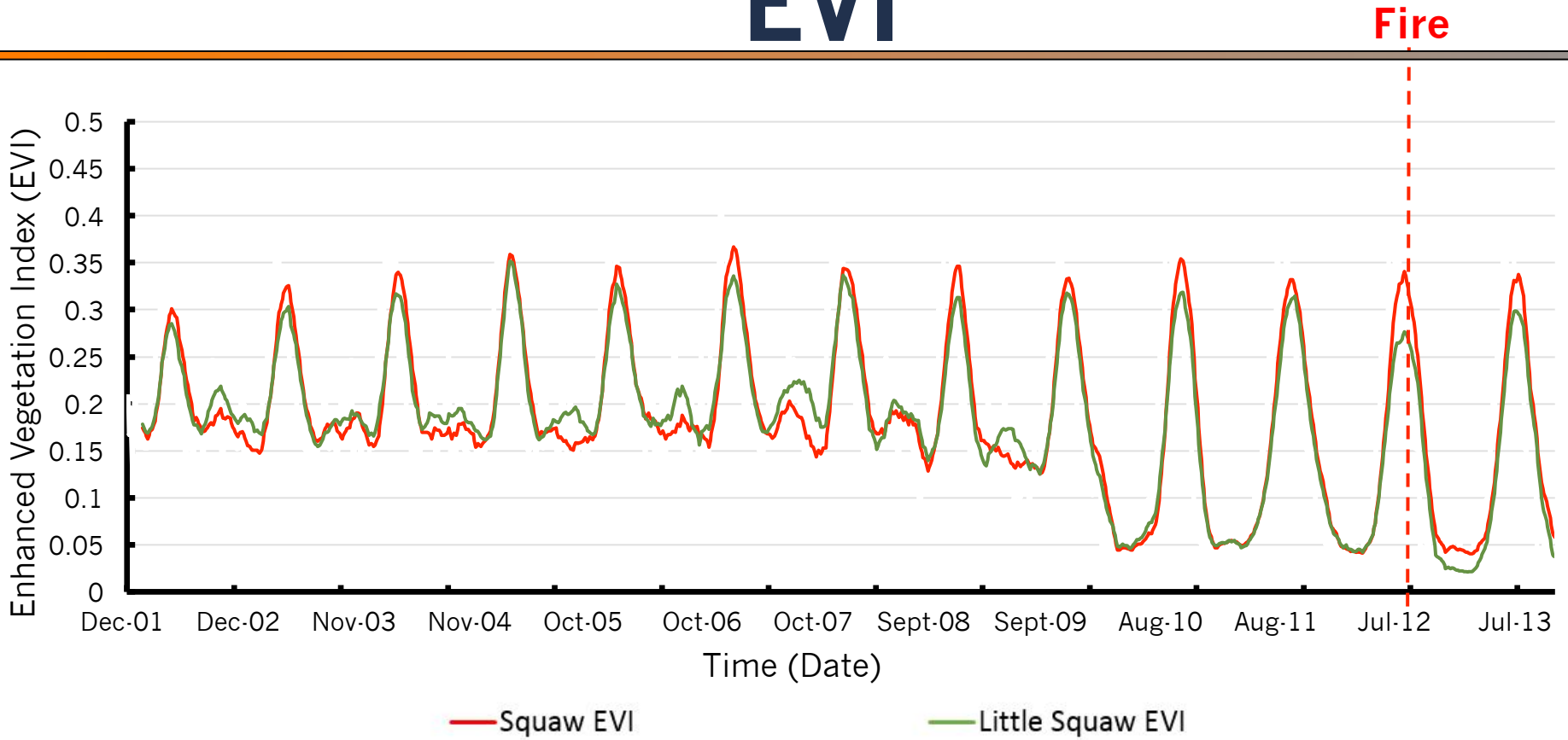


The fire occurred in spruce forest with mostly spruce beetle killed trees



Time series of beetle infestation

EVI



EVI (MOD13Q1 and MYD13Q1) and impact of fire. Significant decrease in vegetation in Squaw (control) and Little Squaw (burn) from WY 2008-2014 (P = 0.002 and 0.0004, respectively).

$$EVI = 2.5\left[\frac{\rho^*_{NIR} - \rho^*_{RED}}{\rho^*_{NIR} + C_1\rho^*_{NIR} - C_2\rho^*_{BLUE} + L}\right]$$

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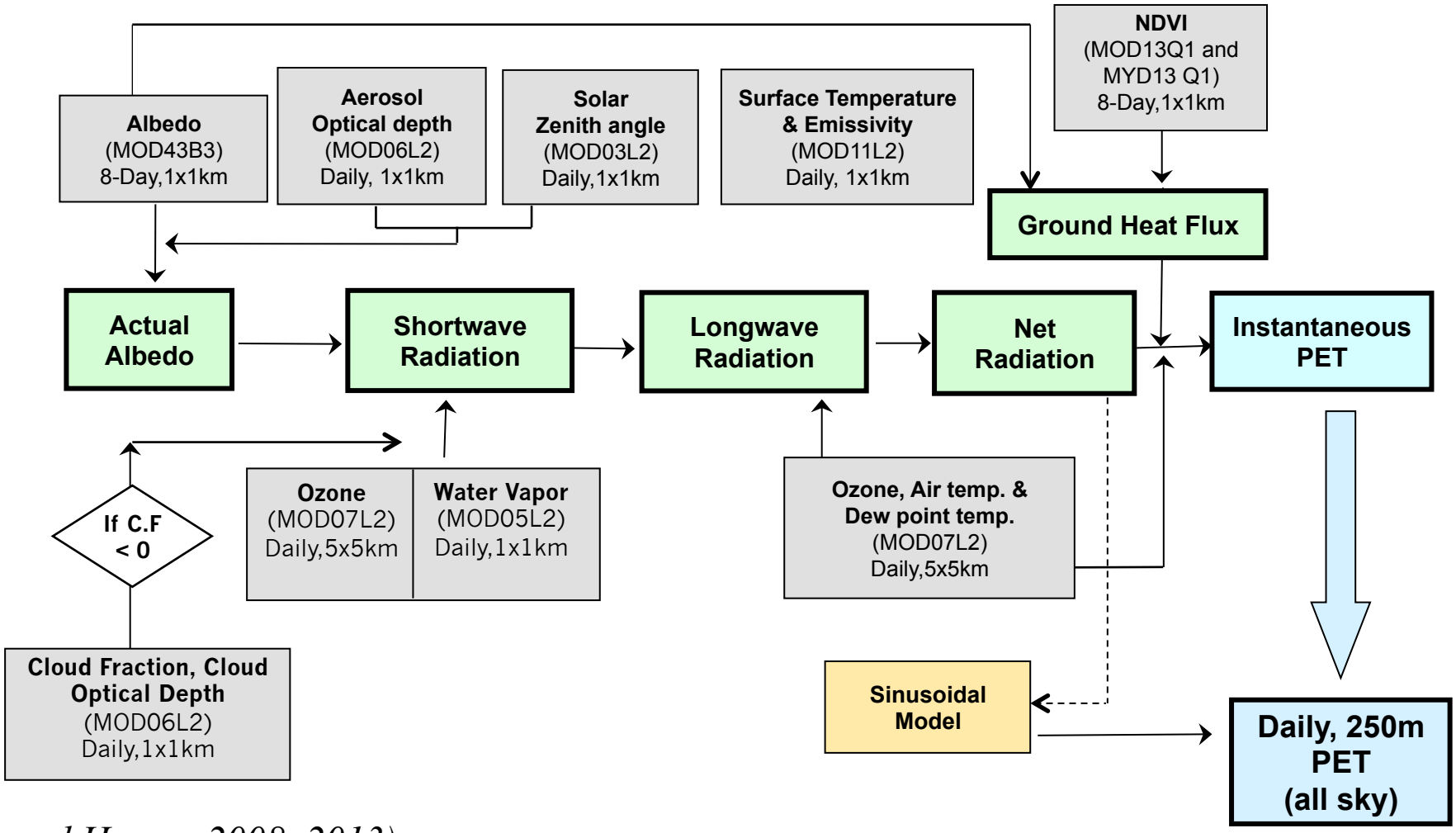
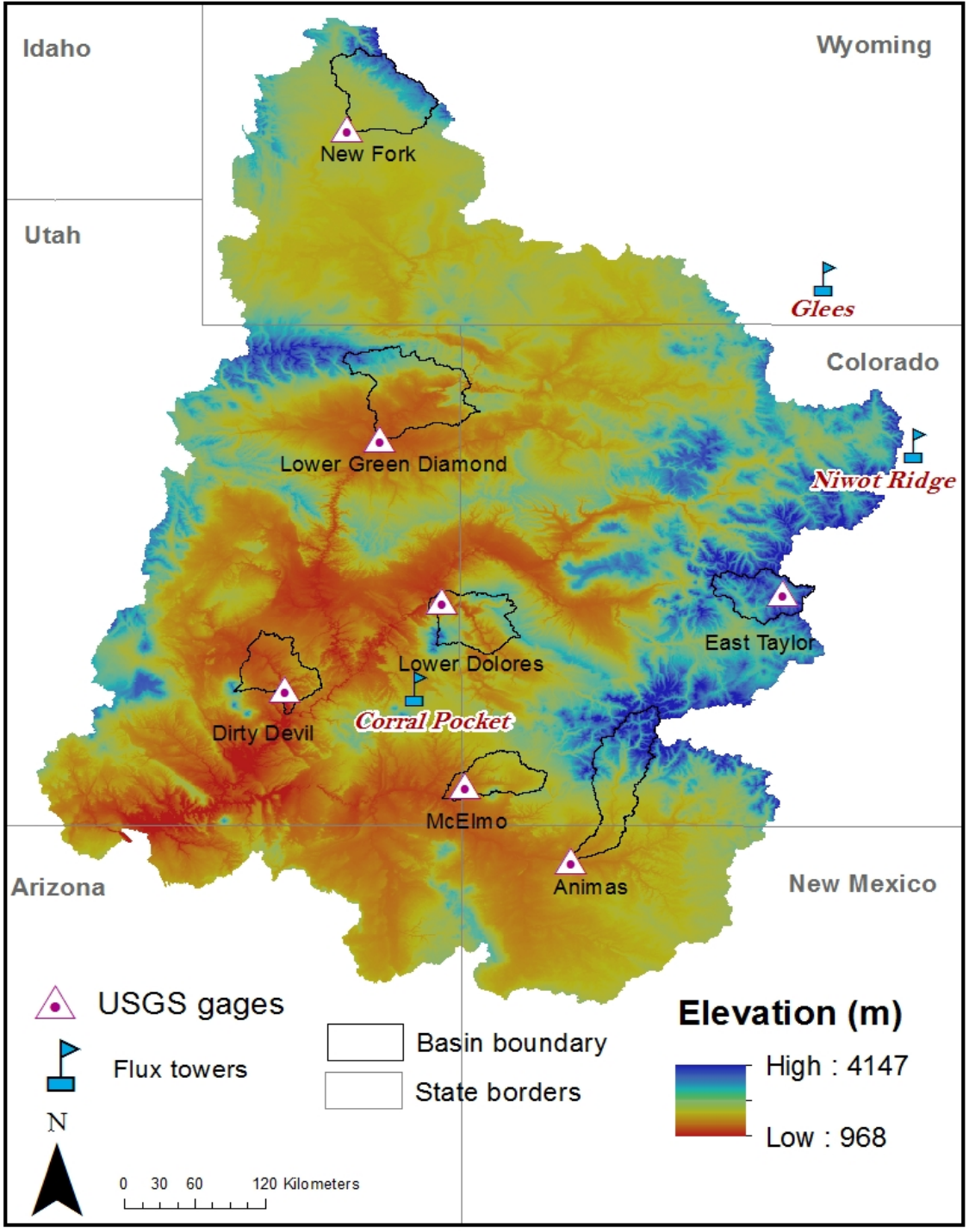
MODIS-PET ALGORITHM



