Investigation of the Effects of Changing Climate on Fires and the Consequences for U.S. Air Quality, Phase 2

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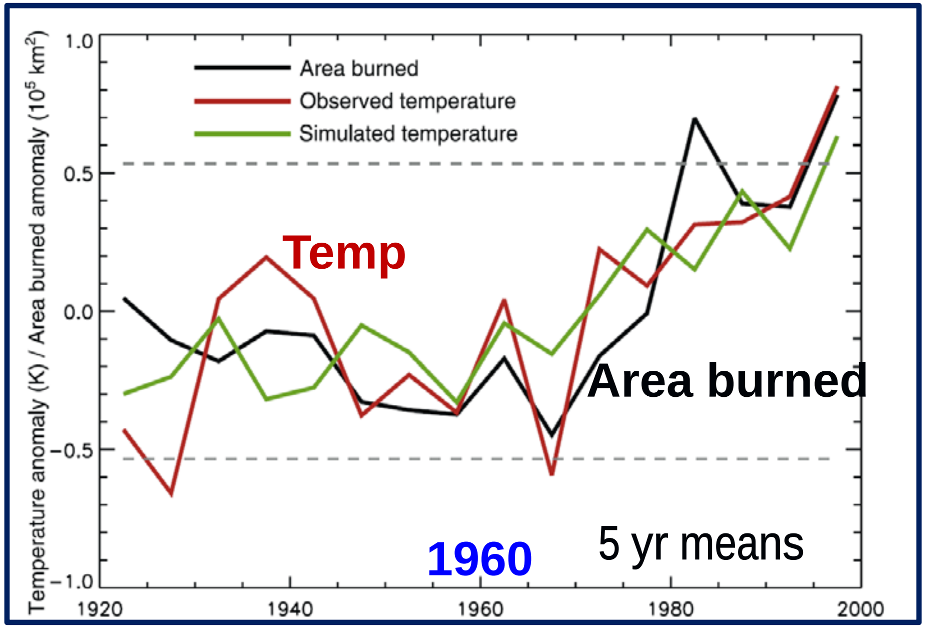
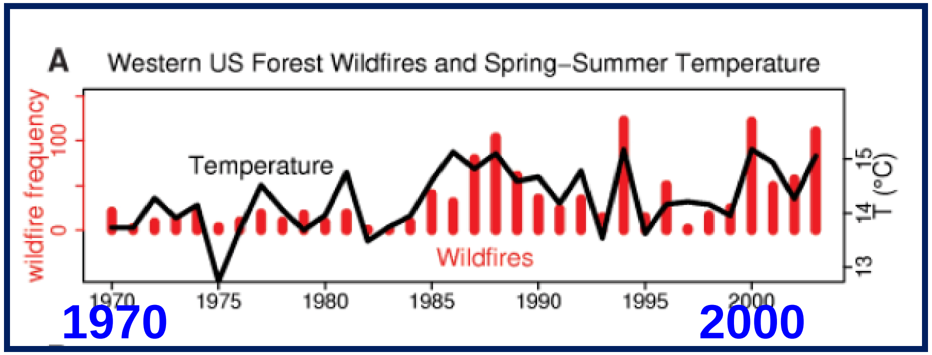
Fires are increasing in North America



Area burned in Canada has increased since the 1960s, correlated with temperature increase.

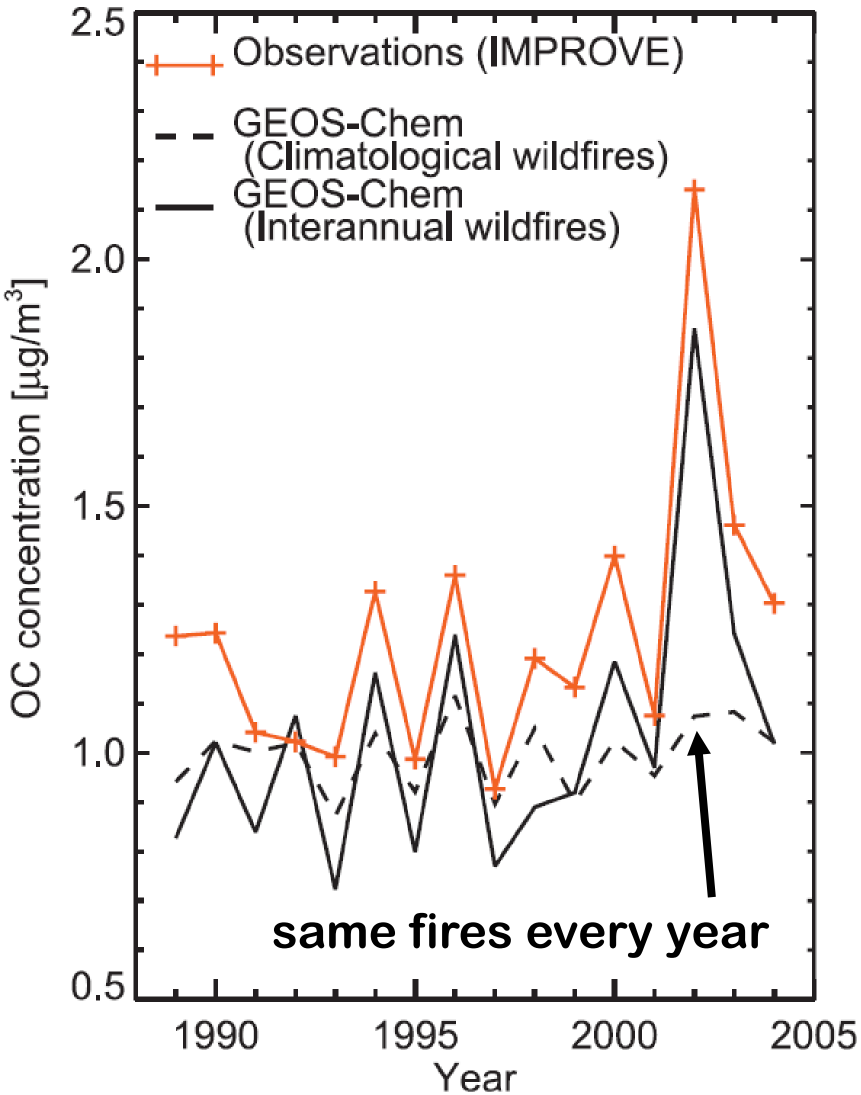
Gillett et al., 2004



Increased fire frequency over the western U.S. since 1970: related to warmer temperatures, earlier snow melt.

Westerling et al., 2007

Wildfires drive interannual variability of organic carbon aerosols in the western U.S. in summer



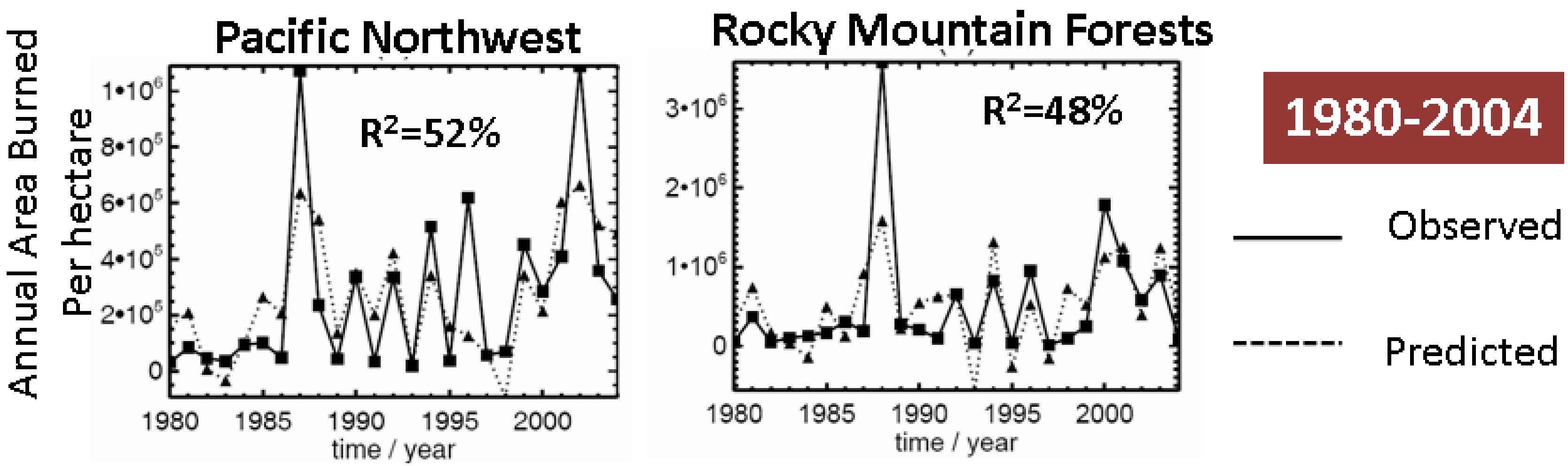
18 year aerosol simulation with monthly fires in the western US:

Model gives same variability as observed OC in summer at IMPROVE sites in the West (1987-2004)

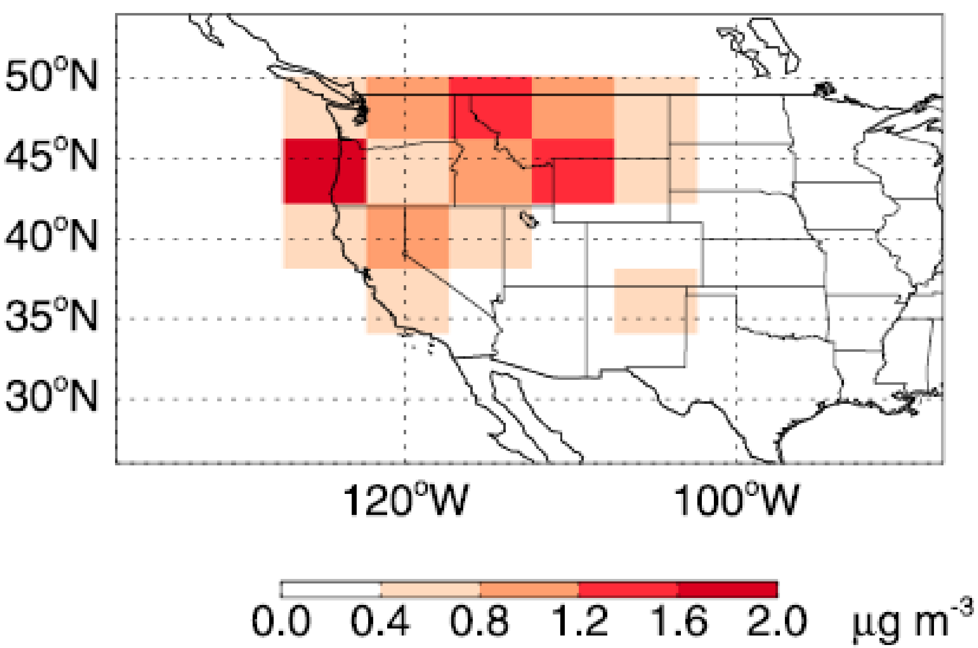
OC contribution to total fine aerosol:
55% in high fire years
40% in low fire years

Spracklen et al., GRL, 2007

Phase 1: prediction of fires in a future climate



Change in OC in 50 years



OC increases by 40%
EC increases by 20%

Spracklen et al., JGR, 2009

Phase 2 Goals

- Predict changes in fires in boreal North America
- Improve prediction of shrub and grassland fires
- Potential increases in length of fire season?

