Simulating Long-Term, Inter-annual Fire Regime Variability in the Continental United States: Applications to Regional Haze Planning

Matt Mavko, John Bannister, Evan Burgess, and Keith Silcock, Air Sciences Inc.

2019 International Emissions Inventory Conference

August 2, 2019

WESTAR
Western States Air Resources Council

WRAP
Western Regional Air Partnership

AIR SCIENCES INC.

Fire Scenarios for Regional Haze Planning

- Updates to Round 1 SIPs are due in July 2021, will include emissions reduction benefits expressed as 2028 Reasonable Progress Visibility Goals
- Monitoring data tracking metric changed “worst” to “most impaired” using chemical species sorting
- Tracking metric attempts to remove most contributions from wildfire and dust sources by complex/inferred relationship to measured carbon and dust on filters
- SIPs need to quantify progress to date and project future improvement by 2028 while fire is increasing
- Regional photochemical modeling of all emissions sets future visibility goals
- Draft RHR guidance allows for removing effects of increased Rx fire, unclear/uncertain process
- Source mix is complicated and variable at Class I areas in terms of source regions and in time – changing mix controllable U.S. & international vs. natural/uncontrollable
- Source apportionment regional modeling is limited to SO_4 and NO_3 impacts to align with tracking metric assumptions
- Potential future fire sensitivity scenarios in regional modeling bound relative SO_4 and NO_3 improvements to support weight of evidence for setting visibility goals at each of 100+ Class I areas in the WESTAR-WRAP region

Fire Scenario Development Steps

- 5-year Representative Baseline Activity and Emissions
  - Daily locations
  - Sizes
  - Fire types (planned and unplanned)
- Future Year Activity and Emissions
  - Scenarios evaluating possible future outcomes
  - Scale one or more inputs for each scenario
    - Number, size, and/or distribution of events
    - Fuels
    - Emission factors
    - Distribution of events

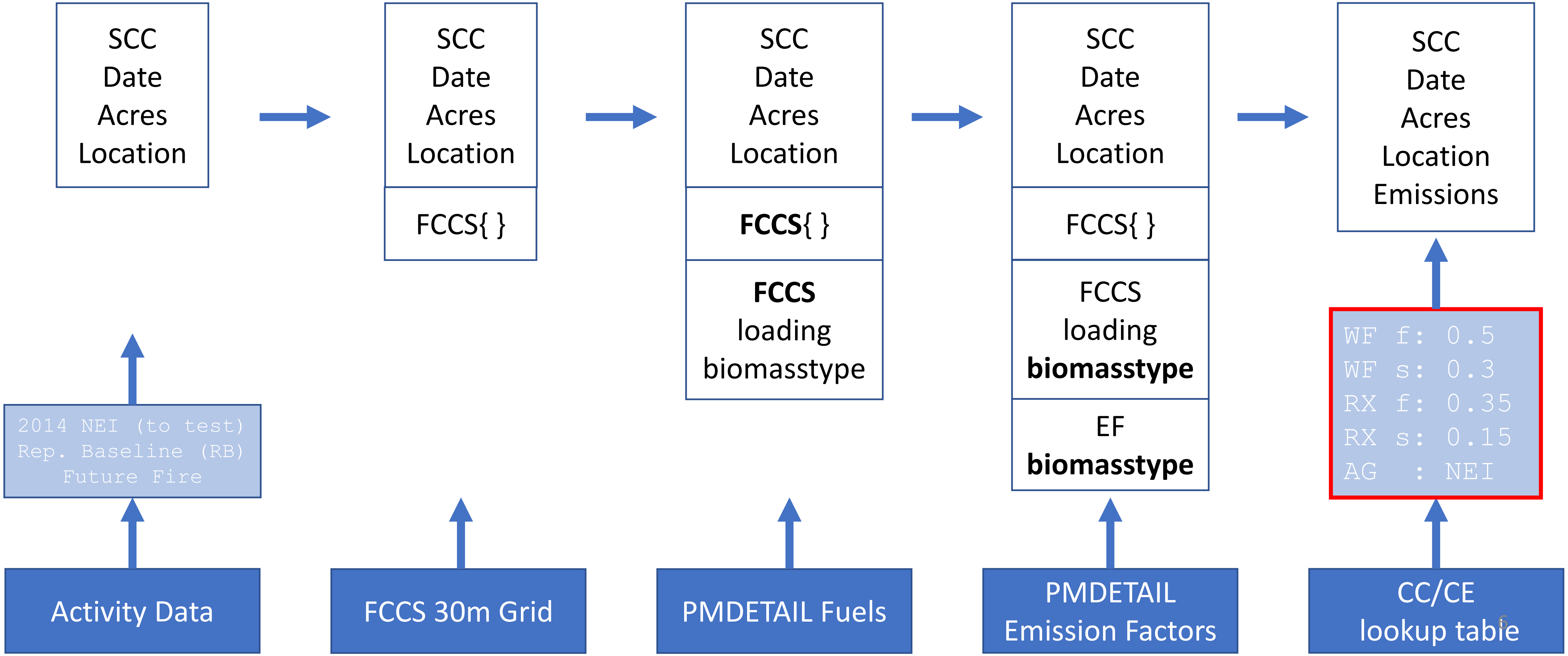
Representative Baseline (RB) Development Steps

- Activity Data
  - Daily fire location
  - Daily fire size
  - Fire type (planned and unplanned)
  - Fuel characteristics
- Emissions Calculations
  - Fuel consumption
  - Speciated emissions
  - Heat release (CMAQ plume rise algorithm)
  - Plume characteristics (CAMx WRAP plume rise algorithm)

RB – Emissions Calculations

- Build framework to process and format activity data
- Use a basic approach
  - FINN algorithms?
  - WRAP 2002?
  - Allow for adding nuance (type-specific processing)
- Use **readily-available** data sources and approaches
  - FCCS Pre-burn fuel loadings
  - PMDETAIL emission factor database
  - FEPS heat release equation