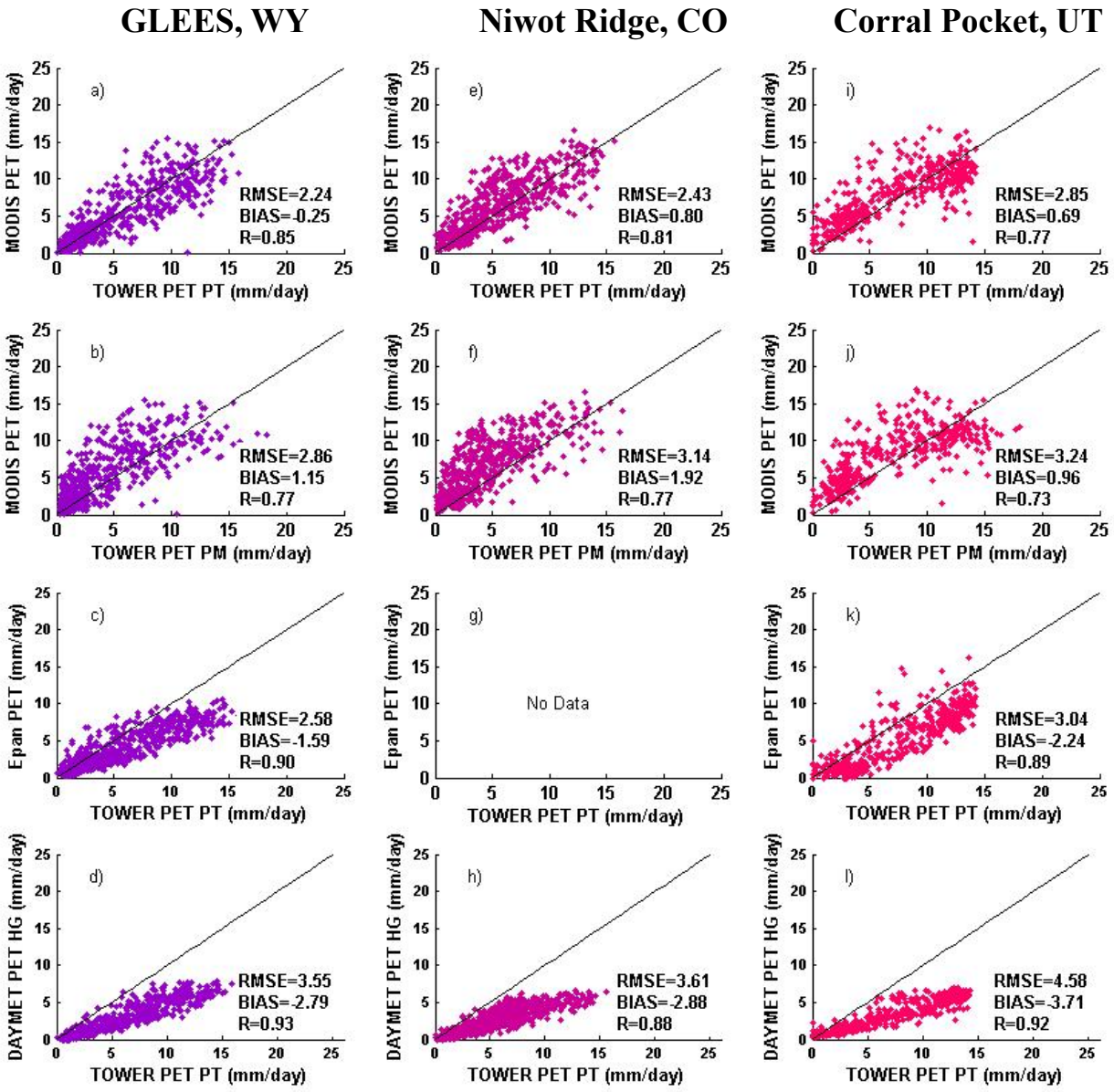
(Kim and Hogue, 2008, 2013)

UCRB – PET Study

- Area: 286,000 km^2
- Elevation range: 1200m-4200m
- Climate:
  north and east: alpine/ subalpine
  south and west: semi-arid
- Snow-dominated upper basin contributes 85-90% of the basin discharge
- Seven diverse basins for model evaluation



PET: Flux Tower Comparisons



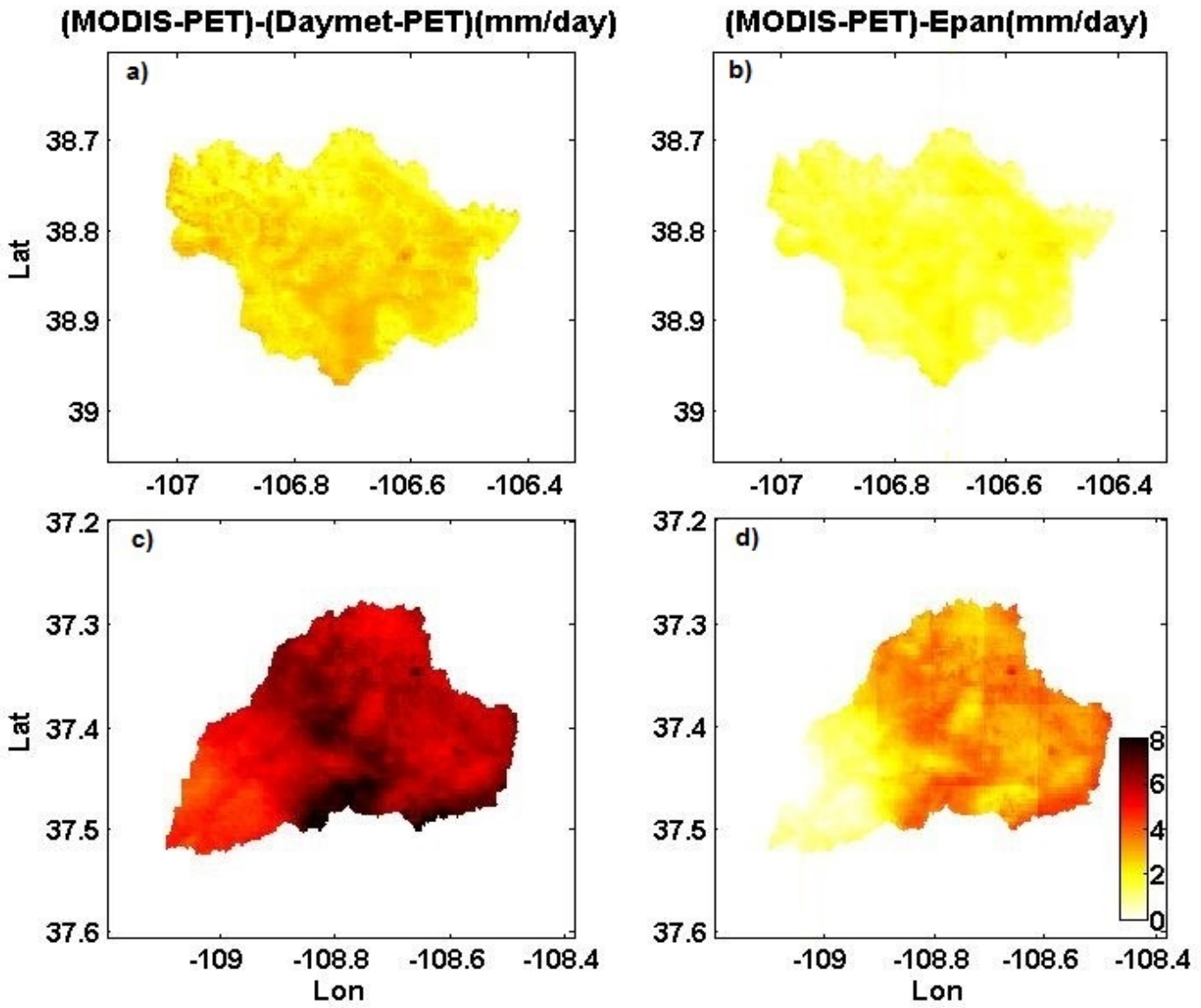
- Models show best performance at high elevation, forested sites
- MODIS-PET generally has lower errors than Epan and Daymet
- MODIS-PET tends to overestimate and Epan and Daymet-PET tend to underestimate flux tower values