- Impacts of land cover changes on fuels?
- Impacts of changing climate on fire severity?
- Effects of changes in lightning on fire ignition?

- Uncertainty analysis using multiple models (GCMs) and scenarios

- Improve calculation of air quality effects using 2ºx2.5º GISS GCM and GEOS-Chem with nesting to 1ºx1º

How do we predict of fires in a future climate?

- Use a gridded data-base of area burned in the western U.S. for 24 years (Westerling et al., 2002).

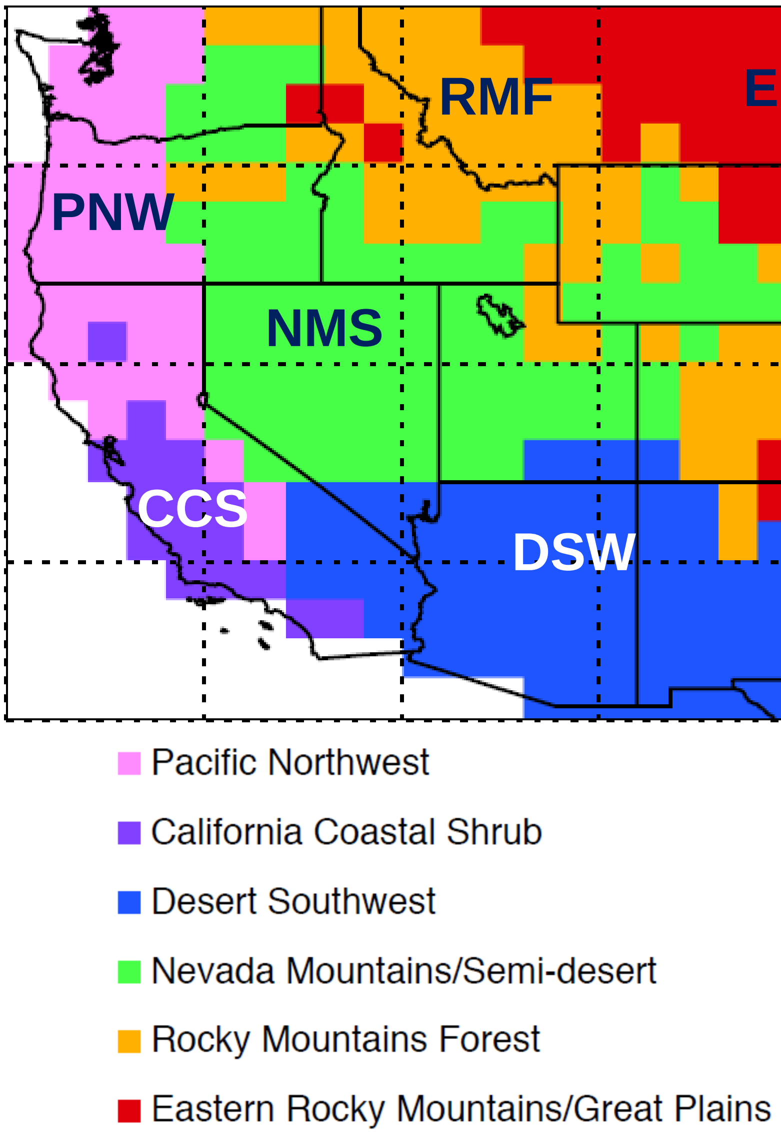
- Determine the relationship between area burned and meteorology by step-wise regression or with a parameterization
  - temperature, RH, wind speed, precip.
  - fire indices from the Canadian Fire Weather Index (FWI) system
  - requires daily met. data

- Use output from the 15 GCMs for the IPCC A1B scenario to predict future meteorology; our earlier work used only the GISS GCM (Spracklen et al., 2009)

- Assume present relationship of fires and meteorology holds in the future

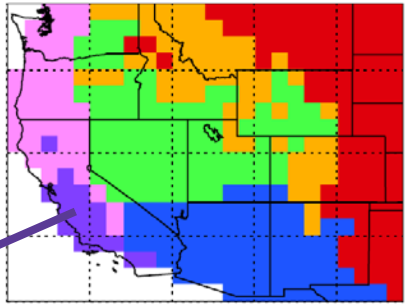
- Use median GCM output to predict future area burned around 2050
- Use GISS GCM to predict air quality (5 year mean) around 2050

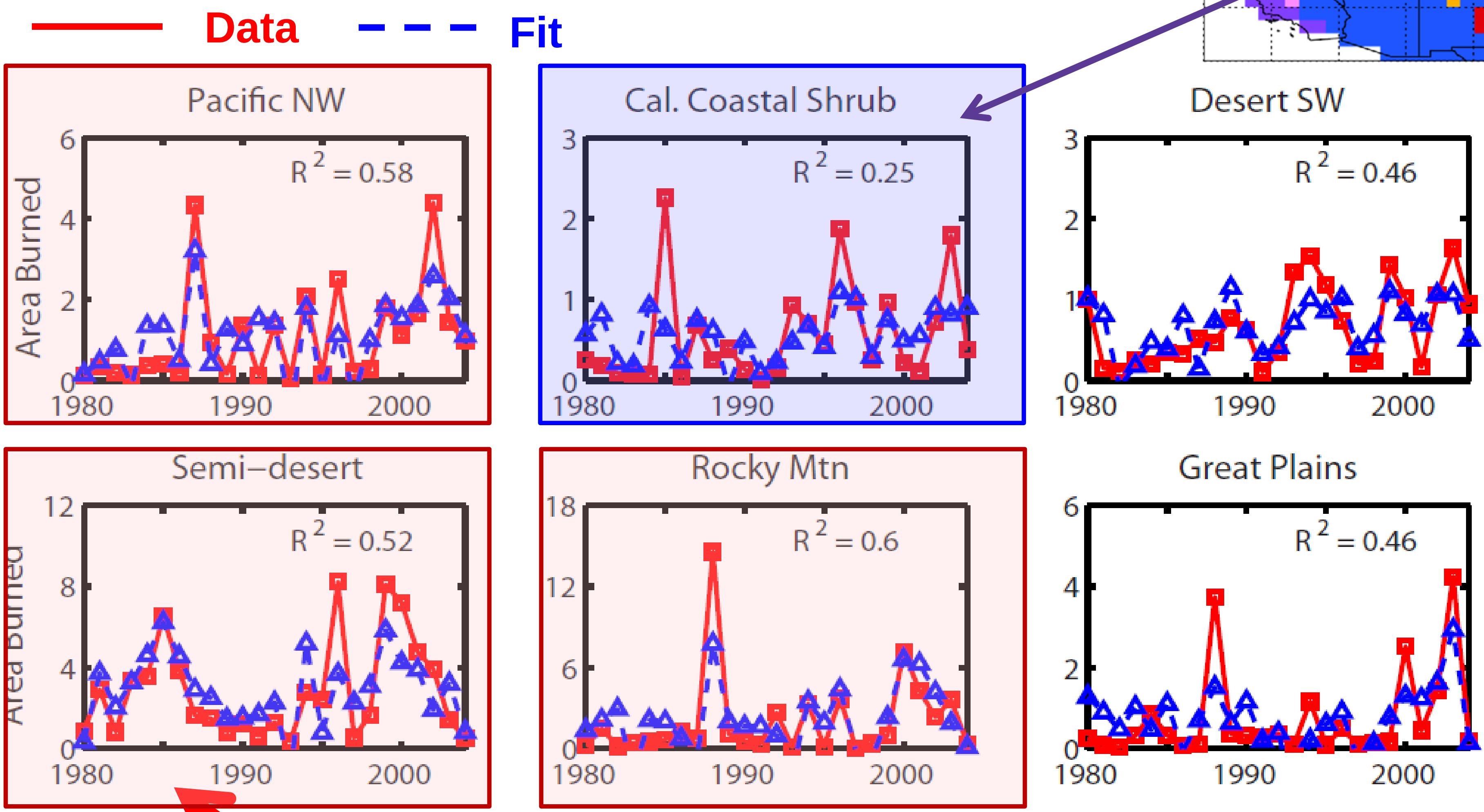
Predictions of area burned are made for large eco-regions for the fire season



Eco-regions are aggregates of the ecosystems of Bailey et al. (1994)

Good regression fits for area burned, except for California coastal shrub





Improved fit – depends on RH the previous summer

Cal. fit also depends on RH the previous winter

Fire parameterization: builds on the data constrained approach of Crevoisier et al. (JGR, 2007) and on Pechony and Shindell (2009)