RB – Emissions Calculations Workflow



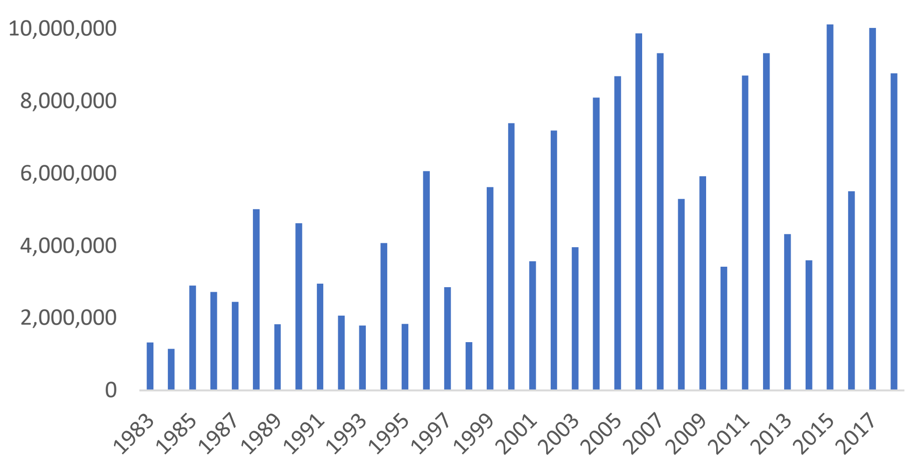
RB Activity Data Development

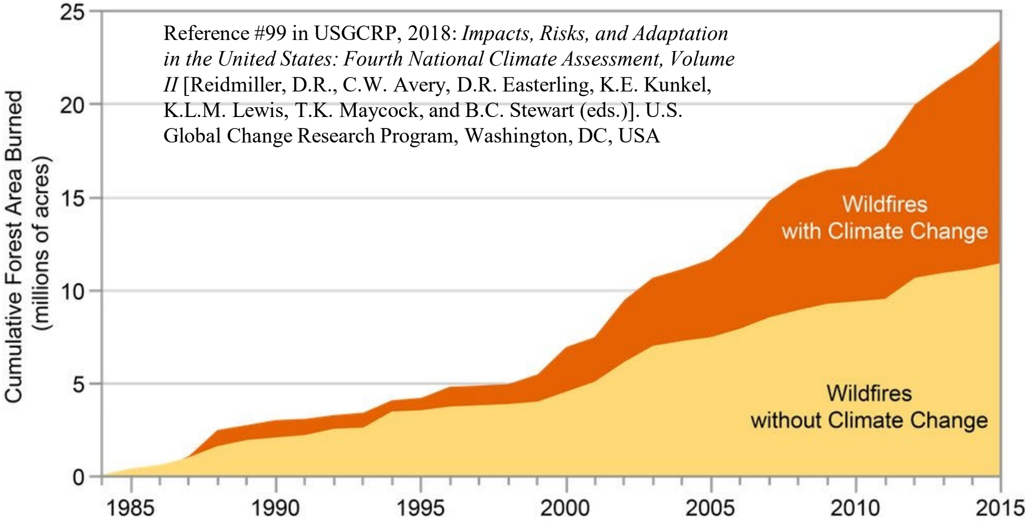
- Activity representative of a 5-year period (2013-2017)
- We do not have complete activity for all fire types over the period
- What assumptions can we make? What limitations can be imposed?
  - Rx and Ag burning consistent (i.e. can we use a single year like 2014)?
  - Wildfire activity highly variable
  - Wildfire activity has changed (increased) *significantly* in the past 5-10 years?
  - Fire activity representative of a multi-year period will be uncoupled from model meteorology

Aside: Trends Wildfire Activity

https://www.nifc.gov/fireInfo/fireInfo_statistics.html

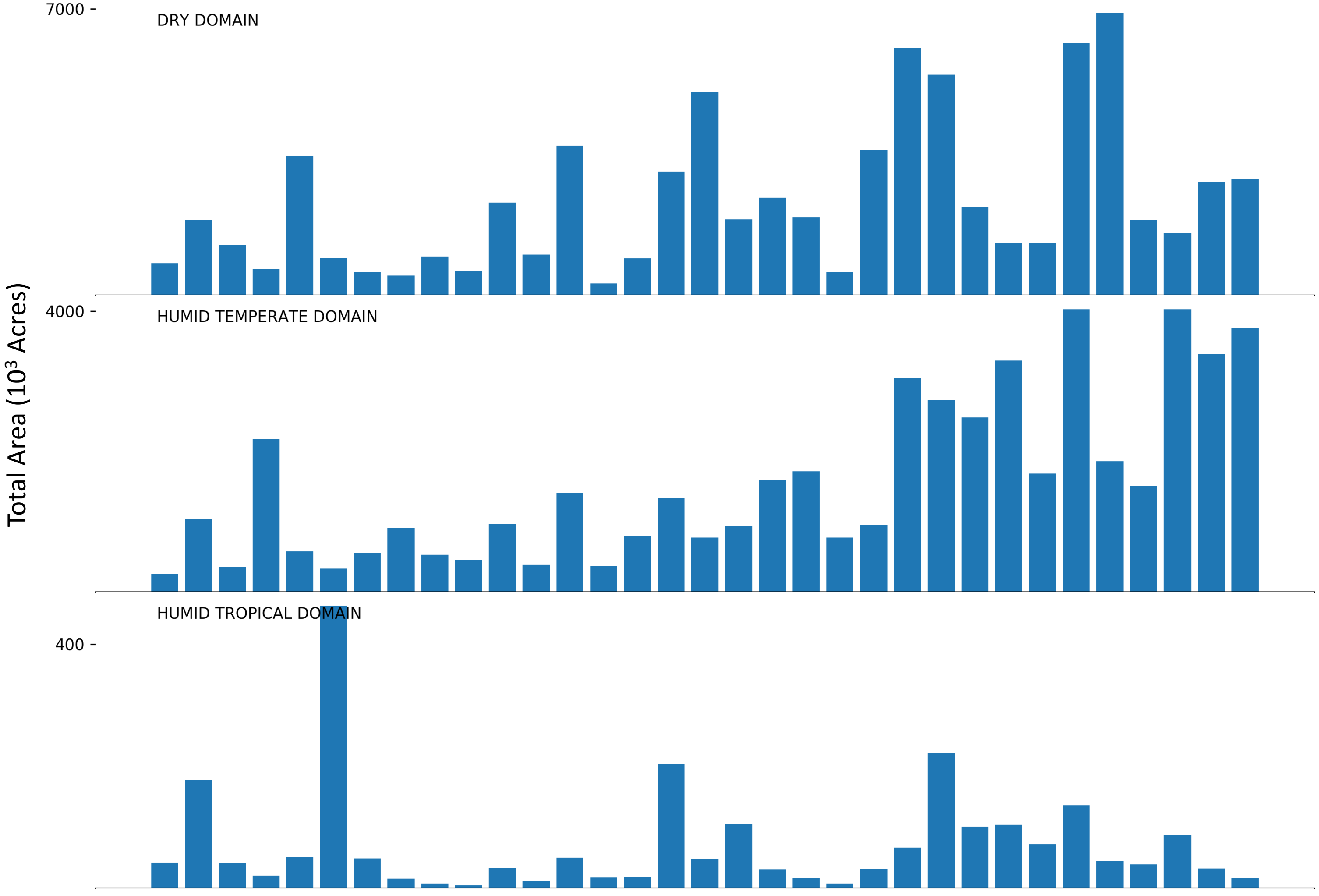
National WF Acres 1983 - 2018





Reference #99 in USGCRP, 2018: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA

MTBS WF Acres 1984-2016

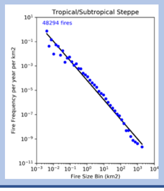


mtbs.gov

RB Activity Data Development

- Build distributions of fires
  - Seasonality (when do fires occur)
  - Size (how big are they)
  - Frequency (how often do they occur)
- Breakdown by ecoregion
- Limit to burnable area within each ecoregion
- Estimate fire growth curves for multi-day fires
- Use **readily-available** data sources and approaches
  - 2014 NEI (Rx and Ag activity)
  - Forest Service Research Data Archive (wildfire climatology 1992-2015)
  - "Malamud" wildfire frequency curves (frequency, size distribution)

RB – Wildfire Activity Data Workflow

	Seed Data	Baseline Acres	Growth	Seasonality	Location
Round 1 (Phase IV)	2002 Base Year	National Data 2000-2003 Average Acres Randomly add/remove events from seed data, by State, until baseline acres achieved	Base Year Event Actuals	Base Year Event Actuals	Base Year Event Actuals
Current	Probability Distributions  	FSRDA database 2012-2015 Average Acres Choose simulation results closest to 5-yr average for each ecoregion	Generic curves from FSRDA database Distributions of days by size bin [by ecoregion]; allocate growth evenly across days	Histograms by ecoregion from FSRDA  Randomly sample histograms to date fires	"burnable area" from FCCS Monte Carlo method to place fires on burnable area within ecoregions

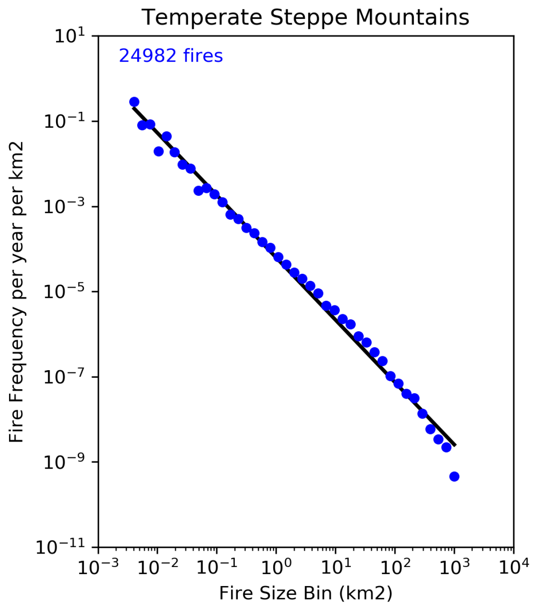
Aside: Wildfire as a Self-Organized System