PT=Priestley-Taylor
PM=Penman-Monteith
HG= Hargreaves

MODIS-PET ALGORITHM

East Taylor Basin

McElmo Basin



(Kim and Hogue, 2008, 2013; Muhammad et al., 2015)

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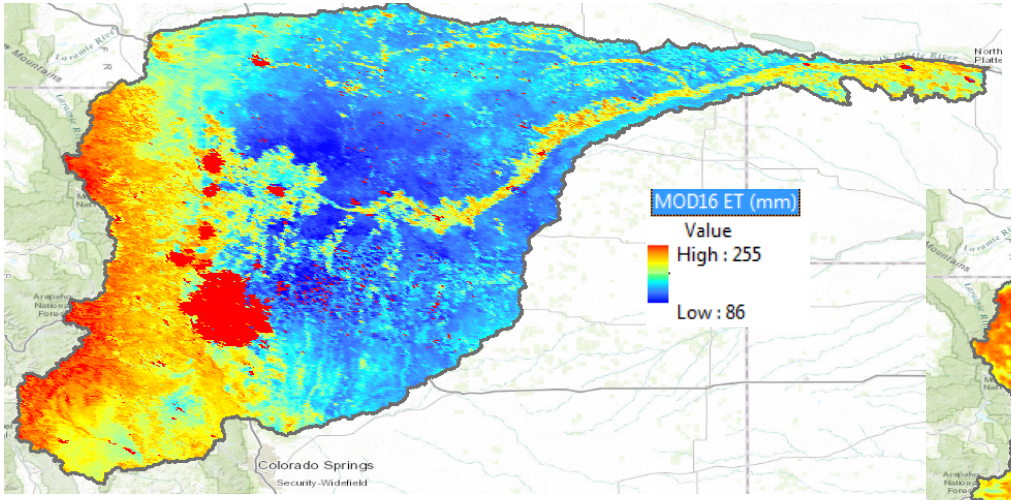
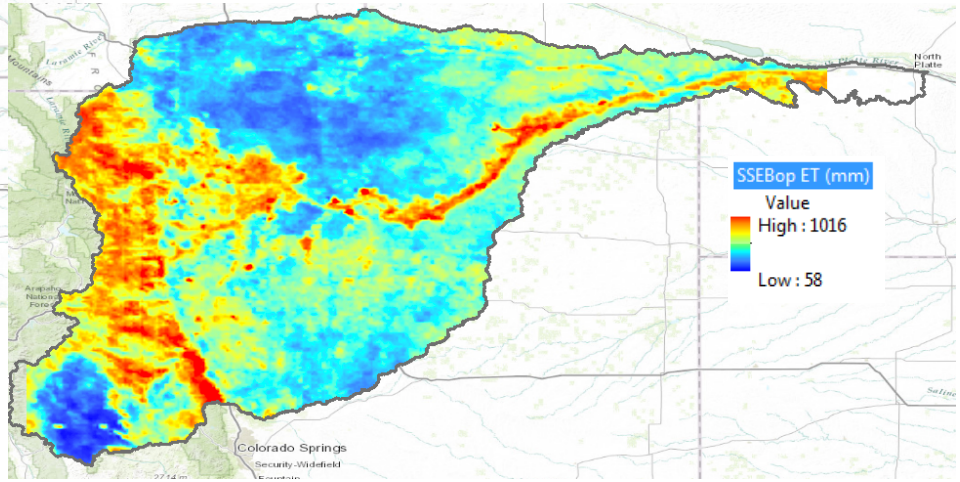
MOD16

- Moderate Resolution Imaging Spectroradiometer global ET
- 1km spatial resolution
- WY 2001-2014
- Terra and Aqua satellites
- Based on Penman-Monteith
- Algorithm uses both atmospheric drivers and the surface energy partitioning process

SSEBop

- Operational Simplified Surface Energy Balance
- 1km spatial resolution
- WY 2001-2013
- Uses weather datasets and MODIS thermal images (LST)
- U.S. Geological Survey (USGS) Geo Data Portal (http://cida.usgs.gov/gdp/).





South Platte River Basin, Colorado

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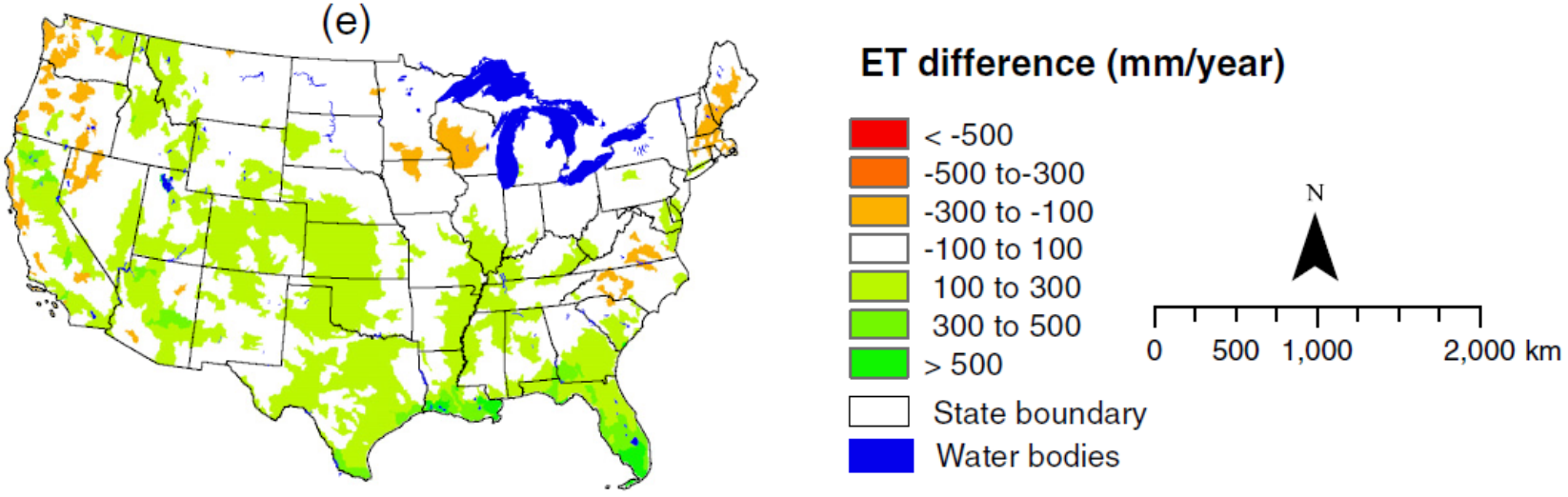
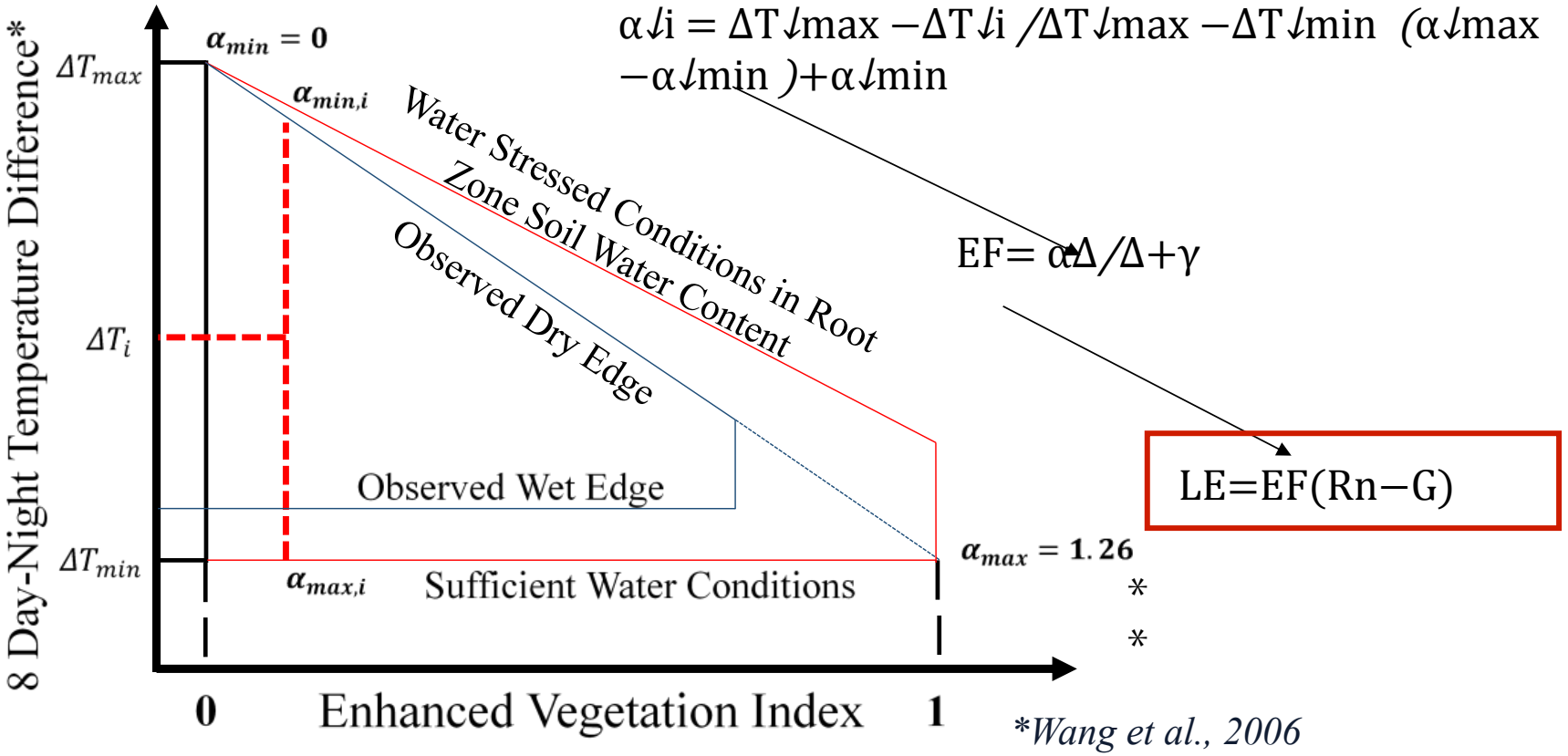