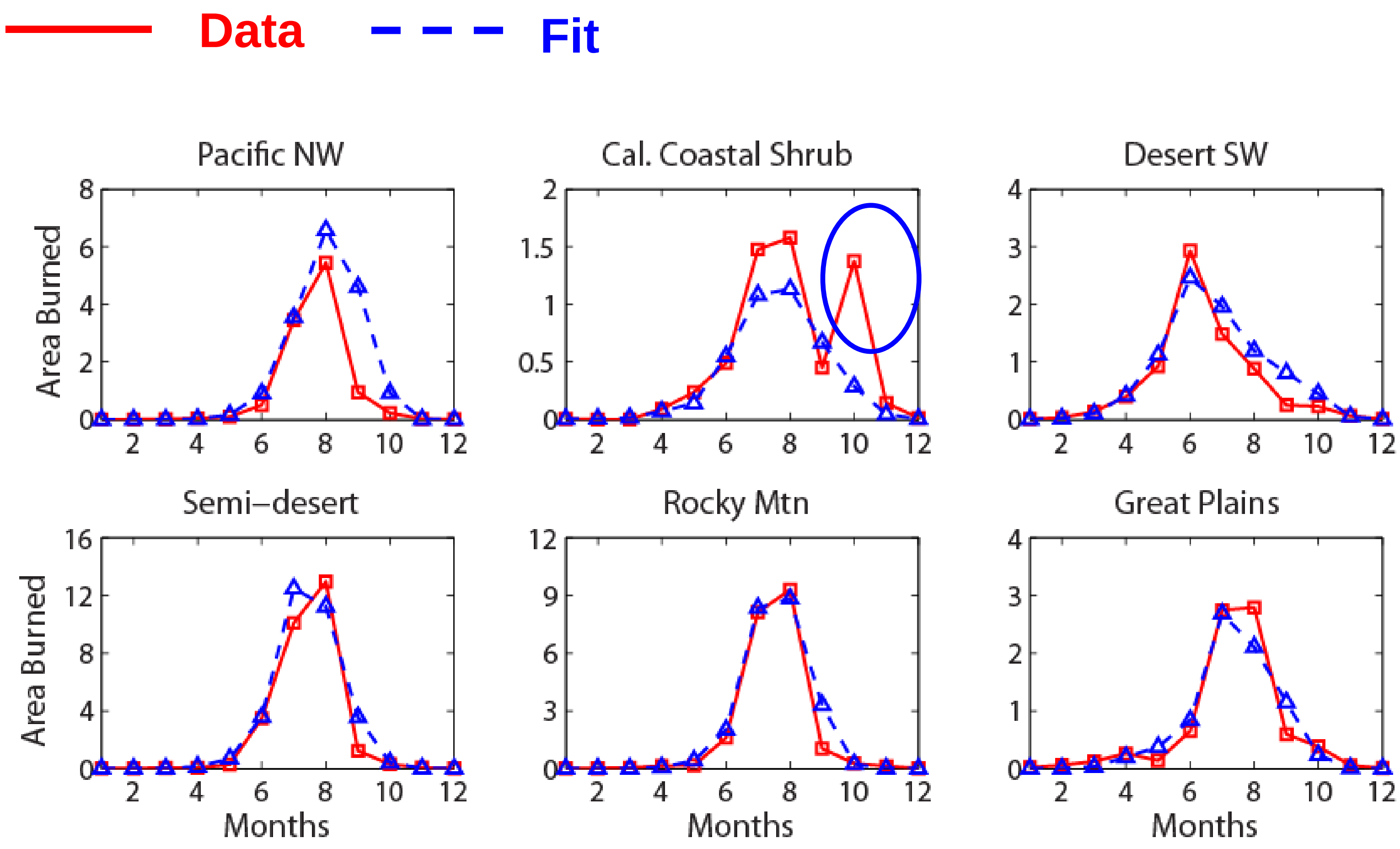
$$\text{Area burned} = f_1(\text{Temp}) \times f_2(\text{RH}) \times f_3(\text{rainfall})$$

$$\ln(AB) = \begin{cases} \dfrac{\alpha \cdot T \cdot (1 - RH/100)^2}{T_t \cdot (R + 0.2)} & \text{if } T > T_t \text{ and } R < R_t \\ \text{no fire} & \end{cases}$$

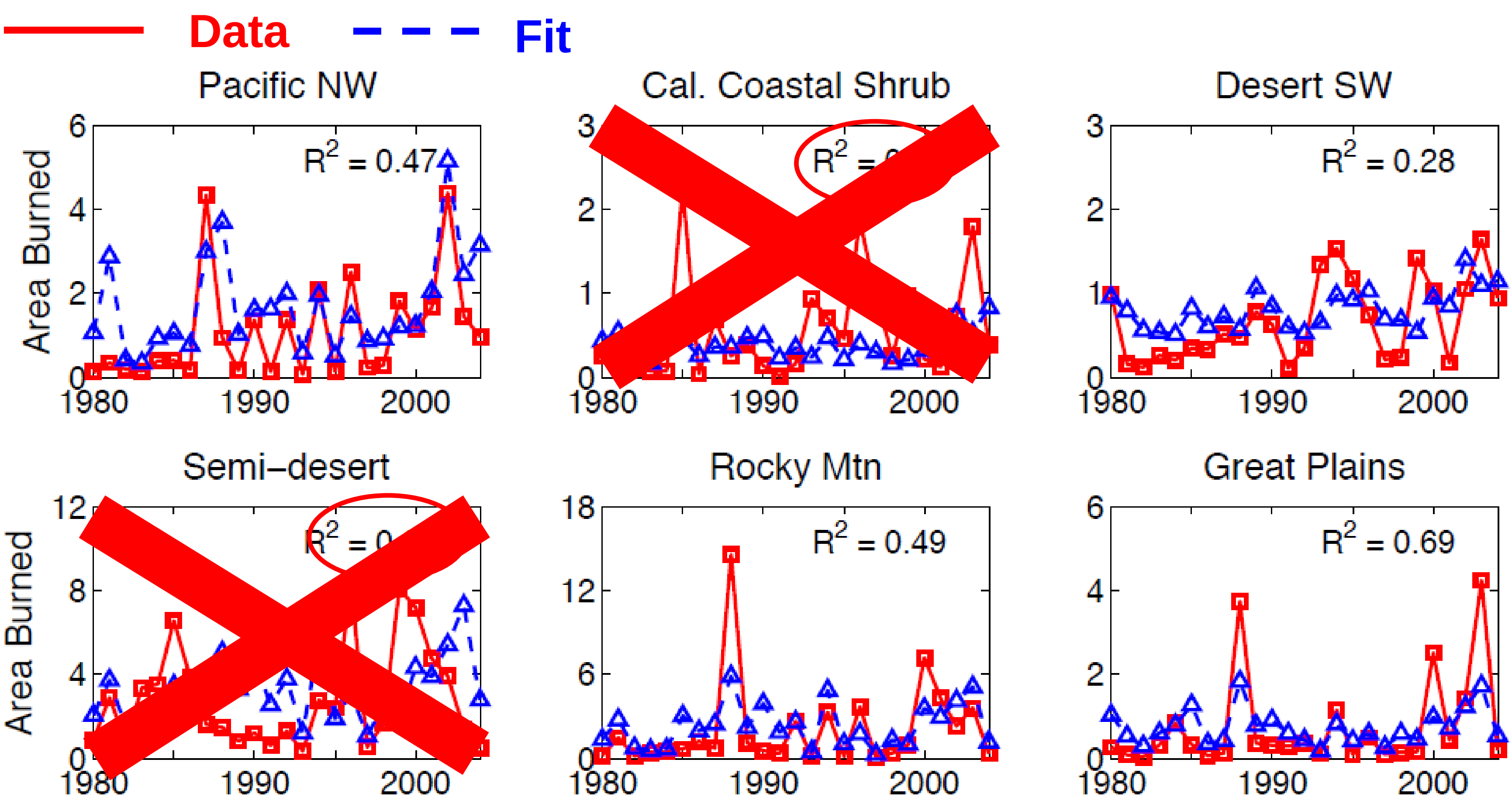
Fire potential coefficients (α) chosen to match long-term area burned for each ecoregion

Predicts seasonality of fires on the 1°x1° grid of the fire data base, uses daily NARR met. data.

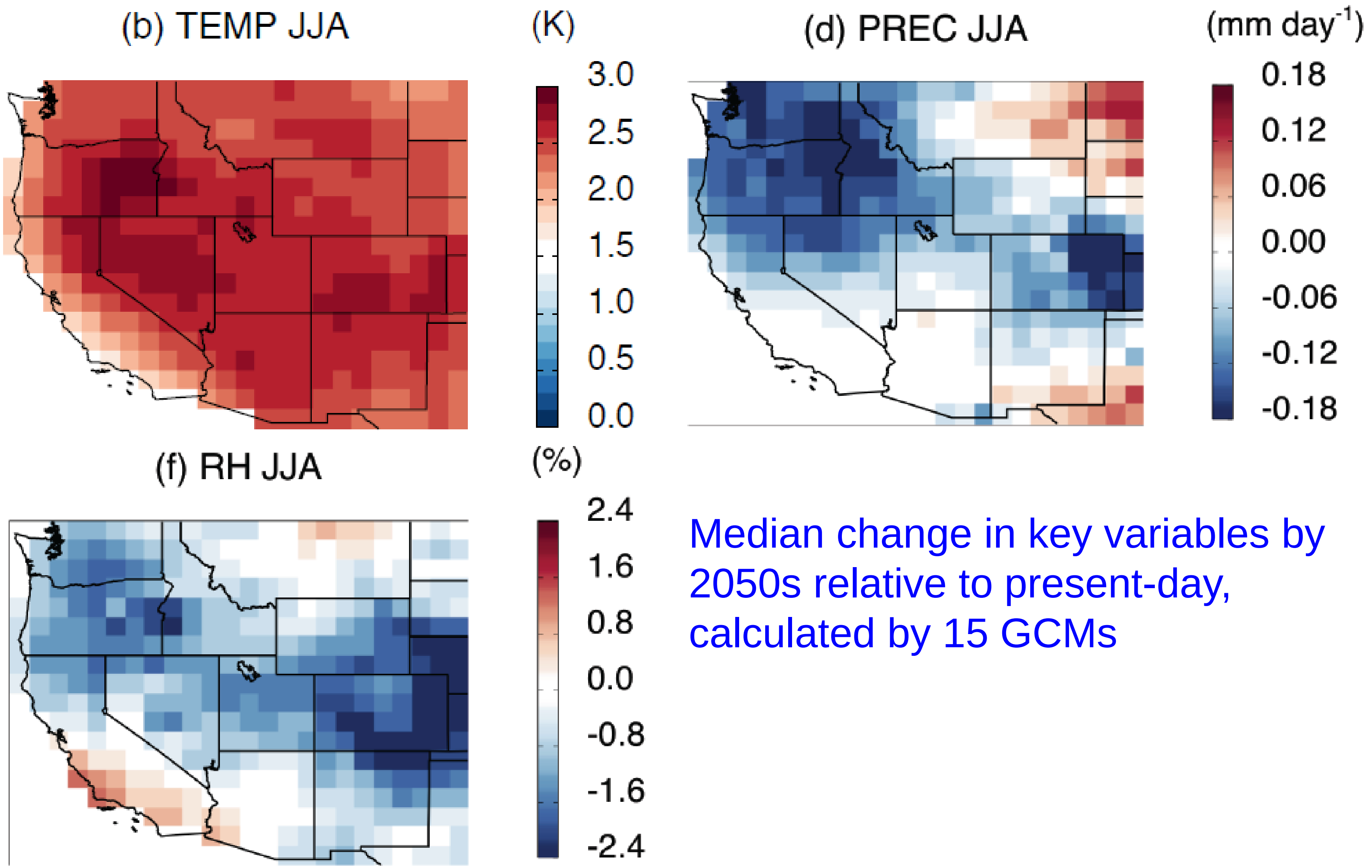
Parameterization predicts seasonality of area burned – except in CA