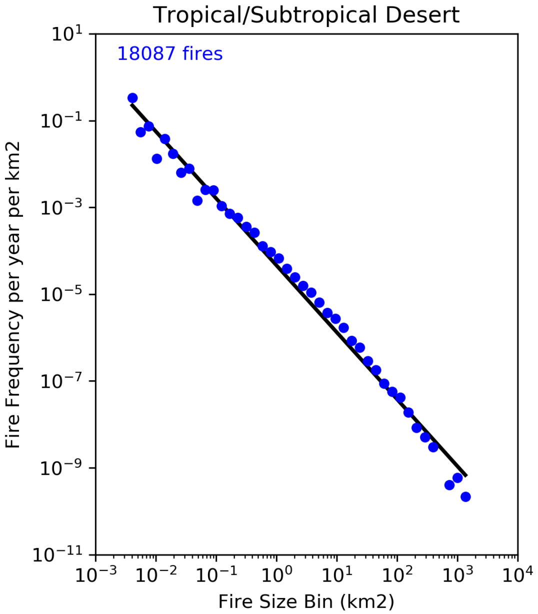
*The hallmark of Self-Organized Criticality is the slow, steady accumulation of an instability, eventually followed by a fast relaxation through 'avalanches' of any possible size: from a single point (e.g., a ~1 acre fire) to system-wide collapse (e.g. mega fire). **

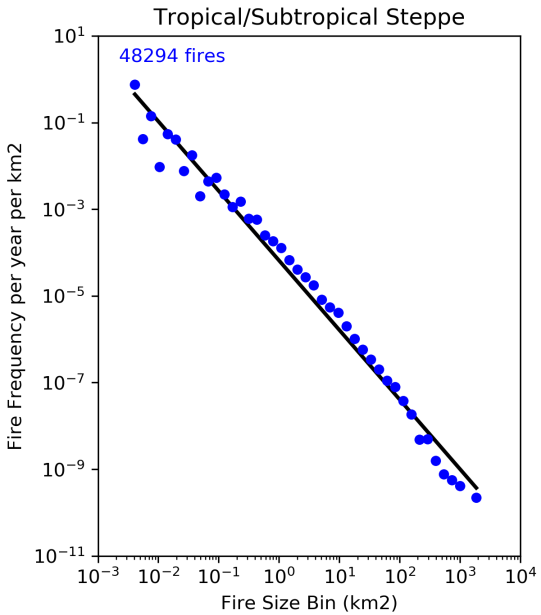
- Wildfire has been shown to follow the concept of ”self-organized criticality” (SOC) over varying spatial and temporal scales.
- Malamud, et al. (2005) applied the concept to ecoregions in the CONUS, revealing consistent but unique “regimes” generally west-to-east.
- The frequency of burns of a given size per unit of ecoregion area compared to binned fire size reveals a power law distribution (linear in log space).

*Adapted from Åström, Jan A., et al. "Termini of calving glaciers as self-organized critical systems." *Nature Geoscience* 7.12 (2014): 874.

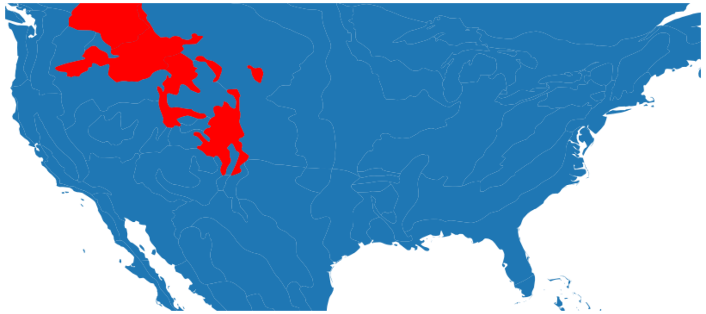
Aside: Wildfire as a Self-Organized System