9. Difference between modeled 2009 annual MOD16, SSEBop ET datasets and validation data (GFET, WBET) summarized for HUC8 sub-basins. (a) MOD16 ET minus GFET, (b) SSEBop minus GFET, (c) MOD16 ET minus WBET, (d) SSEBop ET minus WBET, (e) SSEBop minus MOD16 ET.

TRIANGLE METHOD (AET)

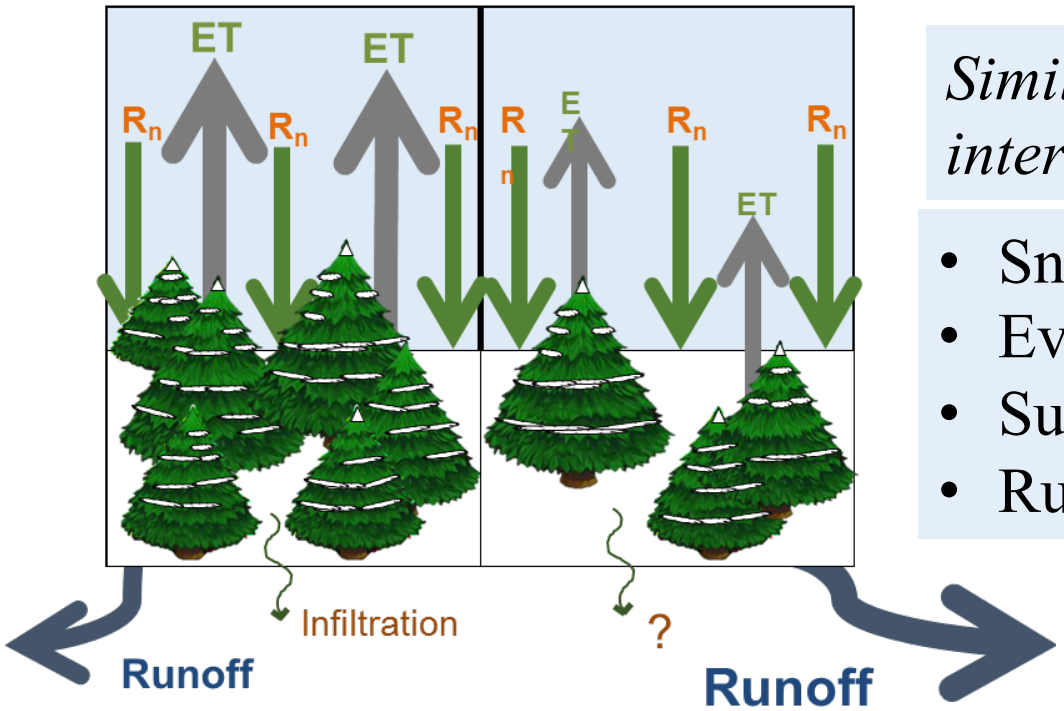
AET with triangle method and remote sensing variables for Rn and G (Kim et al., 2013)



*Wang et al., 2006
**Jiang & Islam (2001)

Sagehen Watershed, No. California

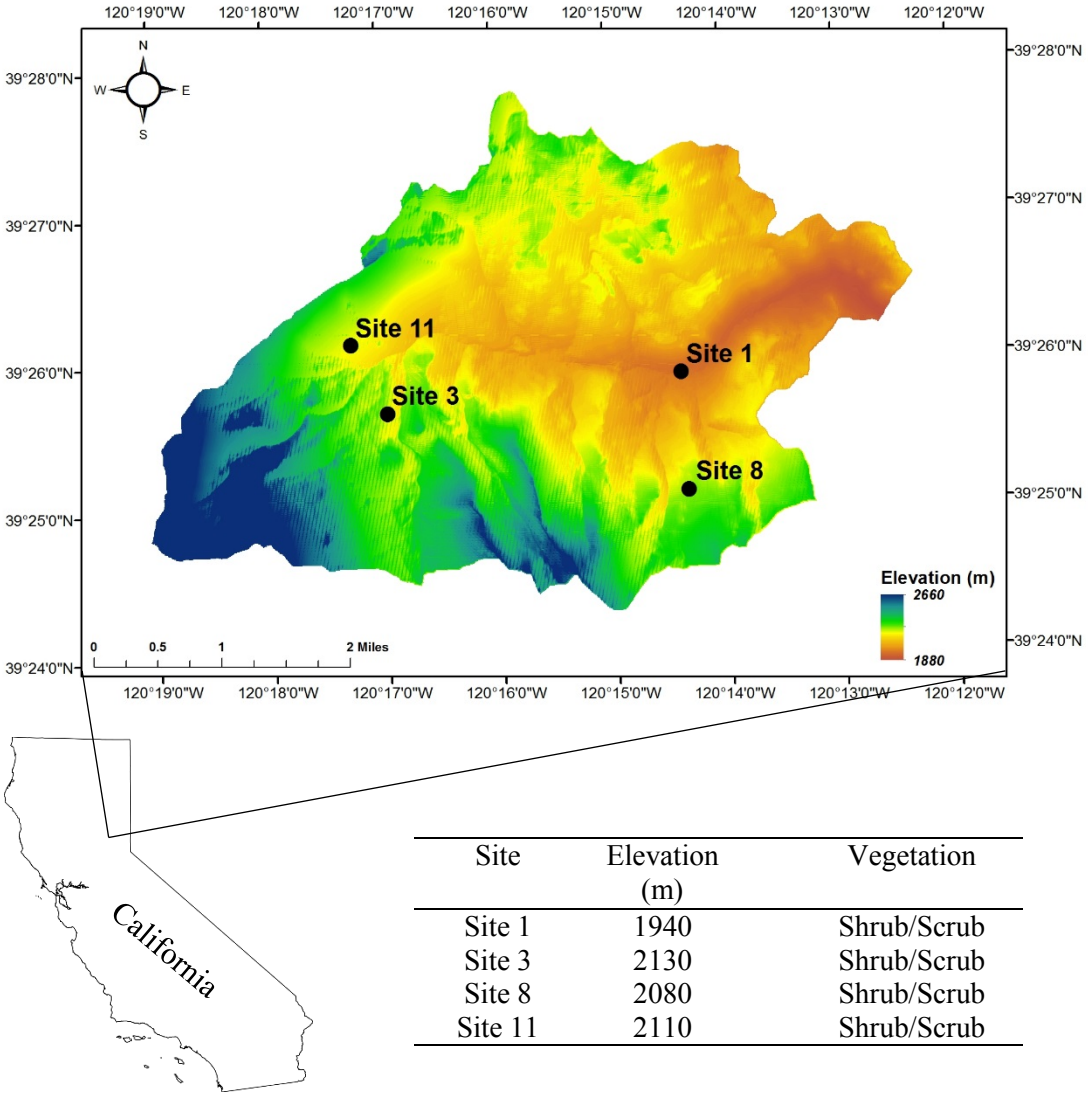
- USFS GTR 237: Managing Sierra Nevada Forests to restore natural forest structure (North et al., 2012)
- Sagehen Experimental forest management prototype for the Sierra Nevada
  - Treatments started summer 2014
- Evaluate variability in fuel treatments and corresponding water yield Understand altered annual and seasonal water budgets