Parameterization is most successful when area burned depends on current meteorology



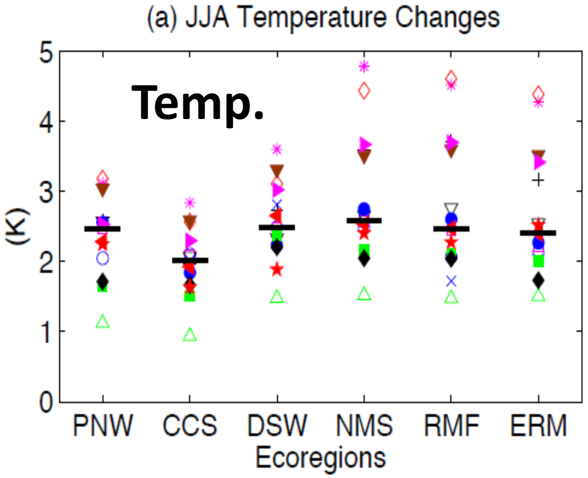
By ~2050, summer will be hotter, less humid, and less rainy in the western US

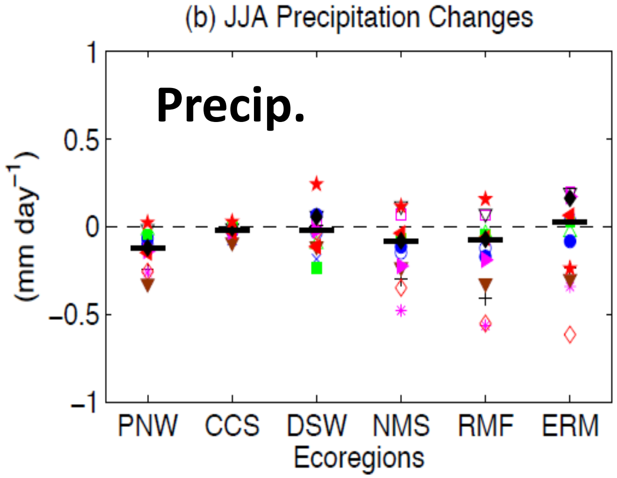


Median change in key variables by 2050s relative to present-day, calculated by 15 GCMs

GCMs show large variation in response to changing greenhouse gases.

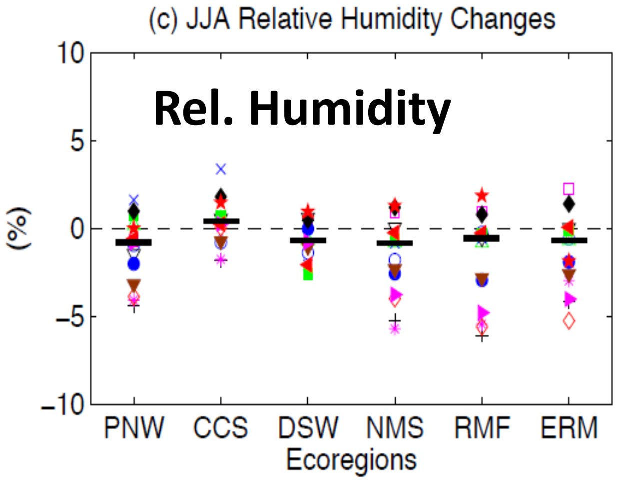
Changes in temp, RH, precip. by 2050s, relative to present-day, for JJA

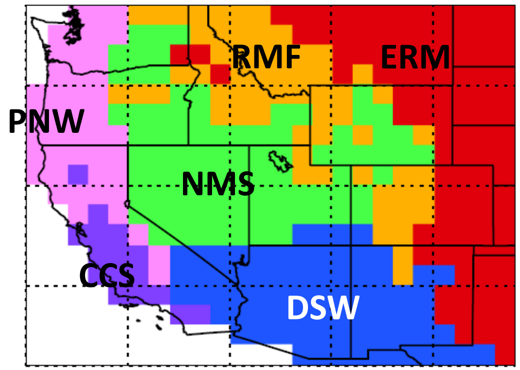




Results from IPCC AR4 ensemble of climate models: warmer, drier, less humid.