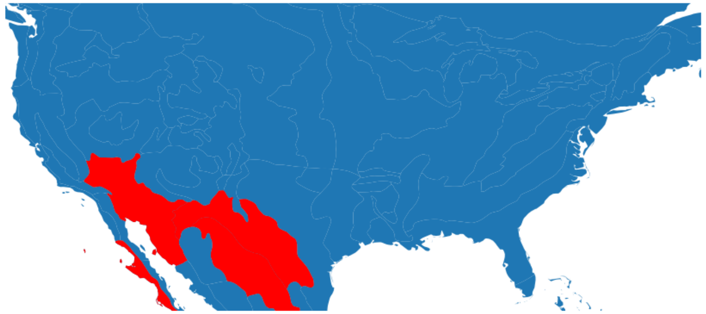




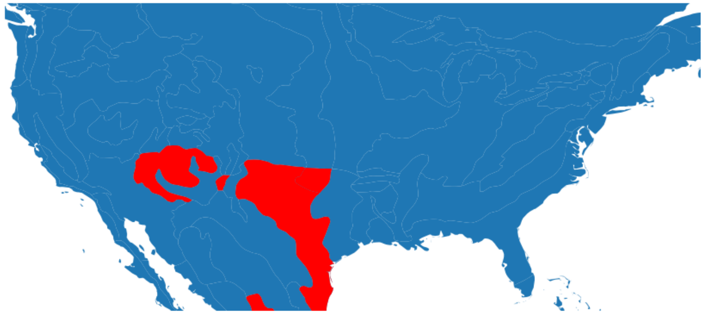
Temperate Steppe Mountains



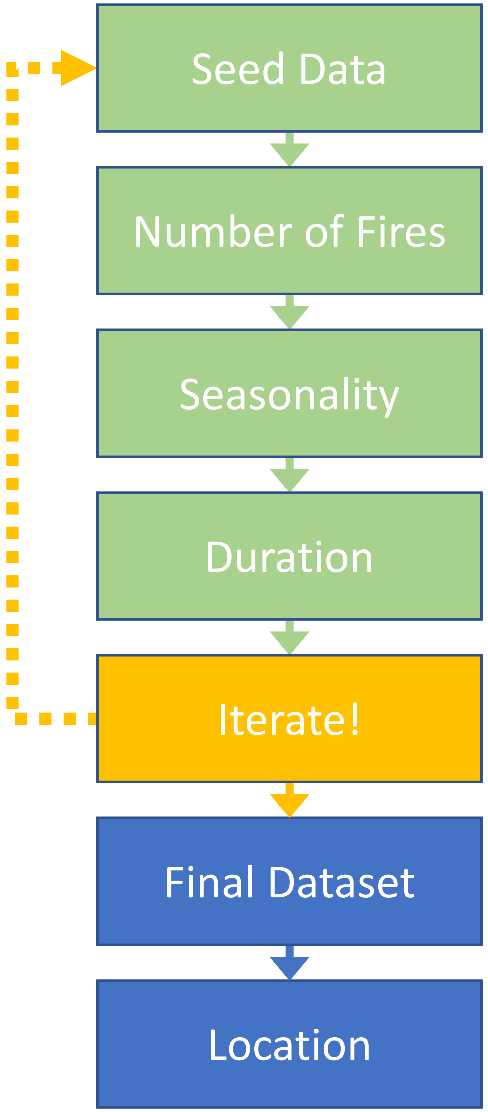
Tropical/Subtropical Desert Division



Tropical/Subtropical Steppe Division



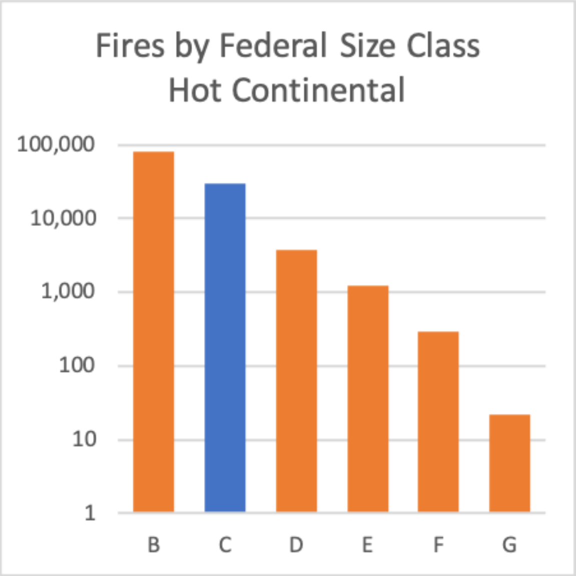
RB – Wildfire Activity Data Workflow



- Transform frequency-area curve to a cumulative probability distribution (from 0 to 1). Use a random number generator (from 0 to 1) to “sample” the distribution.
- Fit a curve to a histogram of fire occurrence from FSRDA database. This ensures values are > 0, allows for fire count larger than has been observed.
- Select a start month from histograms by fire size class.
- Select a duration from histograms by size class and month.
- Run simulation 100 times for each ecoregion
- Pick a simulation for each ecoregion (depends on application)
  For RBv1, match to last 5 years of FSRDA dataset
- Use a random number generator to select an X and Y from ecoregion “box.” Repeat if location is in non-fuel area or outside ecoregion polygon.

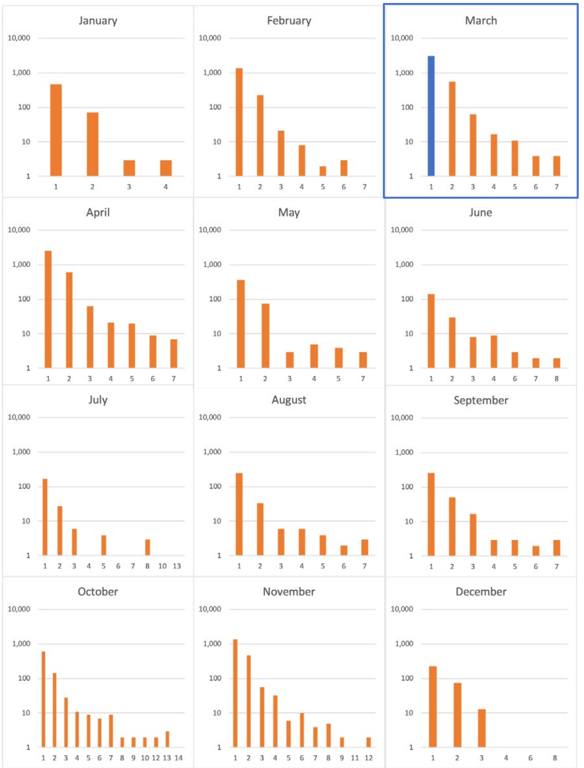
RB – Wildfire Activity Data Workflow

Sample from area-frequency distribution
Example:
- *Hot Continental ecoregion division*
- *Size Class C is randomly selected*



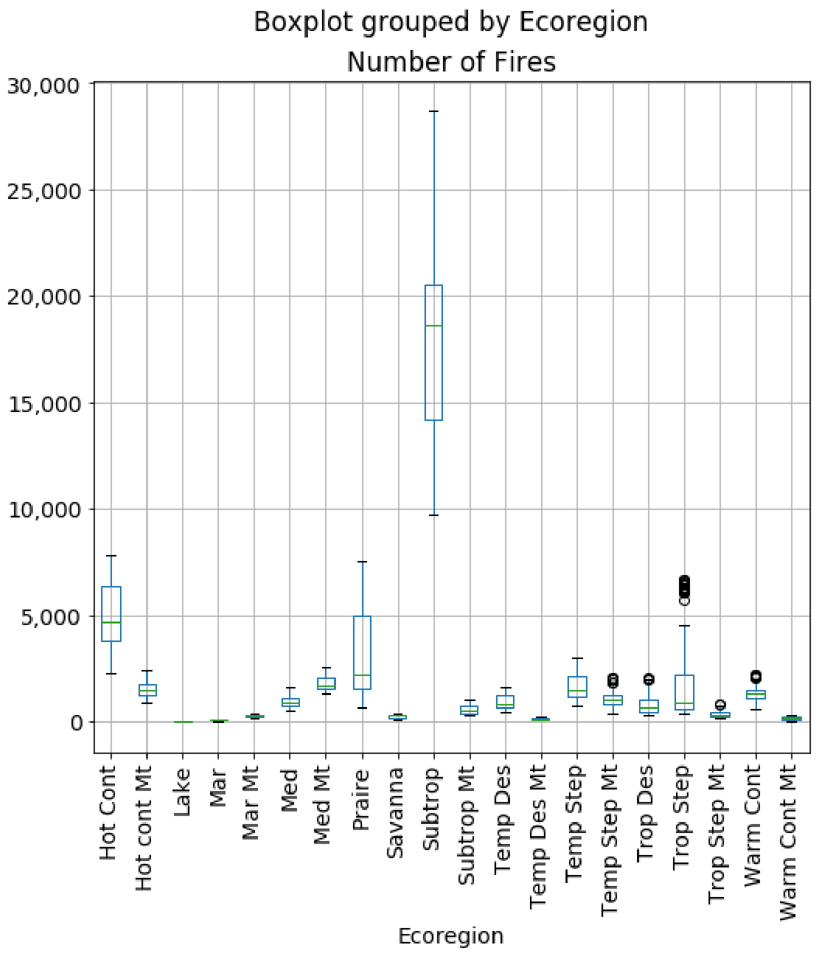
Sample from seasonal distribution
- *Hot Continental*
- *Size Class C*
- *March is randomly selected*

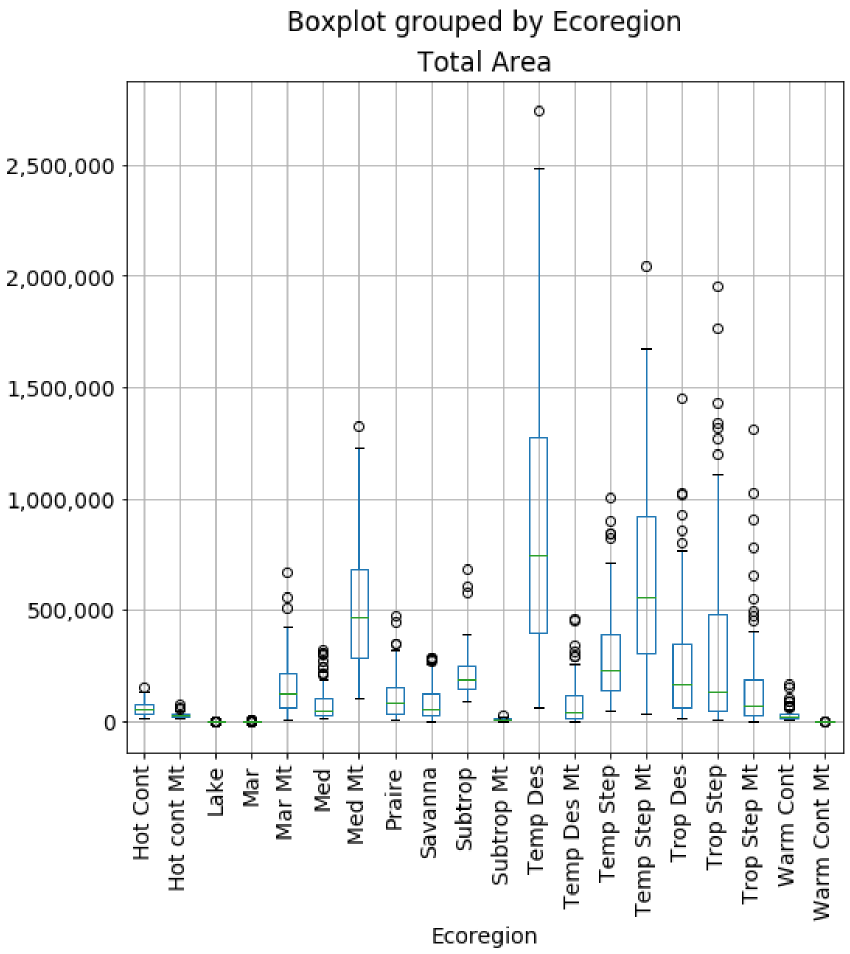
Sample from day-length distribution
- *Hot Continental*
- *Size Class C*
- *March*
- *Length of 1 day is randomly selected*