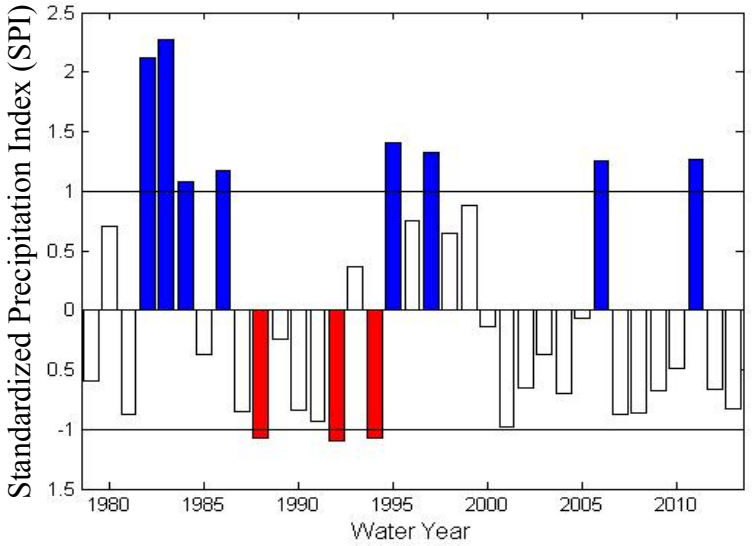
Similar R_n, less canopy, and less interception will alter:

- Snow Regimes (melt & timing)
- Evapotranspiration (ET)
- Sublimation
- Runoff and Water Yield

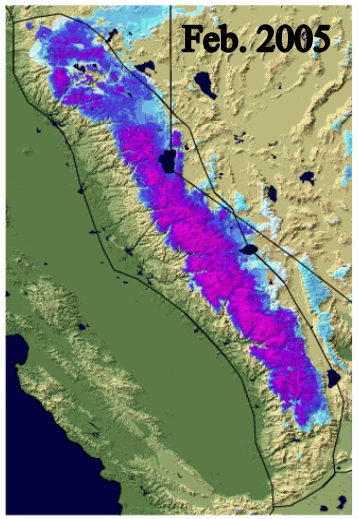
Study Area – *Sagehen Watershed*

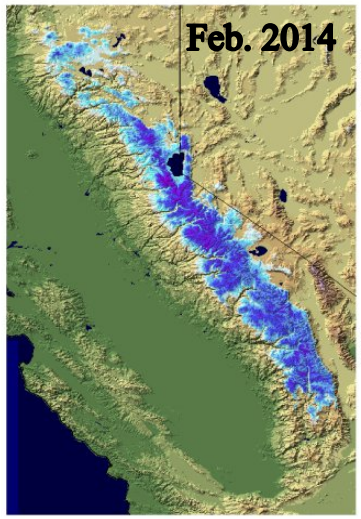


Site	Elevation (m)	Vegetation
Site 1	1940	Shrub/Scrub
Site 3	2130	Shrub/Scrub
Site 8	2080	Shrub/Scrub
Site 11	2110	Shrub/Scrub

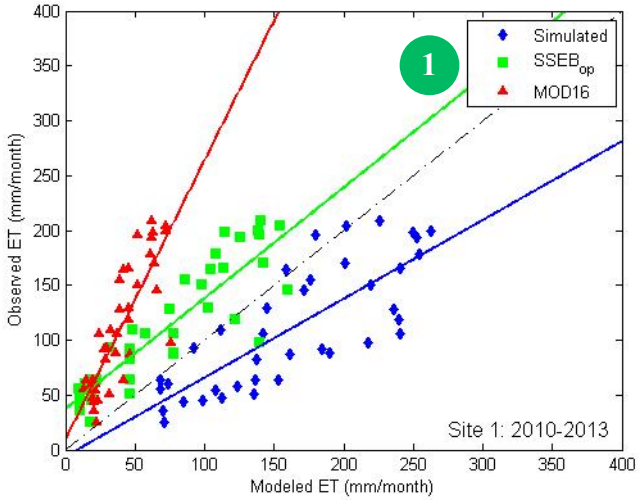


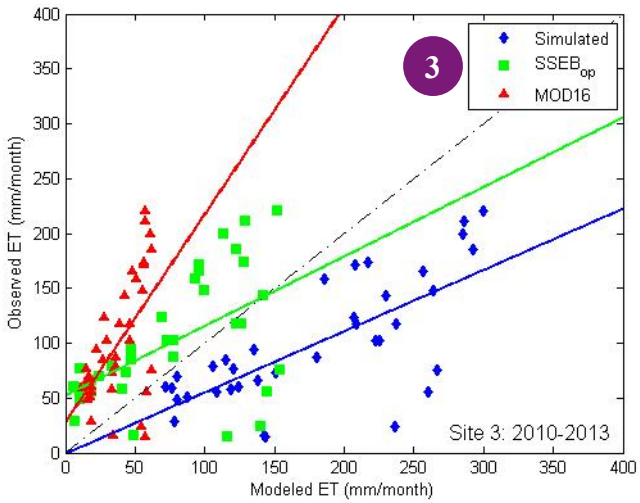
Snow Depth (NOAA NOHRSC)

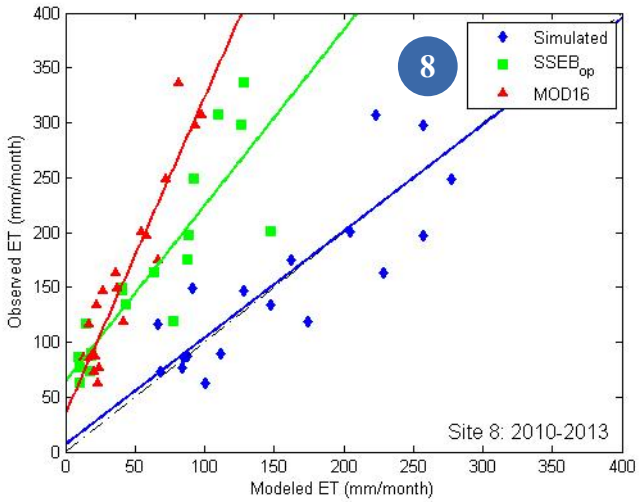


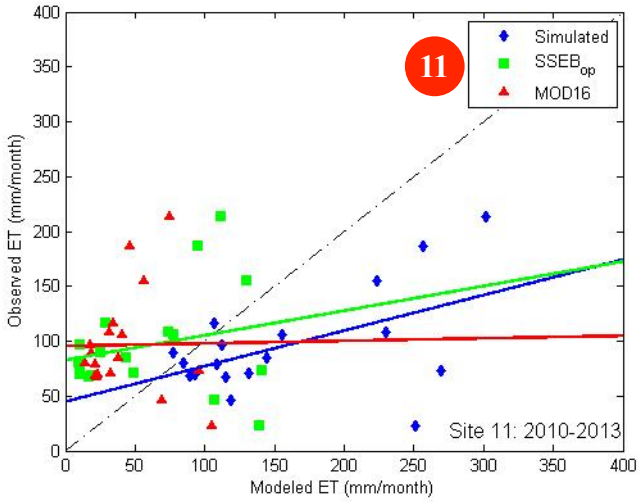


Monthly AET (Triangle, SSEBop and MOD16)

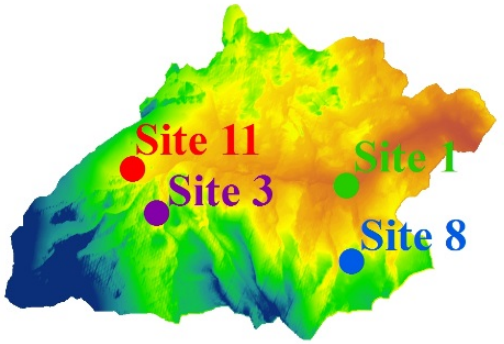






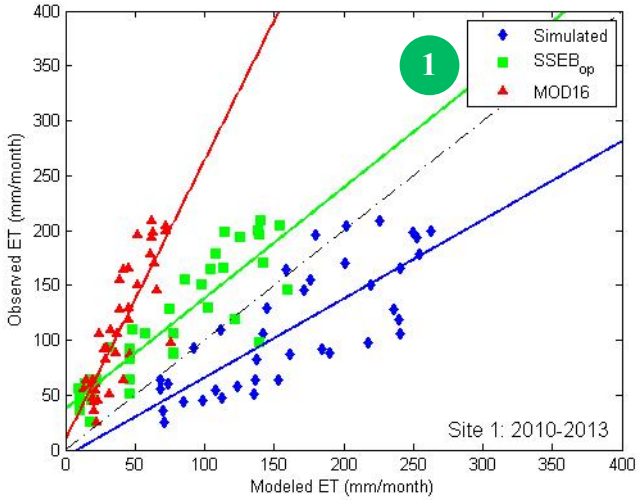


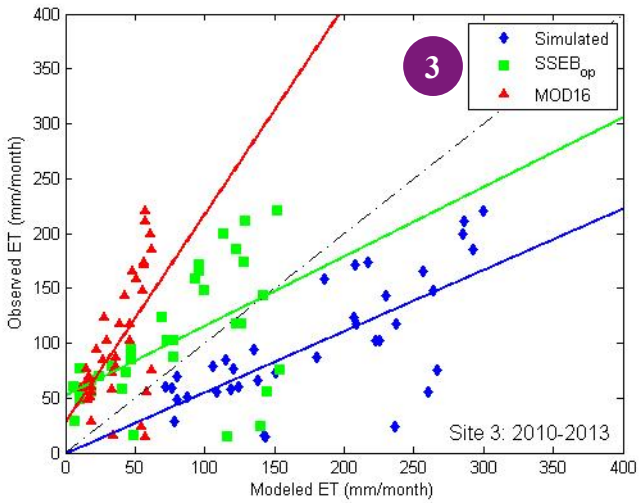
- Monthly total ET (mm/month)
- 1 km Resolution