Symbols are different GCMs

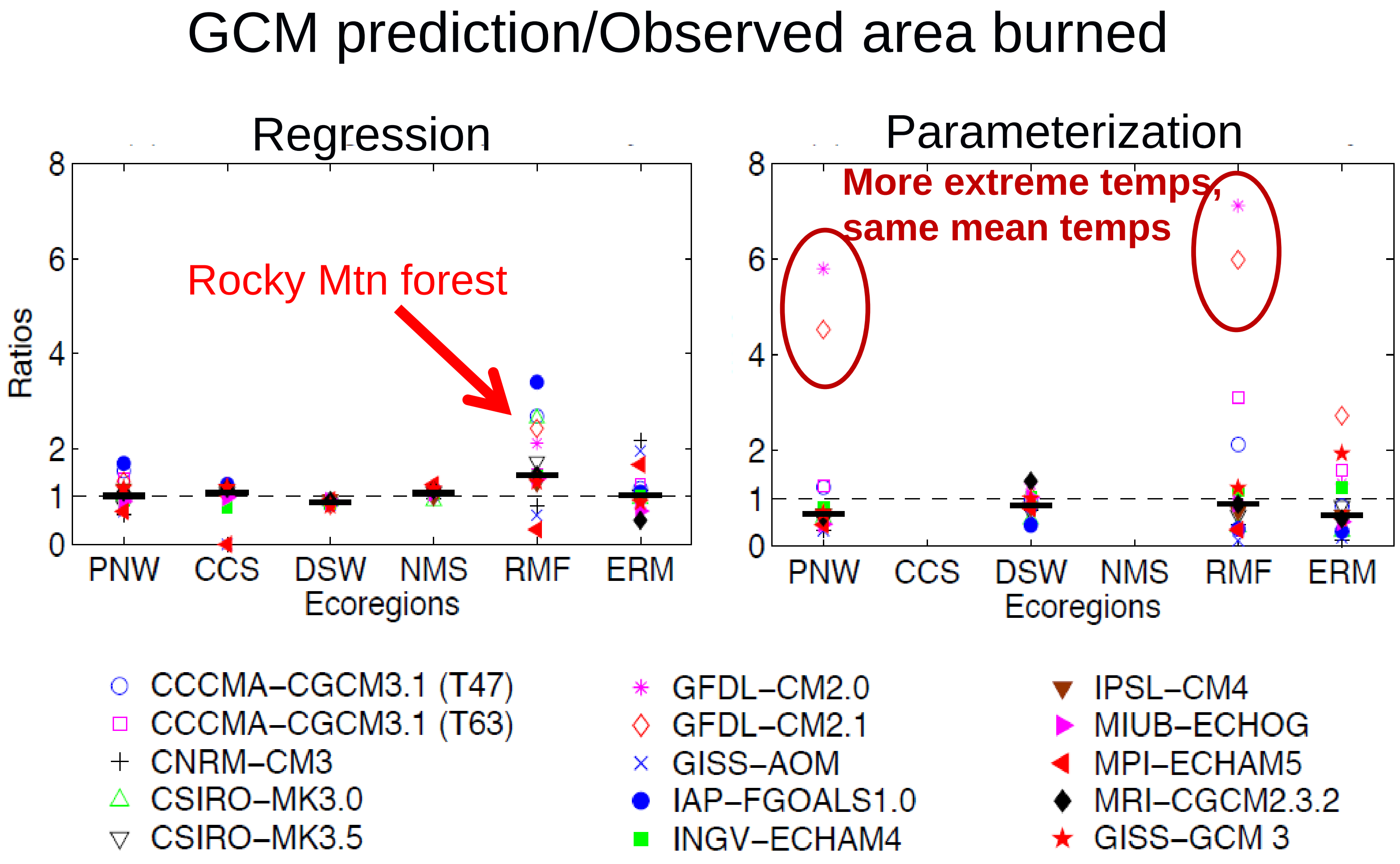




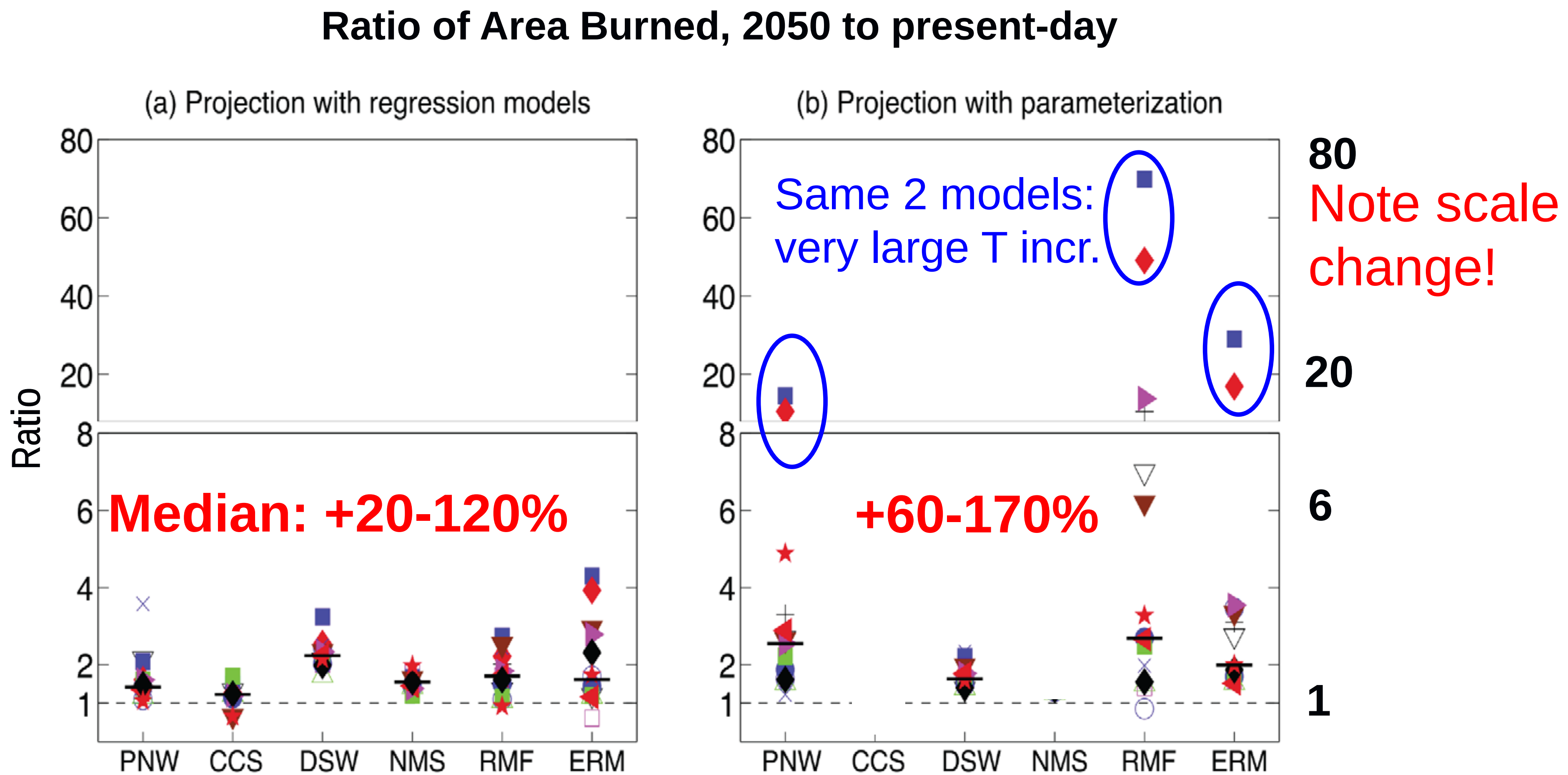
PNW, Pacific Northwest
CCS, California Coastal Shrub
DSW, Desert Southwest
NMS, Nevada /Semi-desert
RMF, Rocky Mountain Forest
ERM, East Rockies/ Plains.

Yue et al., in review.

GCMs predict present-day area burned fairly well for the regression, more outliers for param.



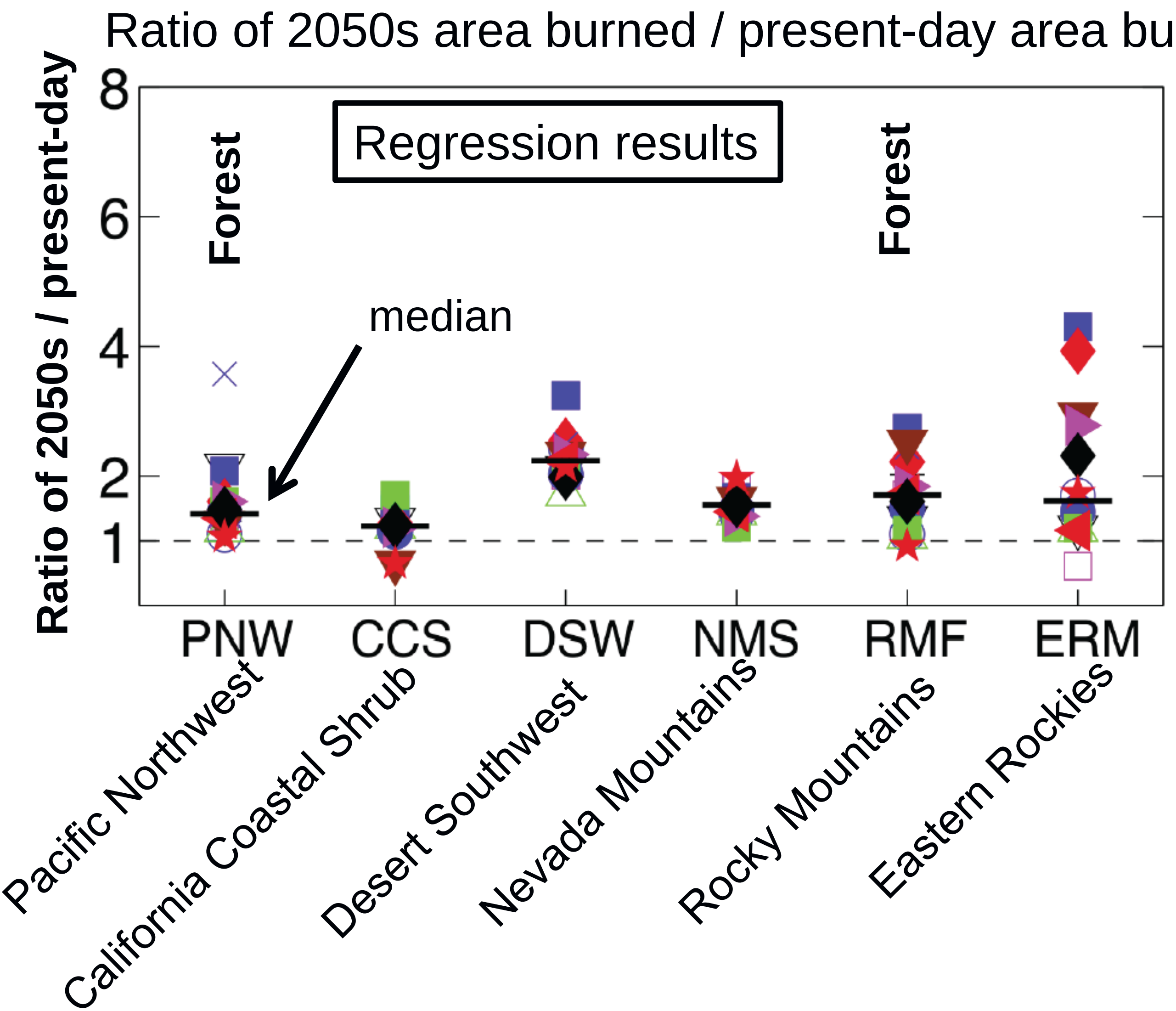
Variability in predicted increase in area burned smaller with regression approach



Almost all GCMs give increases

Very large range for parameterization

Median GCM results show an increase in area burned in all regions



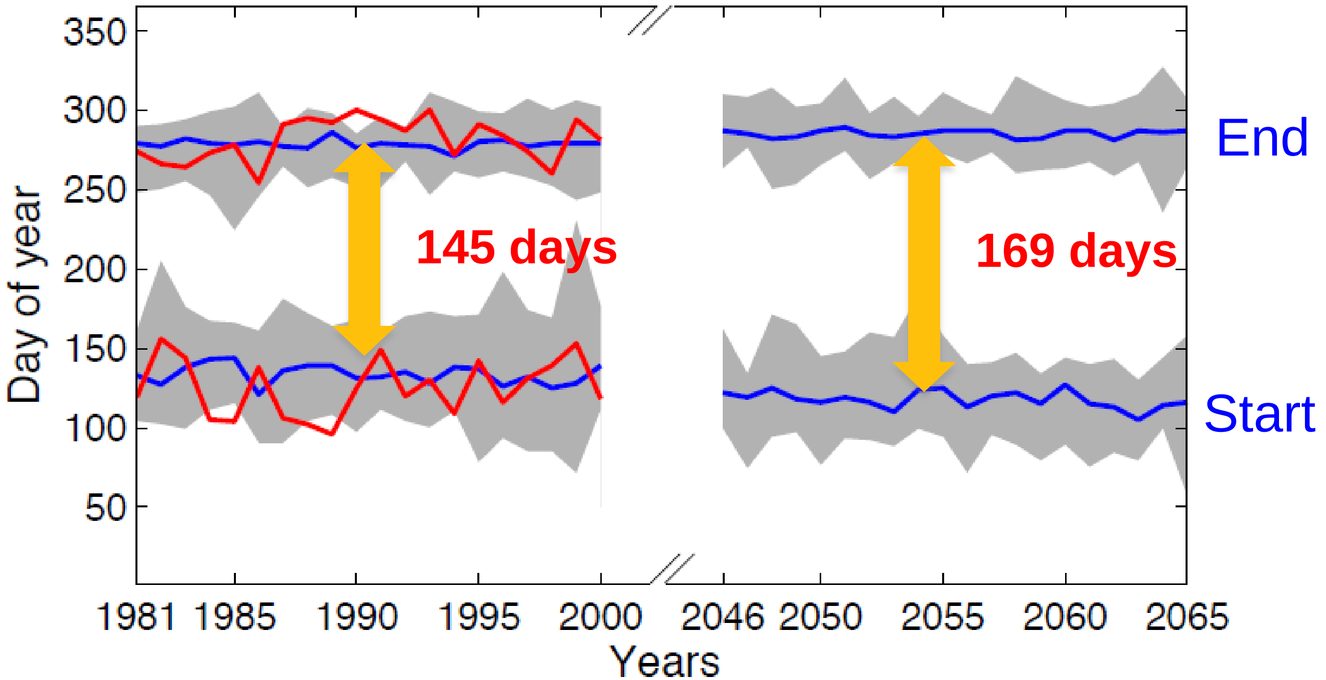
Median changes:

40-70% increase in forested regions

120% incr. in SW

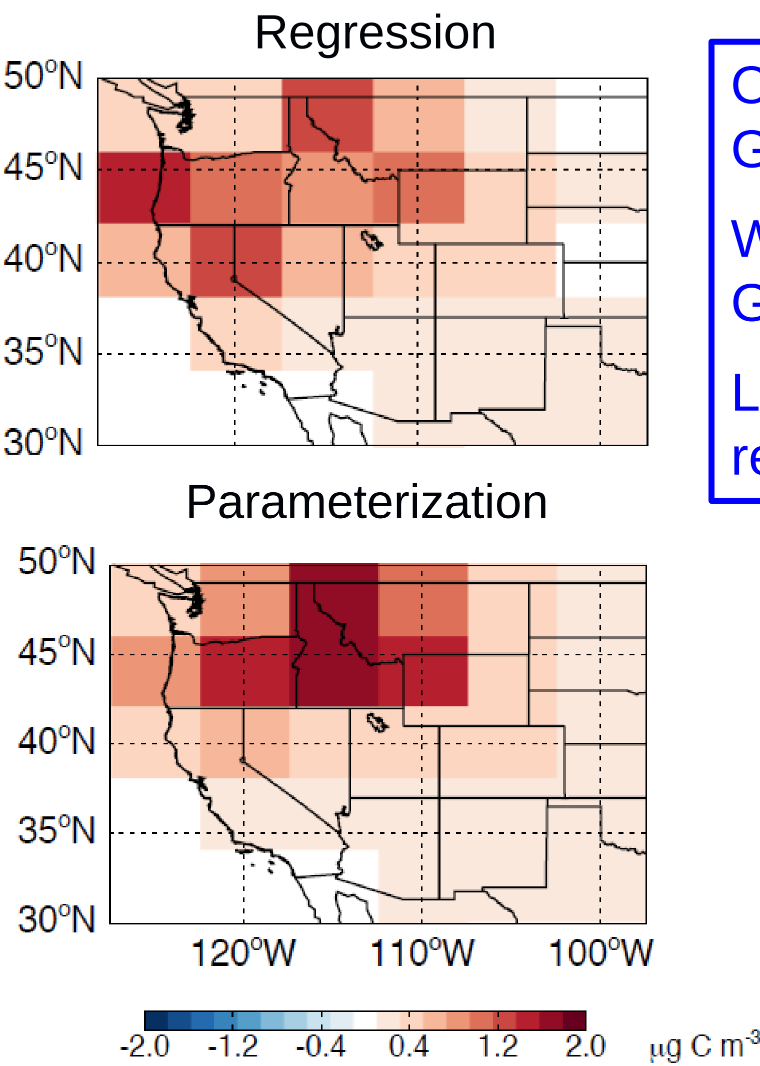
~60% incr. in grass-lands

The fire season increases by ~ 3 weeks relative to present day



Red: present day, using the NARR dataset.
Blue: median dates of the start and end of fire season with GCMs
Gray: spread of the model predictions
Fire season: daily AB > 100 ha in at least one grid box

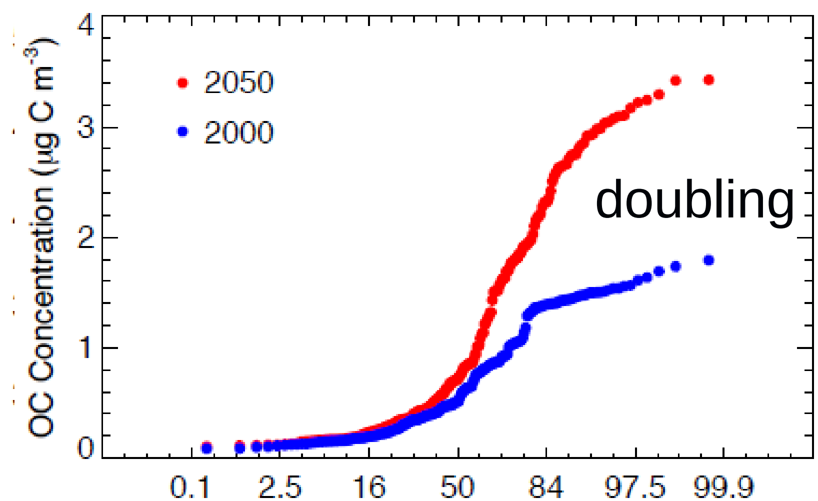
Large increases in organic carbon aerosols in May-Sept. by 2050.



OC from GEOS-Chem CTM driven by GISS GCM3 met. fields.

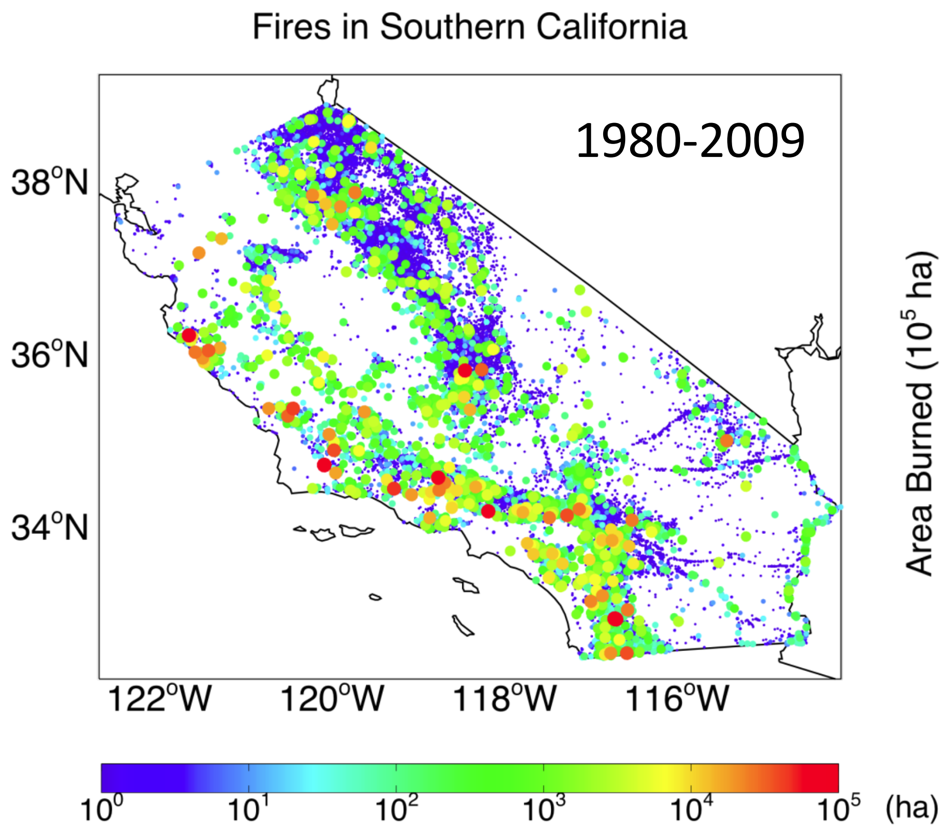
We can't run the CTM with output from 15 GCMs!

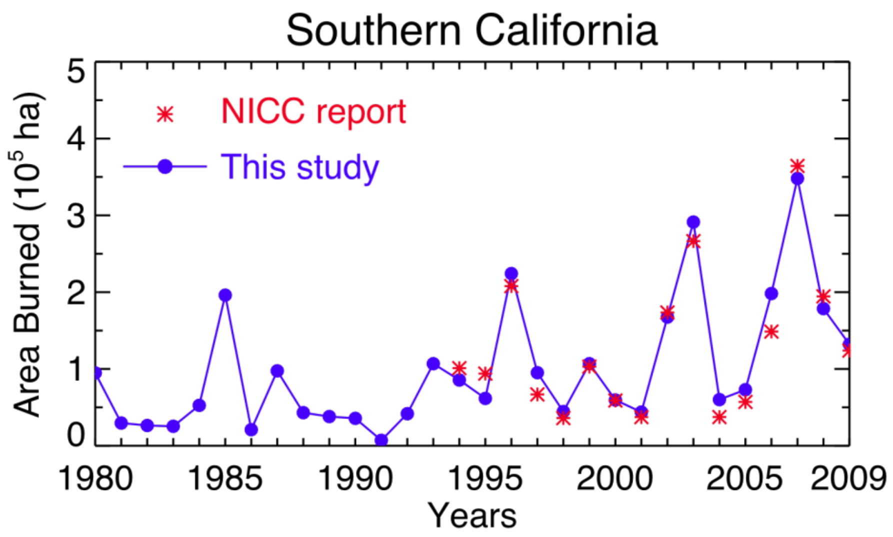
Largest increases in OC from forested regions, and more extreme events



Yue et al., 2012.