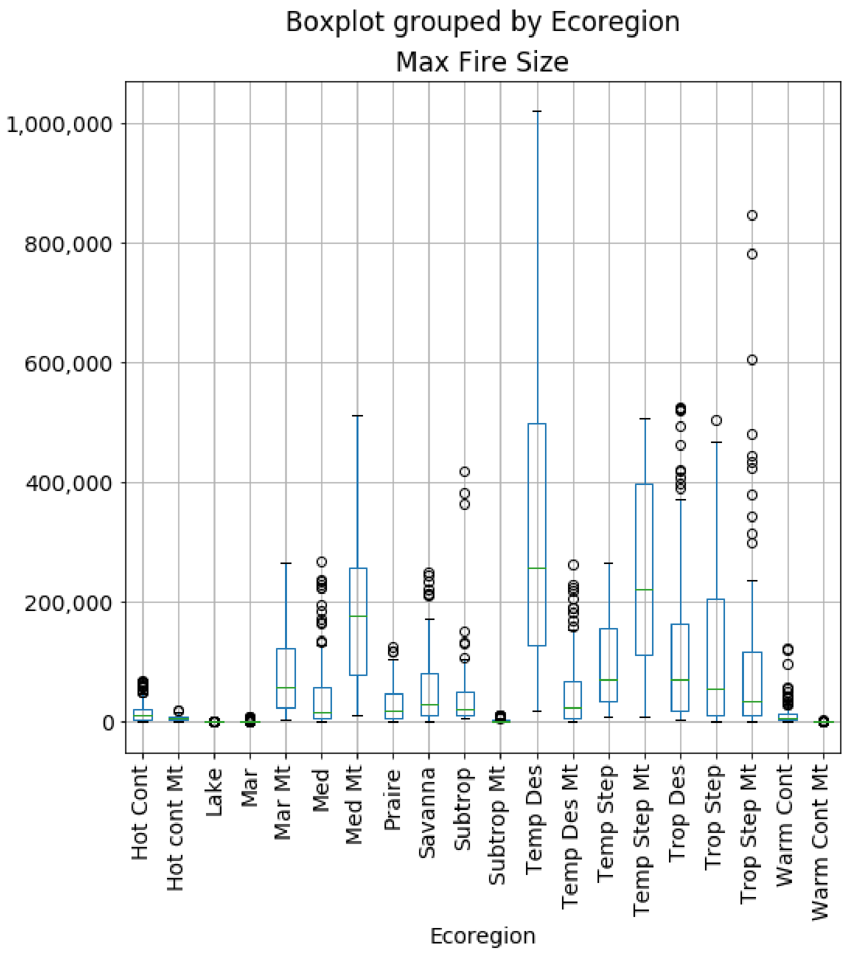


RB – Preliminary Results and Evaluation

Result of running 100 simulations for each ecoregion in CONUS





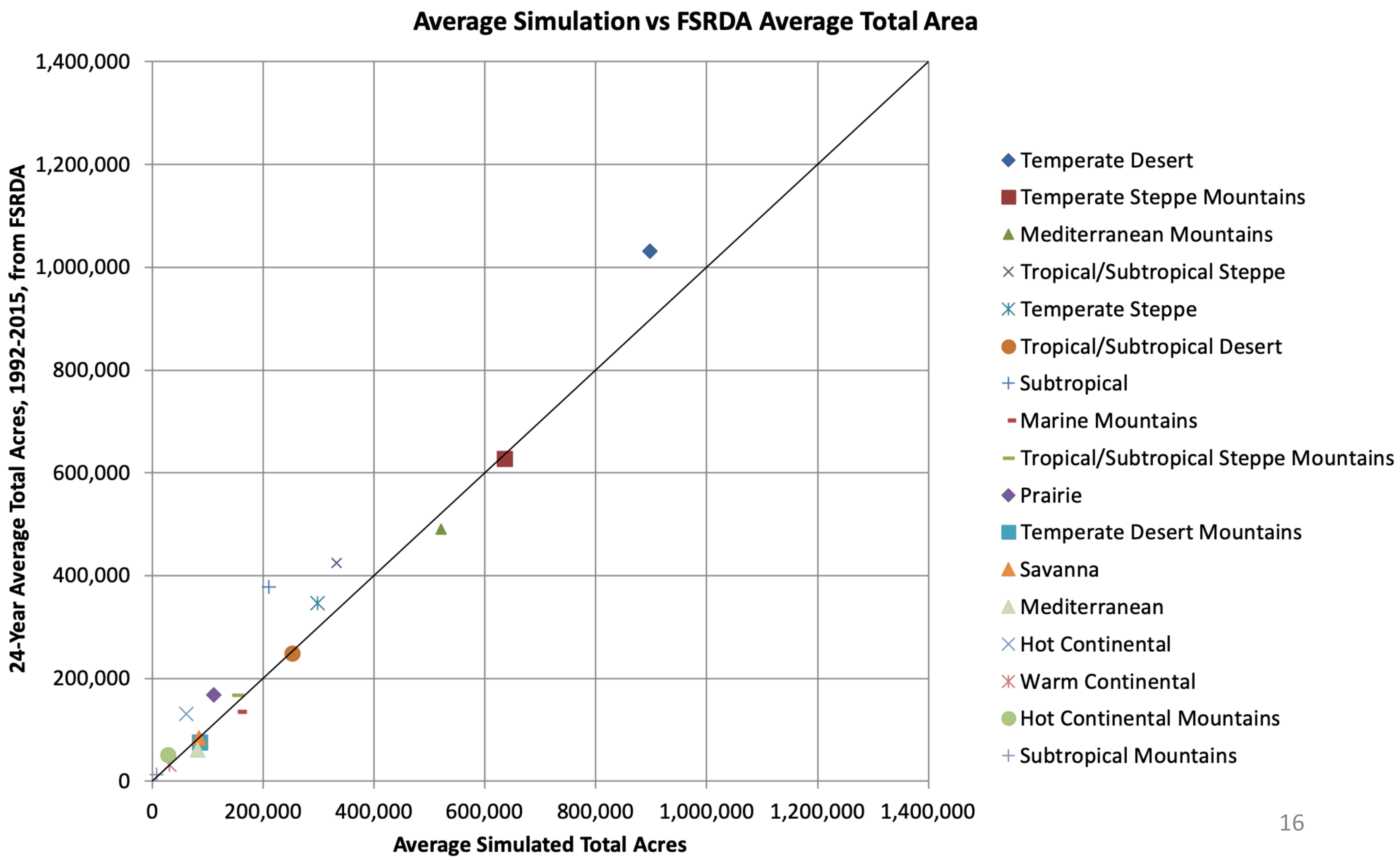


RB – Preliminary Results and Evaluation

Compare average simulation run (in terms of total acres burned) by ecoregion to average total observed acres from FSRDA (1992-2015).