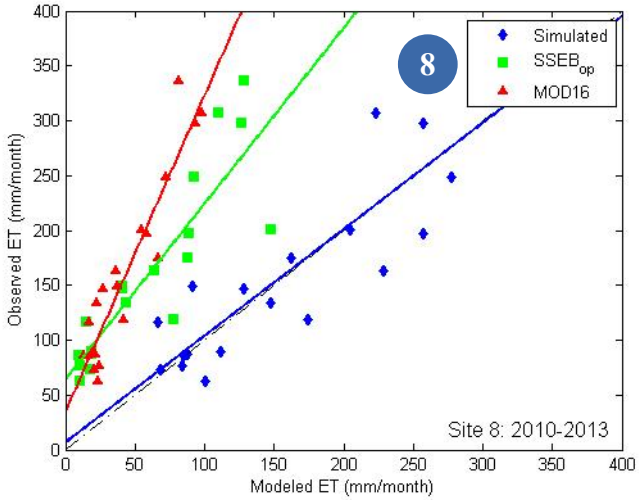


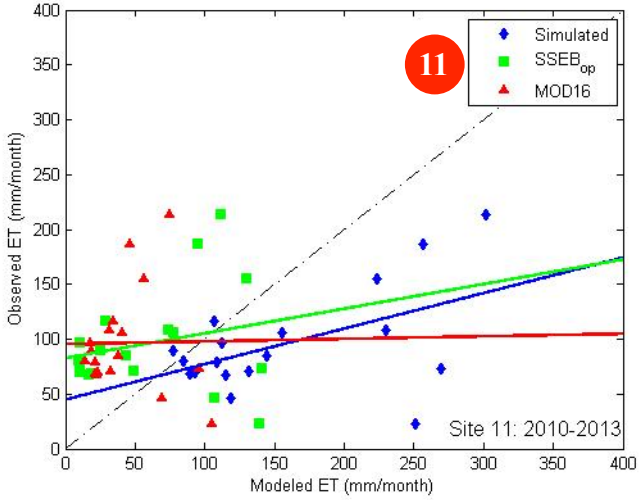
- Poor Performance by MOD16
- SSEBop and MODIS Triangle Method show improved estimations to that of MOD16