Improving fire prediction in Southern California



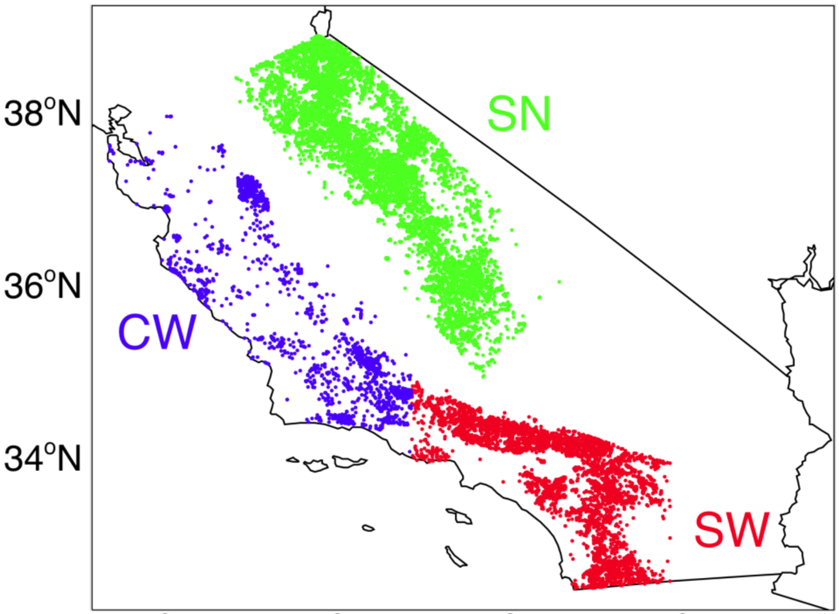


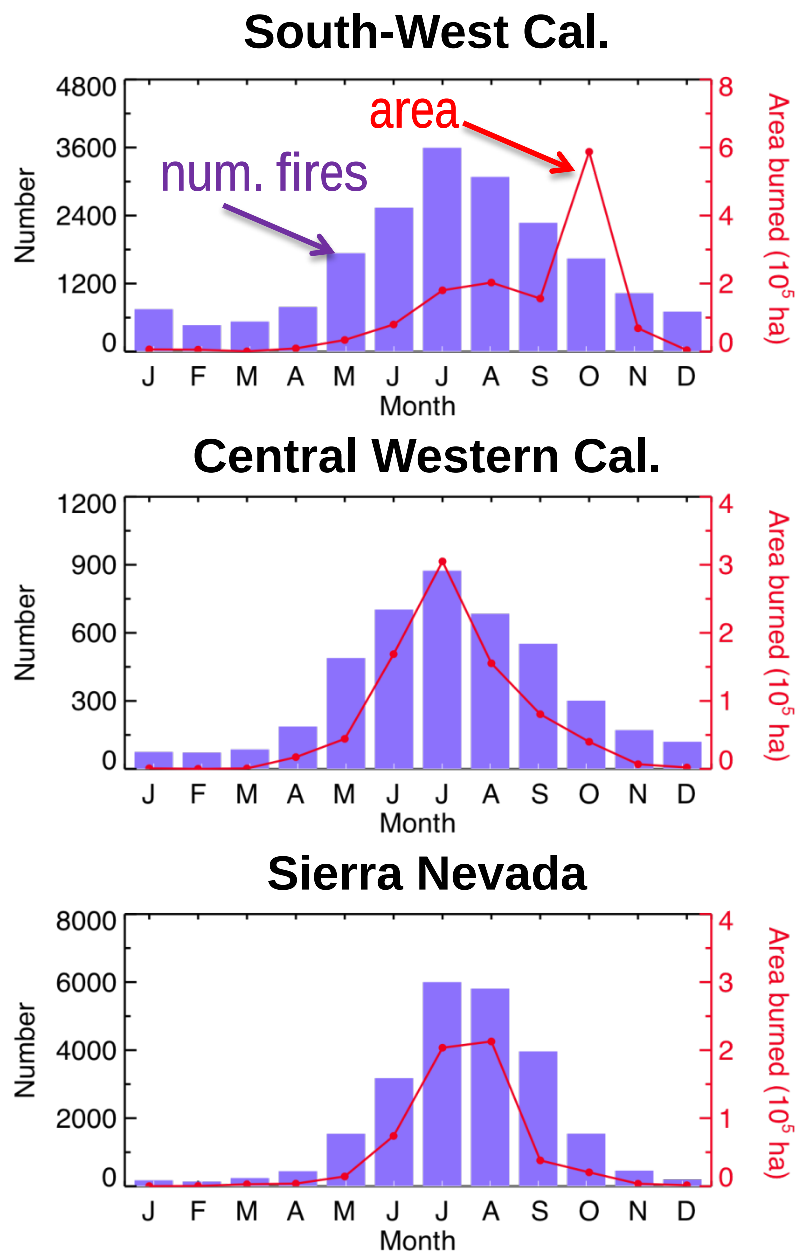
Fire data from US FS, BLM, NPS, FWS, BIA
Used to develop a 0.5° x 0.5° data-base for 1980-2009.

Yue et al., draft ms.

Seasonality of fires in Southern California

Fire regions



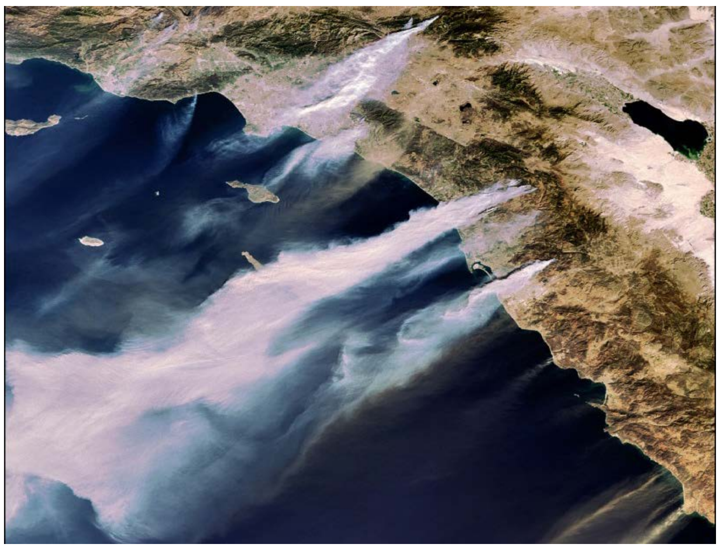


Largest area burned in SW California.

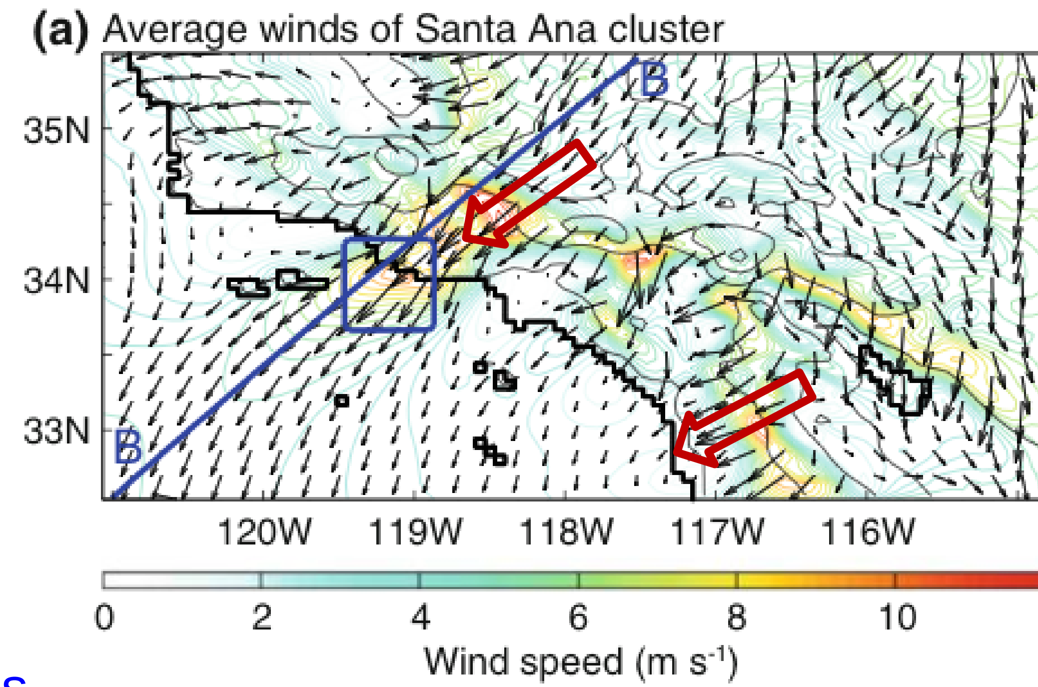
October peak associated with the Santa Ana winds, which are underestimated by large scale models as they lack the detailed topography: need synoptic scale approach

The largest fires in CA are associated with Santa Ana events

Fire plumes (Oct. 2007)



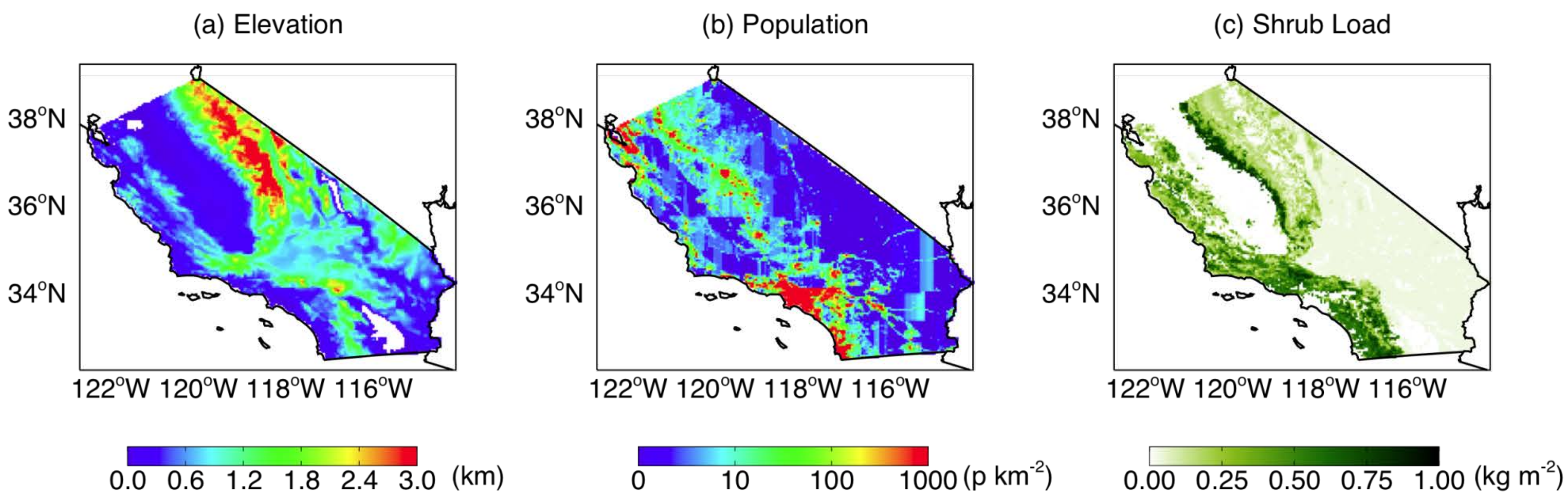
Composite Santa Ana winds



Need finely resolved wind fields to capture Santa Ana in the meteorological record.