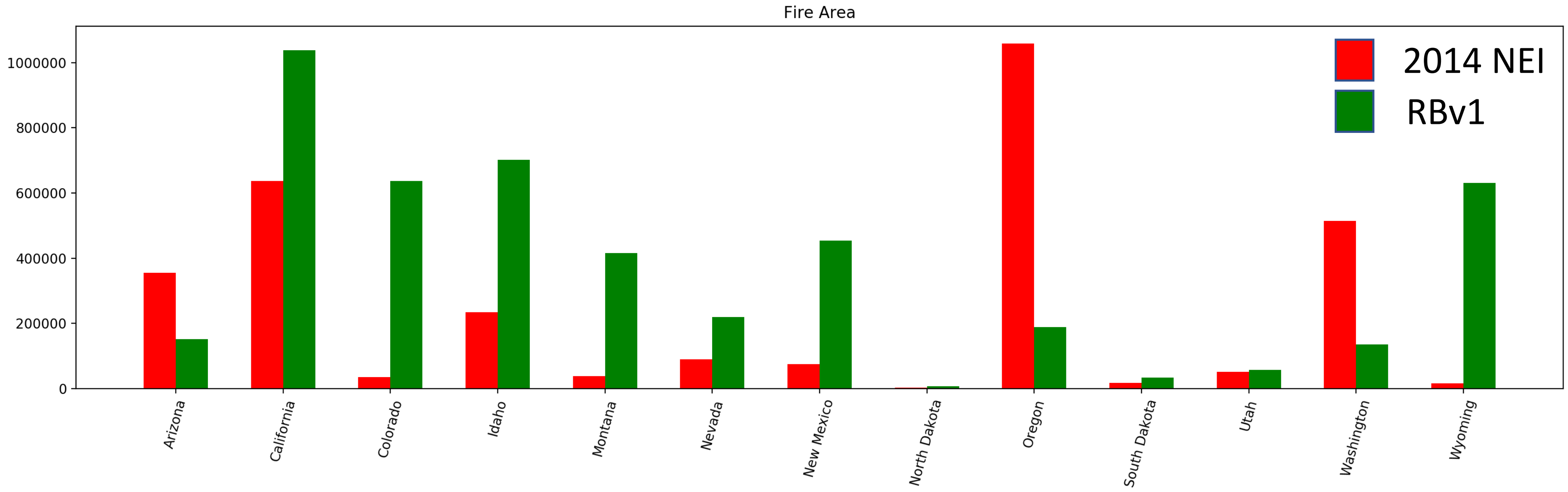
Mostly good agreement but some notable deviations, partially contributed by

- Sparse data (e.g. Hot Continental)
- Lots of fires of similar size (e.g. Subtropical)