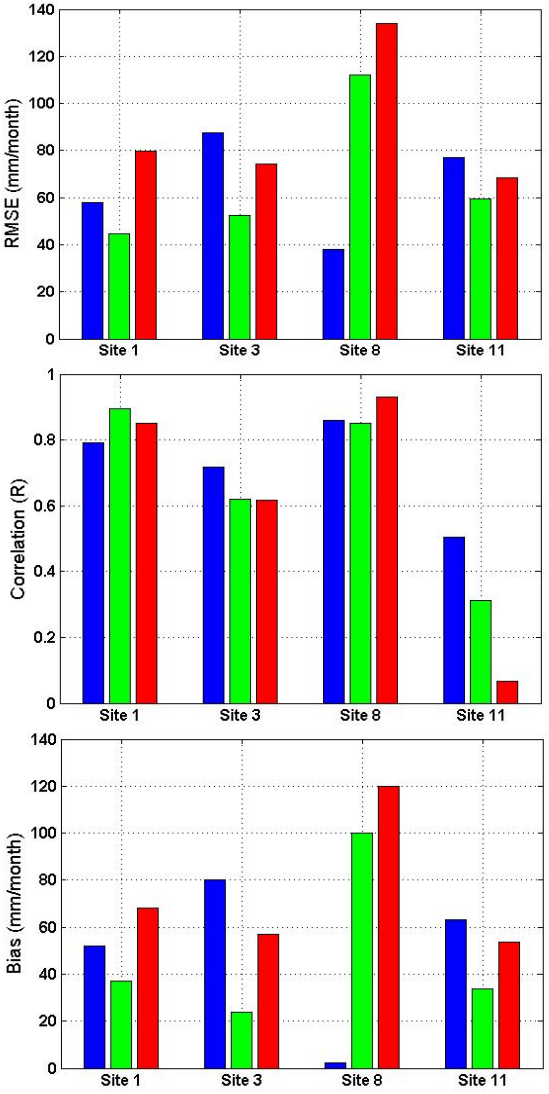
Validation – Monthly AET





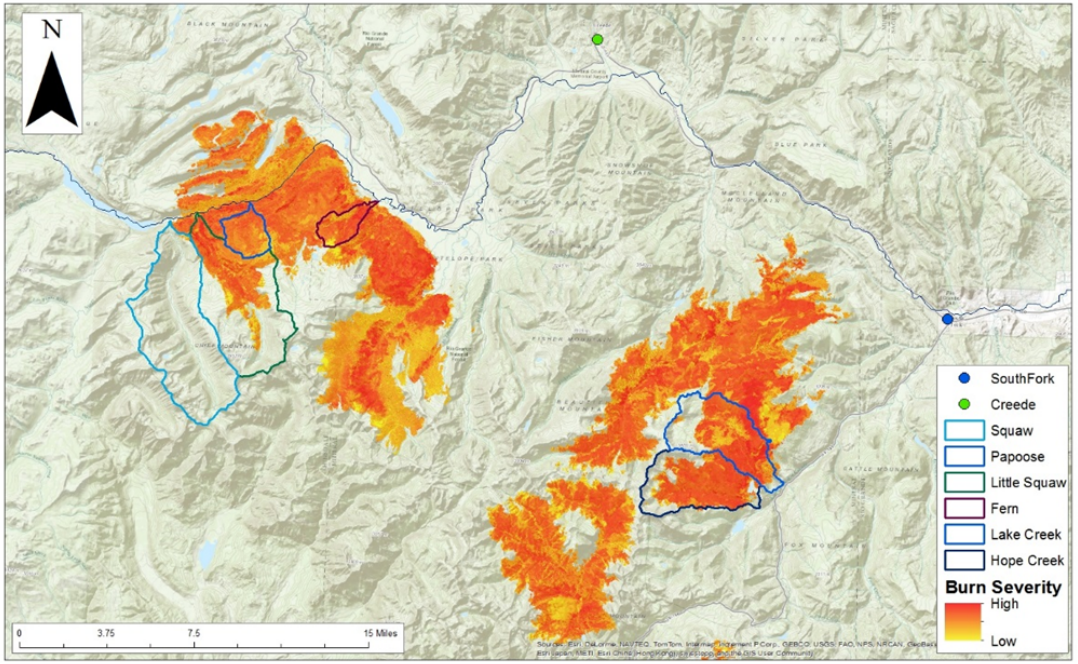




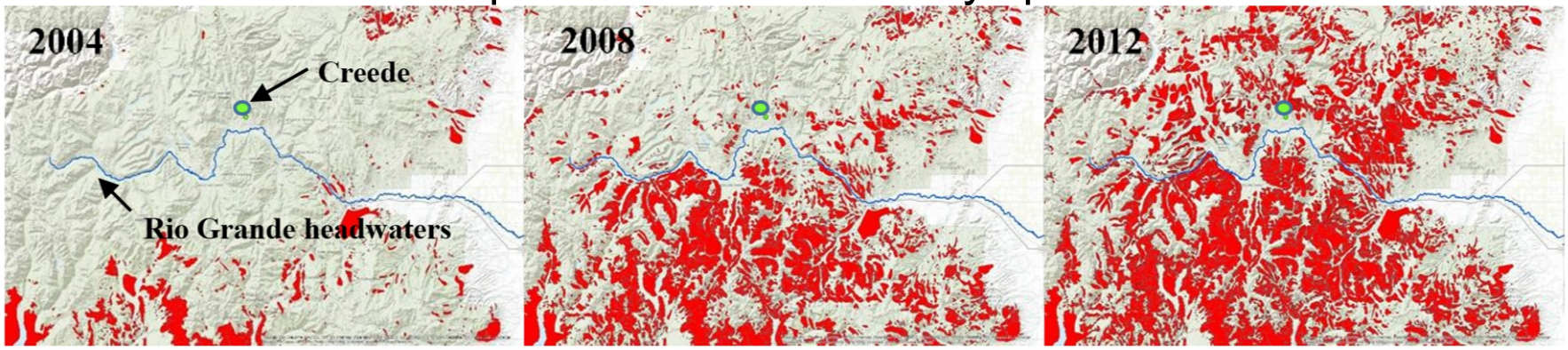


2013 West Fork Complex Fire (450km^2)

Rio Grande Headwaters

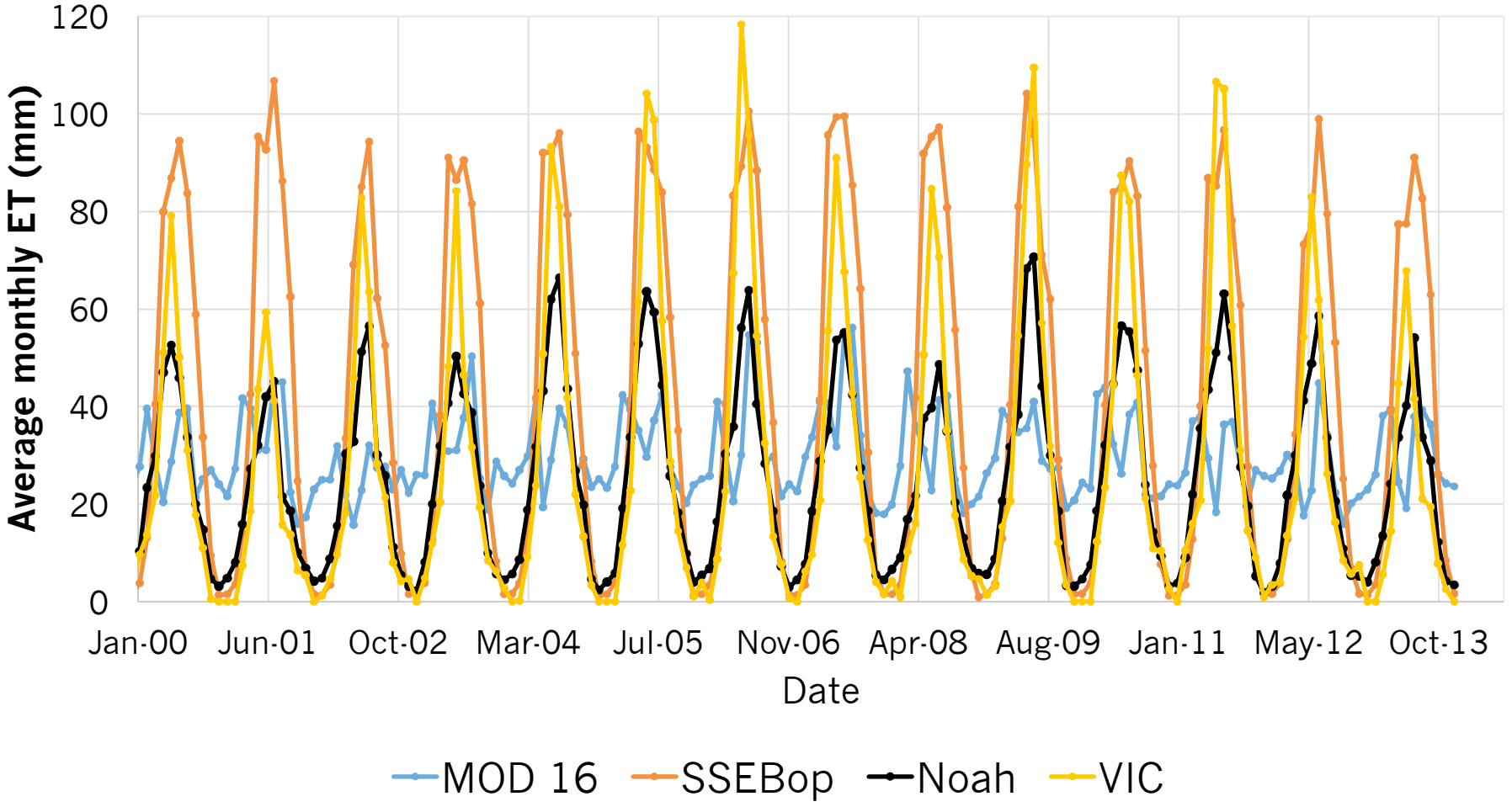


The fire occurred in spruce forest with mostly spruce beetle killed trees



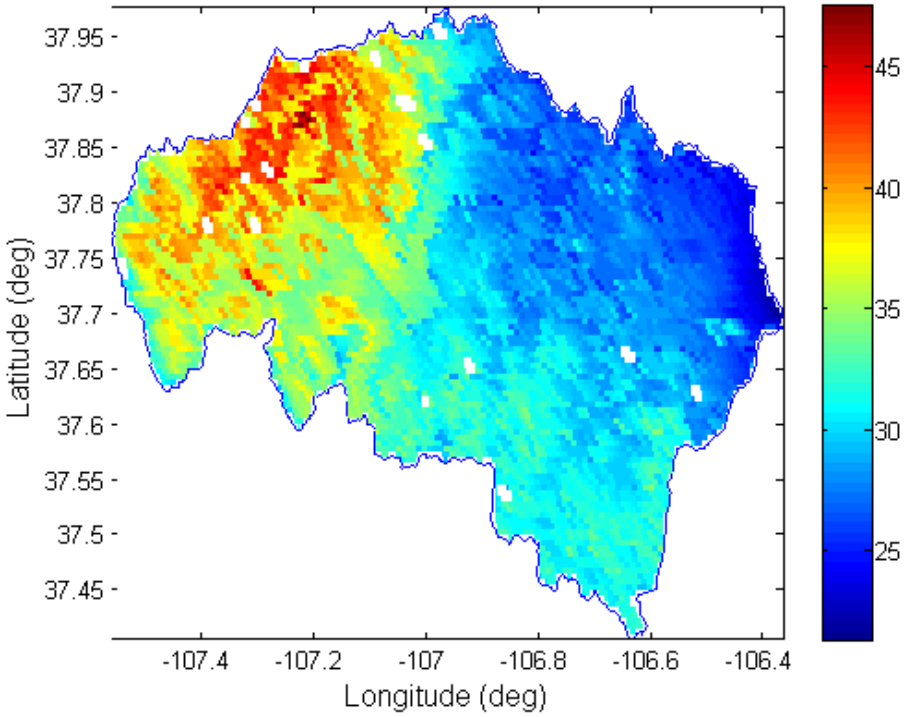
Time series of beetle infestation

ET COMPARISON

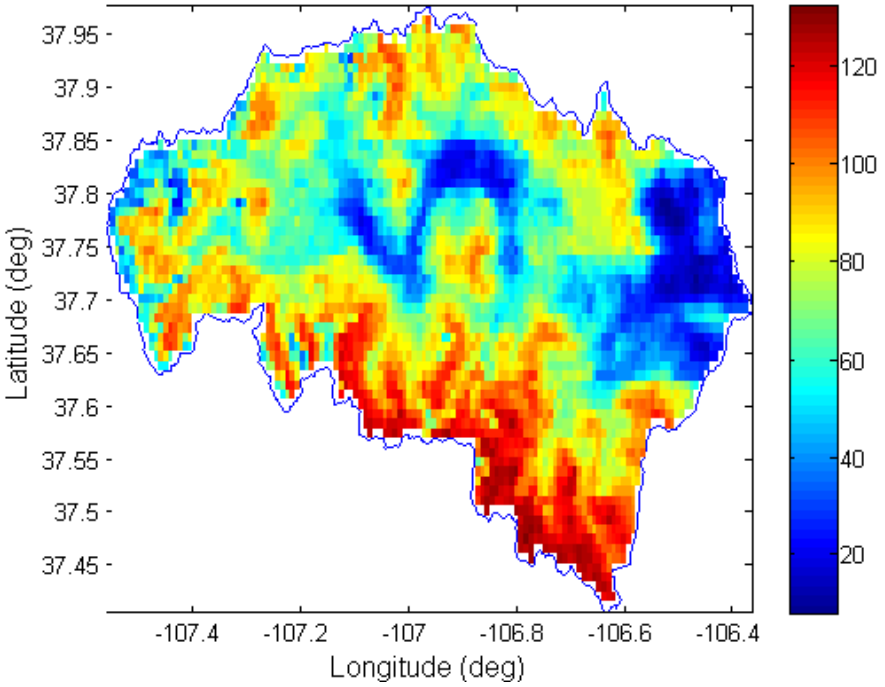


ET COMPARISON

MOD16 MONTHLY



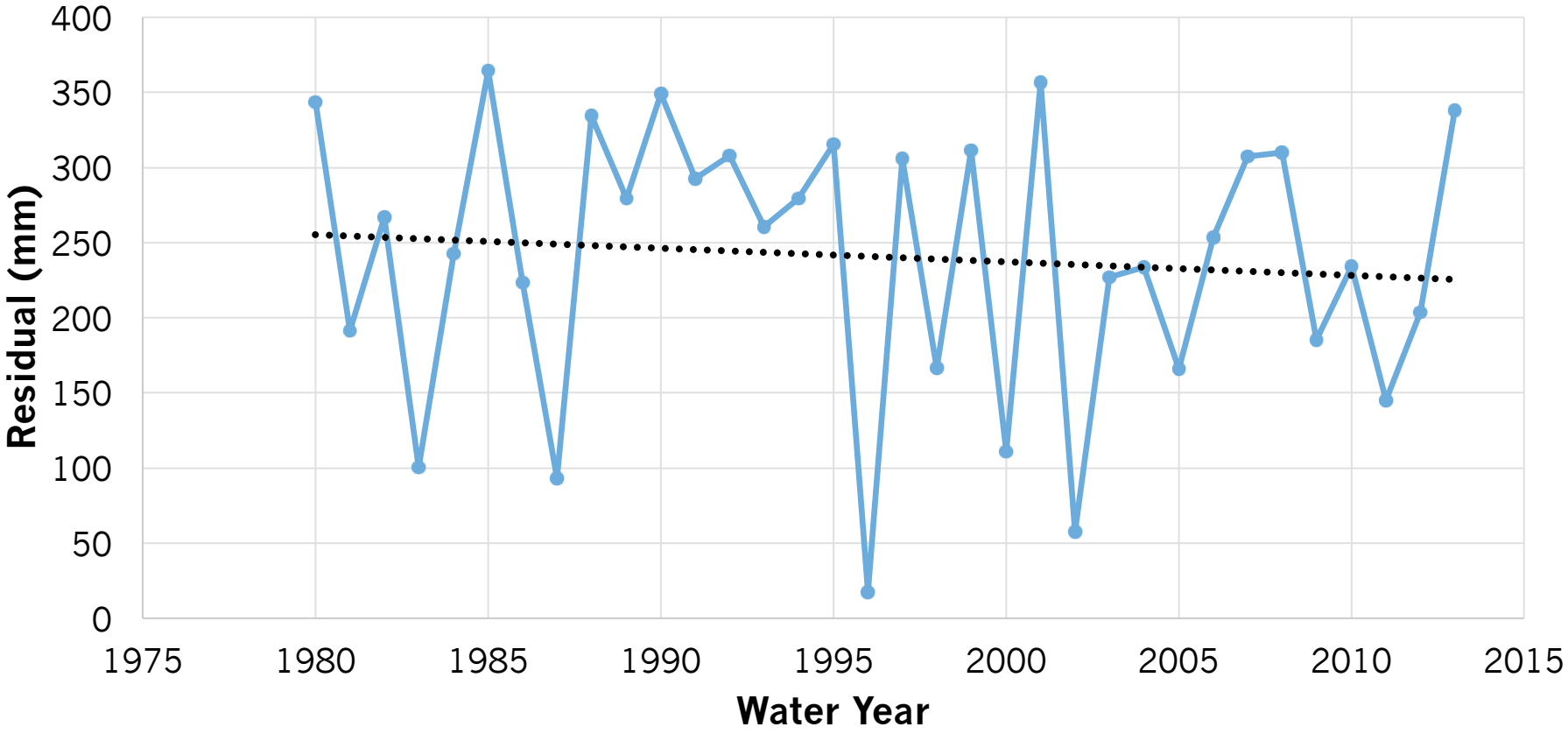
SSEBop MONTHLY



May 2007

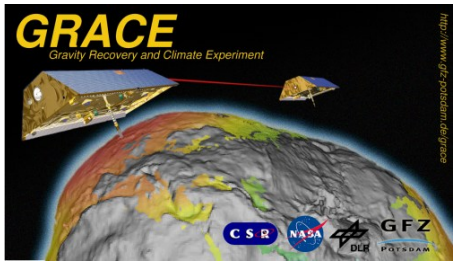
HISTORICAL WATER BUDGET

Recharge (R) = Precipitation (P) – Evapotranspiration (ET) – Discharge (Q)

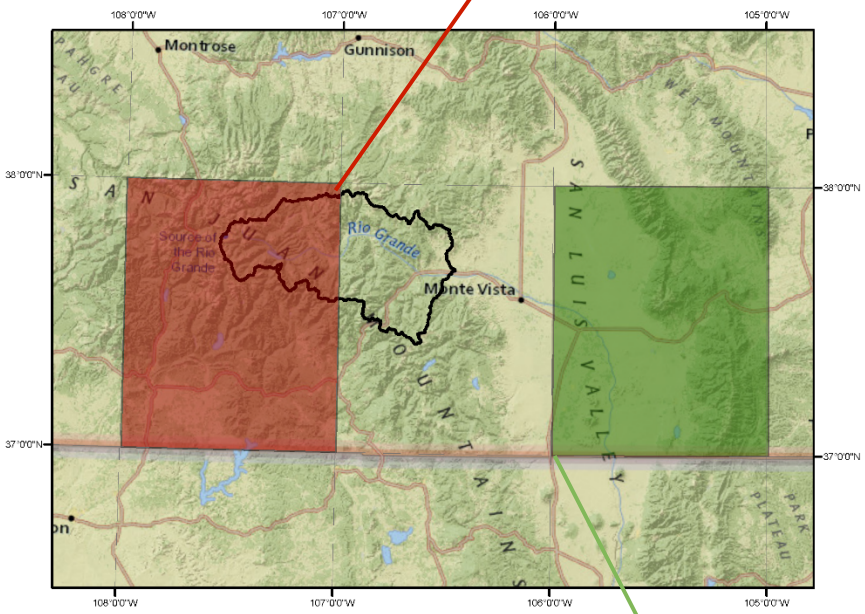


Water budget over the entire upper Rio Grande River basin, using the mean ET value between VIC and Noah, the graph displays the residual water in the watershed (P=0.58).

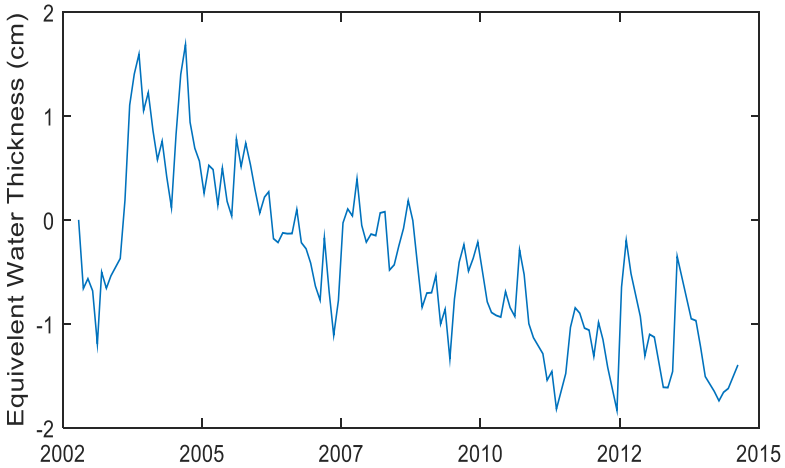
NASA GRACE DATA
(WATER THICKNESS ANOMALIES)

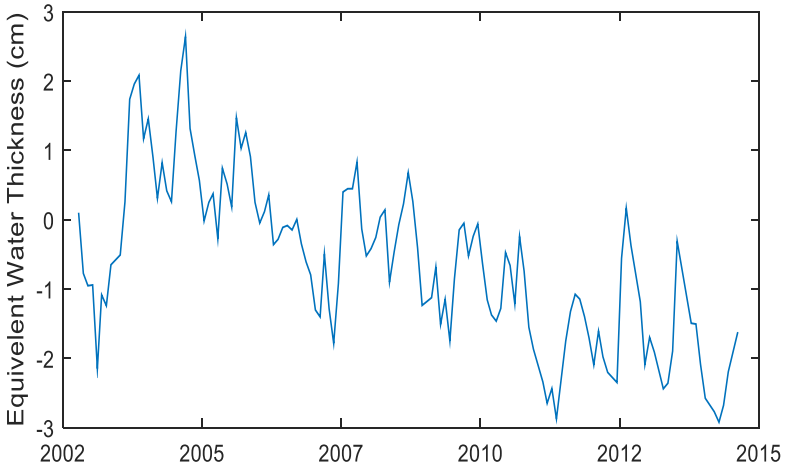


Disturbance



Agriculture





Available since May 2002
~300km resolution
Monthly data

Concluding Remarks

- Natural and anthropogenic disturbance increasing across globe: wildfire, floods, drought, insect infestation, biodiversity change, etc.
- Studies needed on resiliency and long-term impacts to hydrology (water supply and quality), ecosystems, geomorphology, biota, urban-fringe communities, etc.
- Improved tools to facilitate understanding:
  - Remote sensing – spatial and temporal data synthesis
  - Models – parameterizations for long-term simulations
  - Decision Support Systems (DSS) - integration and management

References

Knipper, K., T.S. Hogue, and A. Kinoshita, 2015: Remote Sensing of Evapotranspiration in Western U.S. Mountain Watersheds: A Sensitivity Analysis of the Triangle Method *(in preparation)*