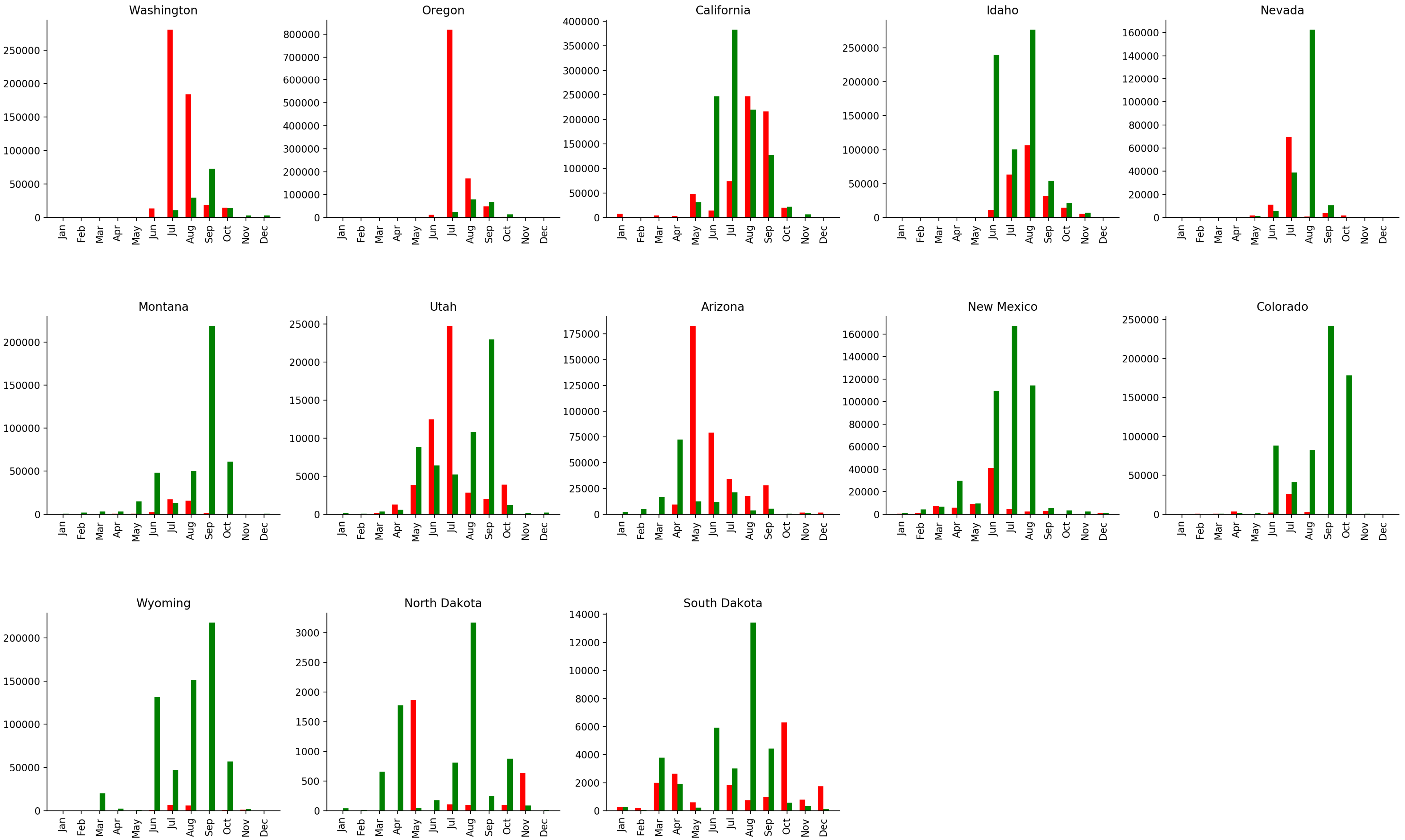


RB – Preliminary Results and Evaluation

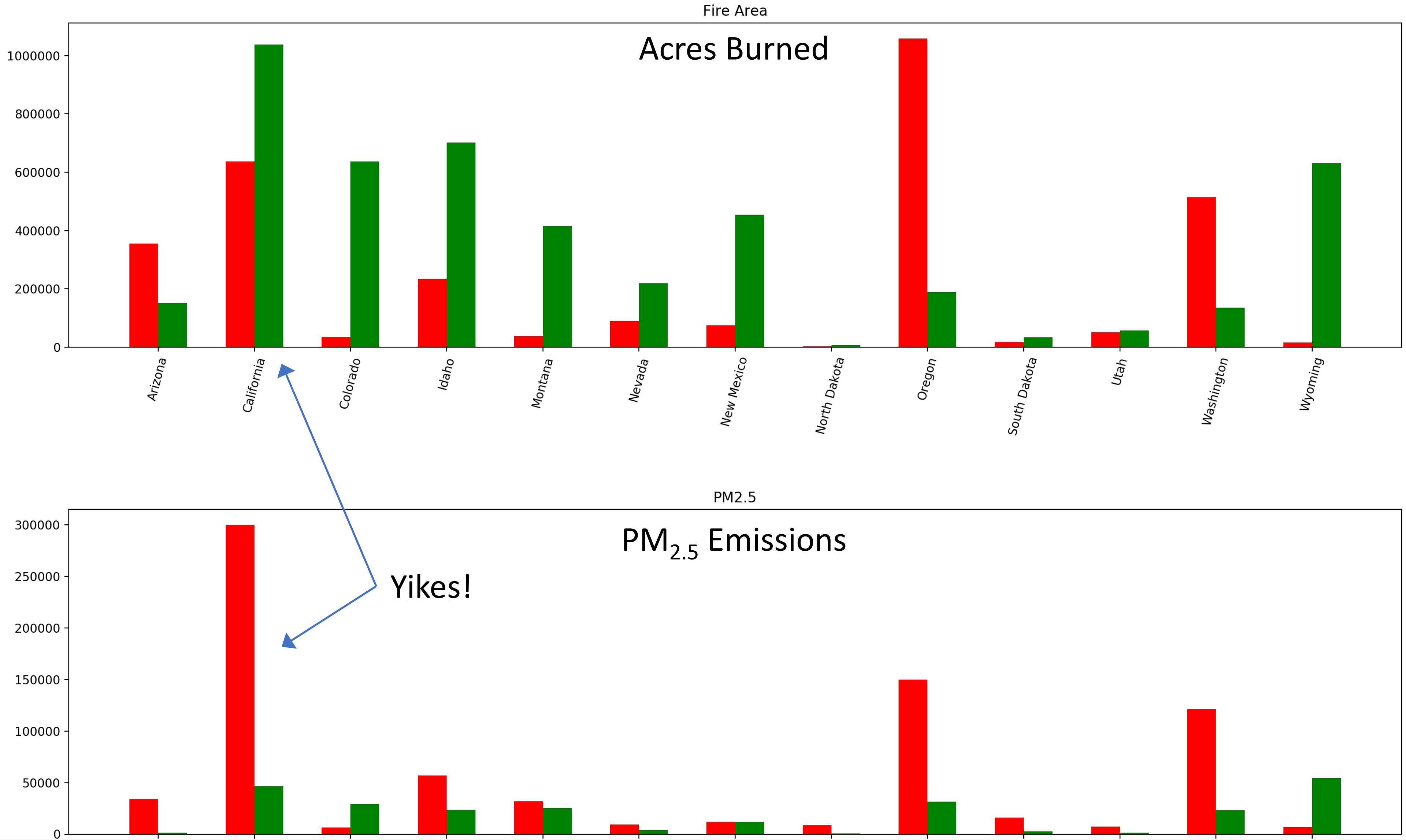
NEI 2014: 3.8MM acres
RBv1: 6.2MM acres



RB – Preliminary Results and Evaluation

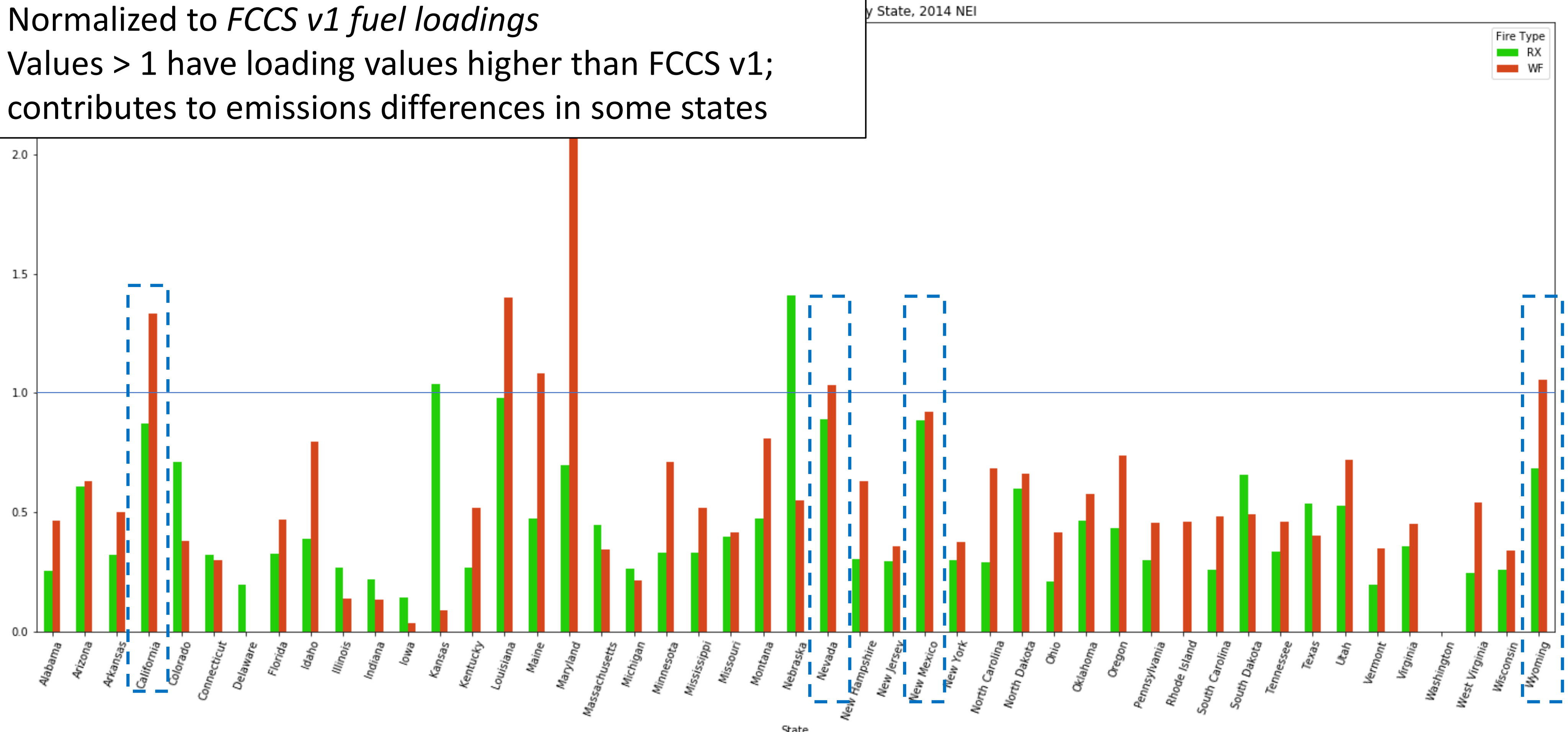


RB – Preliminary Results and Evaluation

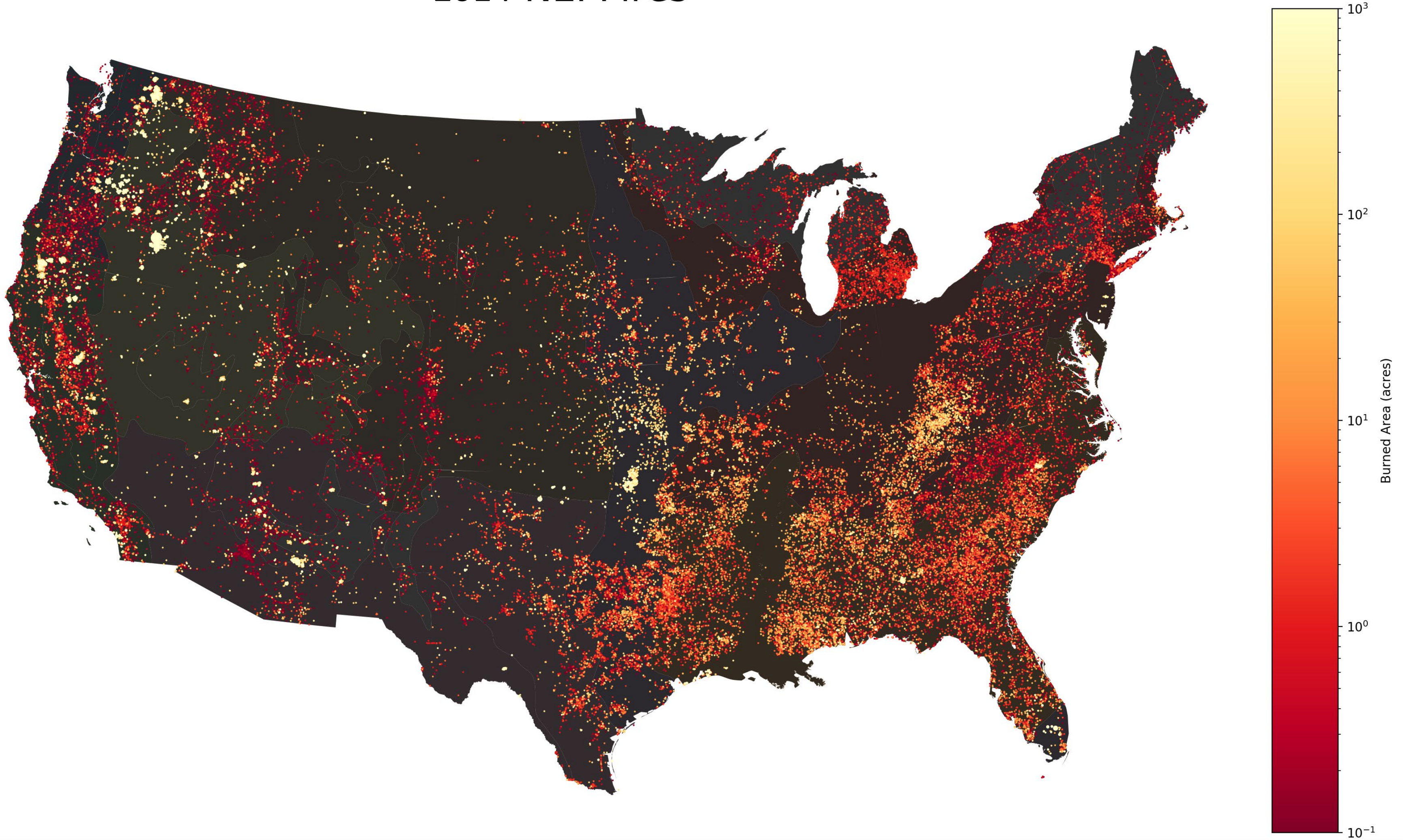


RB – Preliminary Results and Evaluation

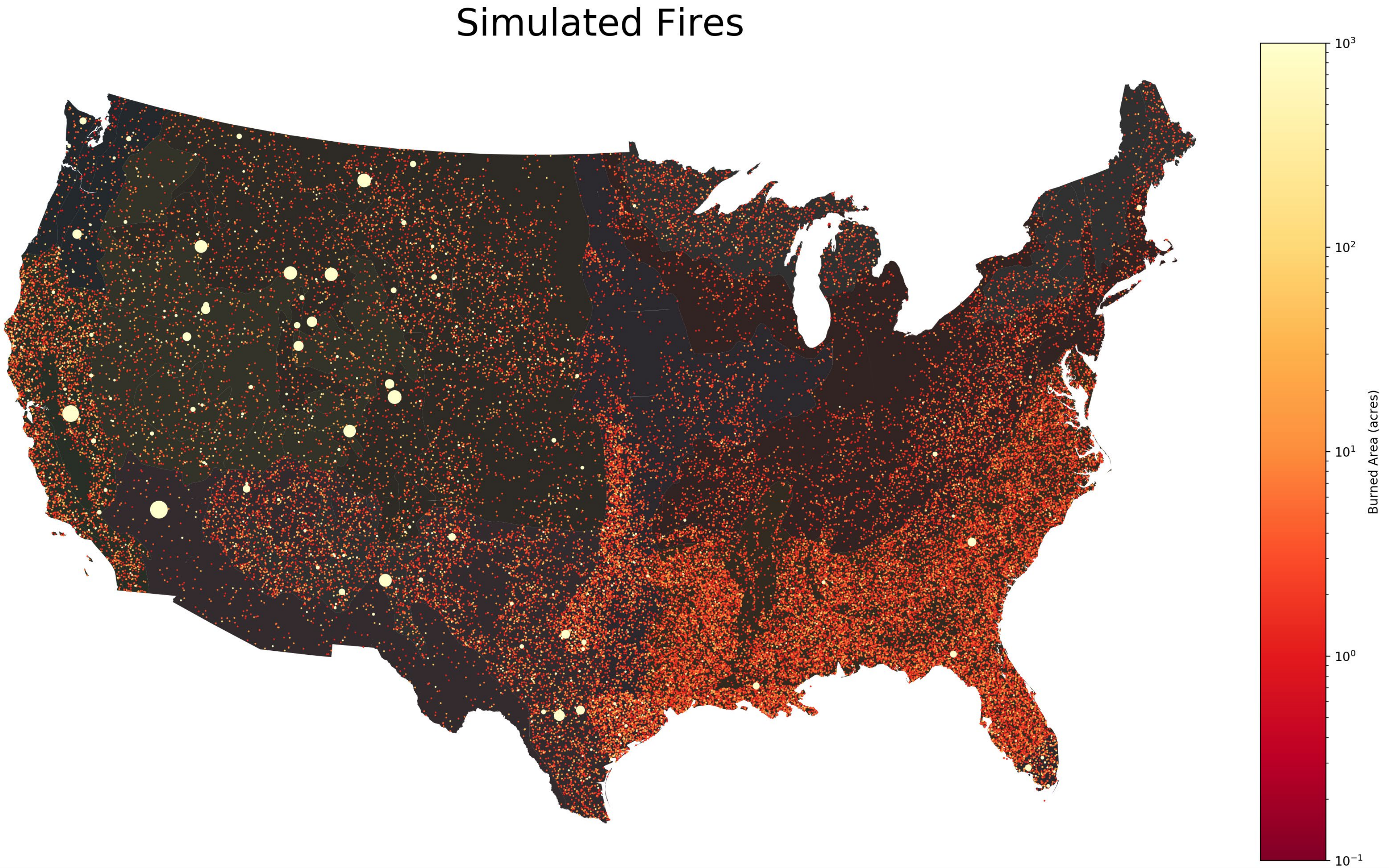
- Plot of average consumption completeness for 2014 NEI
- Normalized to *FCCS v1 fuel loadings*
- Values > 1 have loading values higher than FCCS v1; contributes to emissions differences in some states



2014 NEI Fires



Representative Baseline v1



Next Steps: Improvements and Application to Future Scenarios

- Improvements to RBv1
  - Update fuel loadings to match NEI 2014
  - Update emission factors in PMDETAIL database (esp. PM)
  - Revisit “burnable area” layer
- Future Scenarios (2028-2032)
  - Prescribed burning activity: scale based on land management objectives
  - Wildfire activity
    - Scale activity Introduce “climate forcing” looking at ensemble projections, e.g. Yue, et al.
    - Use existing simulation data (e.g. 90th percentile result).

Acknowledgements and References