Bowman, A.L., K.J. Franz, T.S. Hogue, and A.M. Kinoshita, 2014: MODIS-based potential evapotranspiration demand curves for the Sacramento Soil Moisture Accounting model, *Journal of Hydrologic Engineering (in review)*

Muhammad, B., T.S. Hogue, K. J. Franz and A. Kinoshita, 2014: Assessing Spatial Potential Evapotranspiration Methods for Hydrologic Forecasting in the Upper Colorado River Basin, *JAWRA* (in review)

Kinoshita, A.M., and T.S. Hogue, 2015: Increased Dry Season Water Yield in Burned Watersheds in Southern California, *Environmental Research Letters,*10 014003, doi:10.1088/1748-9326/10/1/014003

Micheletty, P.D., A.M. Kinoshita, and T.S. Hogue, 2014: Application of MODSCAG and MODIS snow cover products in post-fire watersheds in the Sierra Nevada, *Hydrology and Earth System Science,* 18, 4601-4615.

Spies, R., K. Franz, T.S. Hogue and A. Bowman, 2014: Distributed hydrologic modeling using satellite-derived potential evapotranspiration, Journal of Hydrometeorology, doi: http://dx.doi.org/10.1175/JHM-D-14-0047.1

Kinoshita, A.M., T. S. Hogue and C. Napper, 2014: Evaluating Pre- and Post-fire Peak Discharge Predictions across Western U.S. Watersheds, *Journal of the American Water Resources Association,* 50(6), 1540–1557, doi: 10.1111/jawr.12226

Kim, J. and T.S. Hogue, 2013: Evaluation of a MODIS triangle-based evapotranspiration algorithm for semi-arid regions, Journal of Applied. Remote Sensing, 7, 073493, doi:10.1117/1.JRS.7.073493

Kim, J., and T.S. Hogue, 2012: Evaluation and sensitivity testing of a coupled Landsat-MODIS downscaling method for land surface temperature and vegetation indices in semi-arid regions, Journal of Applied Remote Sensing, 6(1), 063569-1-17.

Kim J., and T.S. Hogue, 2012: Improving Spatial Soil Moisture Representation Through Integration of AMSR-E and MODIS Products, IEEE Transactions in Geoscience and Remote Sensing, 50(2), 446-460.

Kim, J. and T.S. Hogue, 2008: Evaluation of a MODIS-based Potential Evapotranspiration Product at the Point-scale, Journal of Hydrometeorology, 9, 444-460.