Thanks to the members of the WRAP Fire and Smoke Workgroup for their time and input, especially Sara Strachan (Idaho DEQ), Paul Corrigan (USFS/Utah DAQ), Bob Kotchenruther (EPA R10), Mark Fitch (NPS) and Tom Moore (WESTAR-WRAP).

Abbreviated reference list:

Åström, Jan A., et al. "Termini of calving glaciers as self-organized critical systems." *Nature Geoscience* 7.12 (2014): 874.

Malamud, Bruce D., James DA Millington, and George LW Perry. "Characterizing wildfire regimes in the United States." Proceedings of the National Academy of Sciences 102.13 (2005): 4694-4699.

Moritz, Max A., et al. "Wildfires, complexity, and highly optimized tolerance." Proceedings of the National Academy of Sciences 102.50 (2005): 17912-17917.

National Interagency Fire Center, National Fire Statistics: https://www.nifc.gov/fireInfo/fireInfo_statistics.html

PMDETAIL Project: https://wraptools.org/pmdetail

Short, Karen C. 2017. Spatial wildfire occurrence data for the United States, 1992-2015 [FPA_FOD_20170508]. 4th Edition. Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2013-0009.4

Yue, Xu, et al. "Ensemble projections of wildfire activity and carbonaceous aerosol concentrations over the western United States in the mid-21st century." Atmospheric Environment 77 (2013): 767-780.