NARR downscaled with MM5 to 6 km
Hughes and Hall (2010)

Fires in Southern California are associated with variations in elevation, population, and fuel load

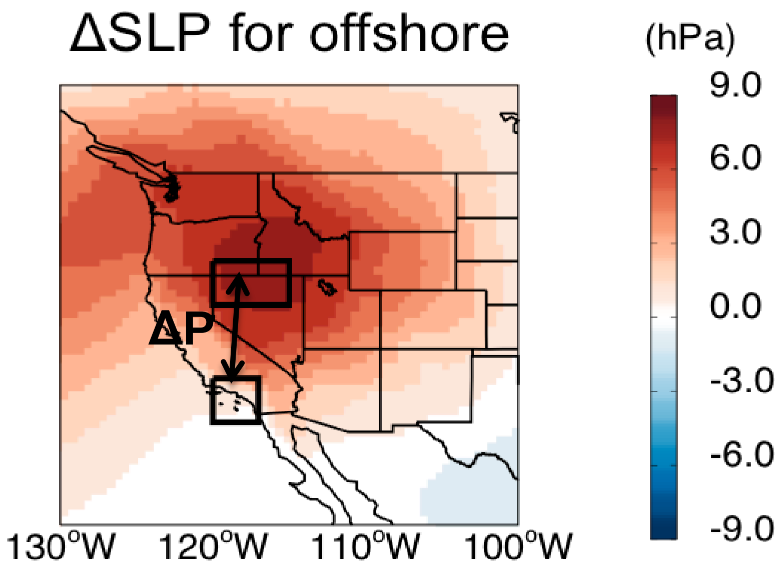


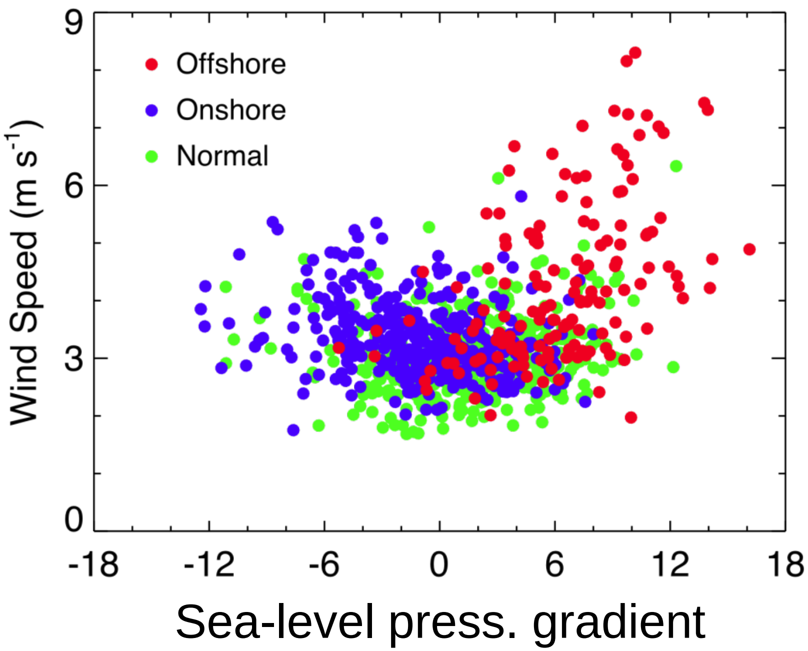
- We add to the parameterization a term for fire occurrence:

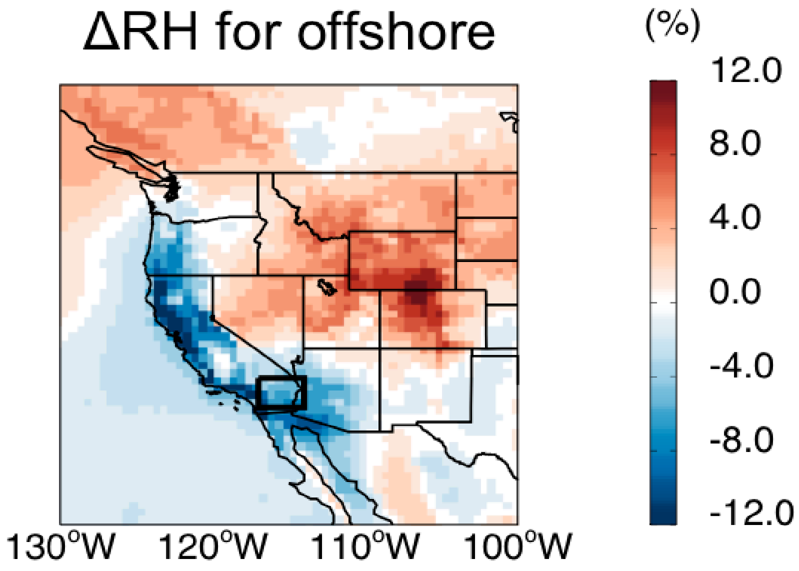
  Occurrence = F(elevation) × F(population) × F(shrub load)

- For southwestern CA, include a term for the occurrence of Santa Ana events – based on synoptic scale events

Sea-level Pressure and RH anomaly during strong offshore wind events

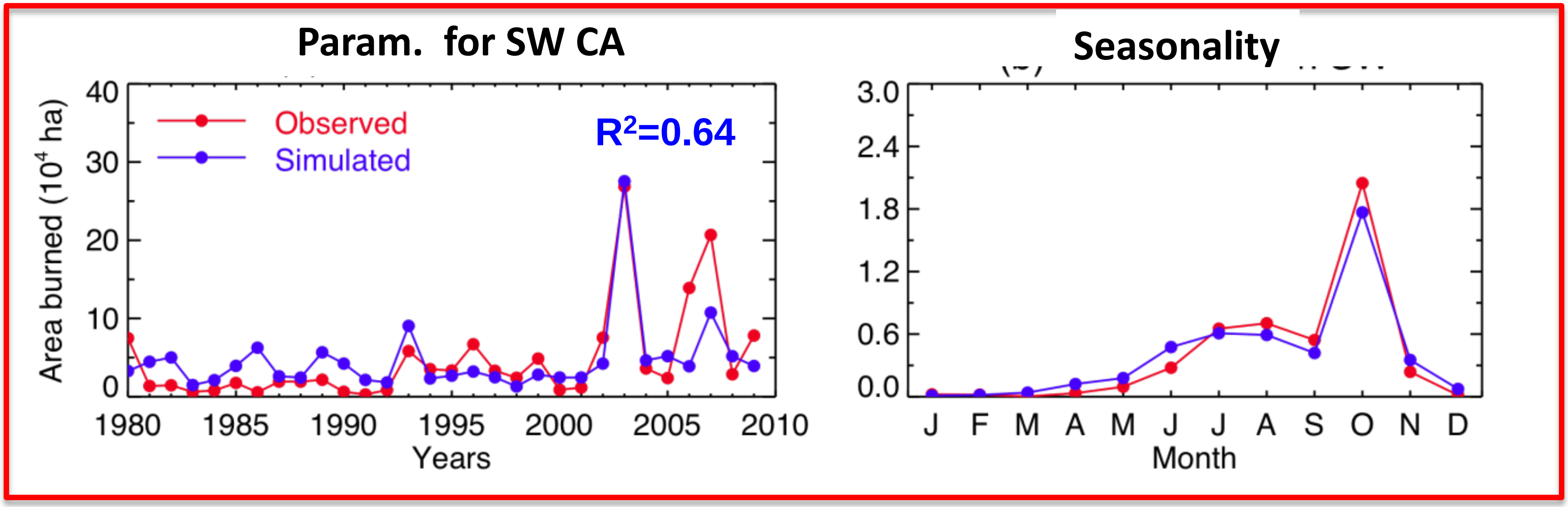




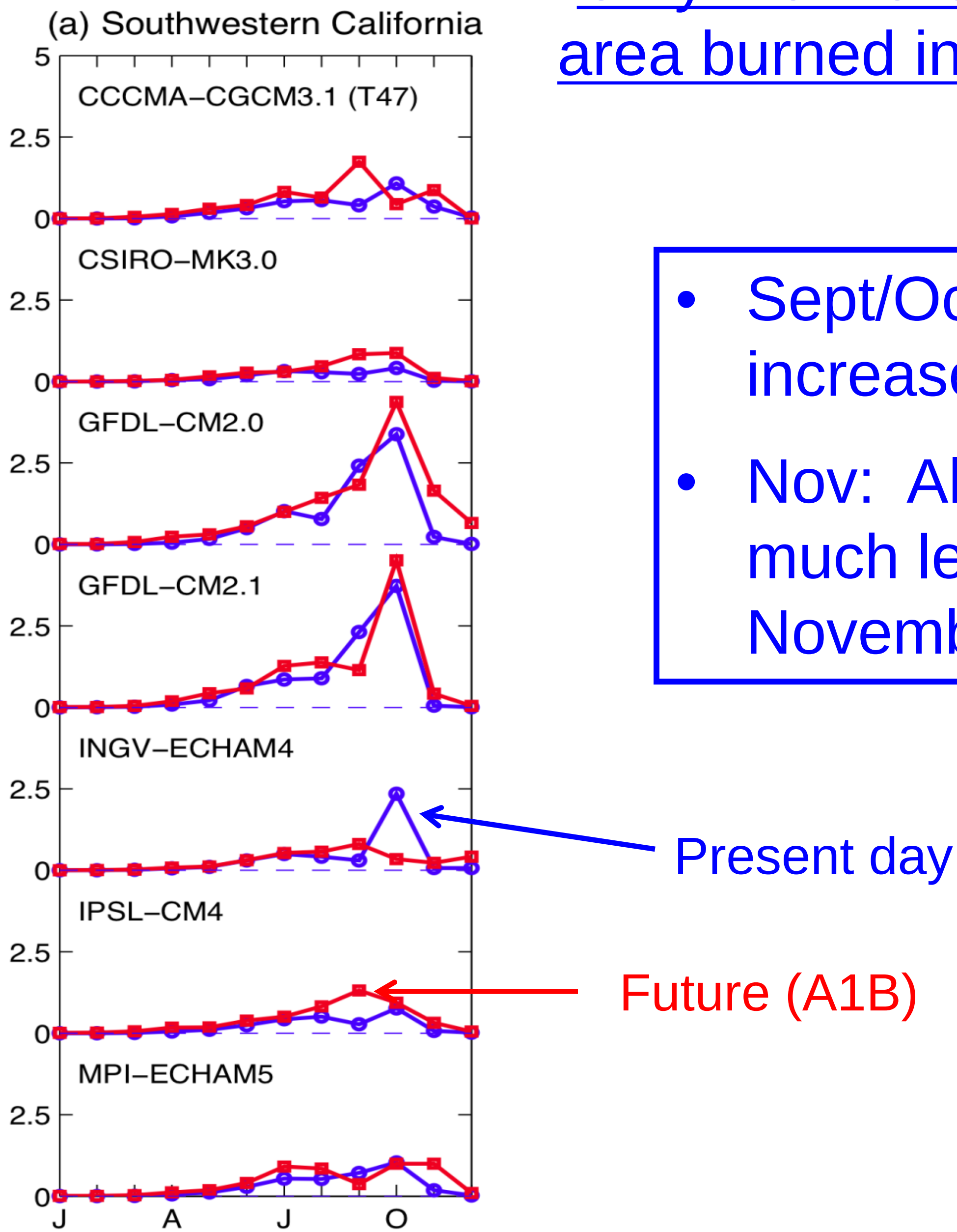


- Use press. gradient and RH in S. Cal. to define Santa Ana events in GCMs
- The strength of offshore wind is associated with the pressure gradient
- Very hot and dry during SA wind events

The parameterization predicts yearly variability and seasonality in south west California

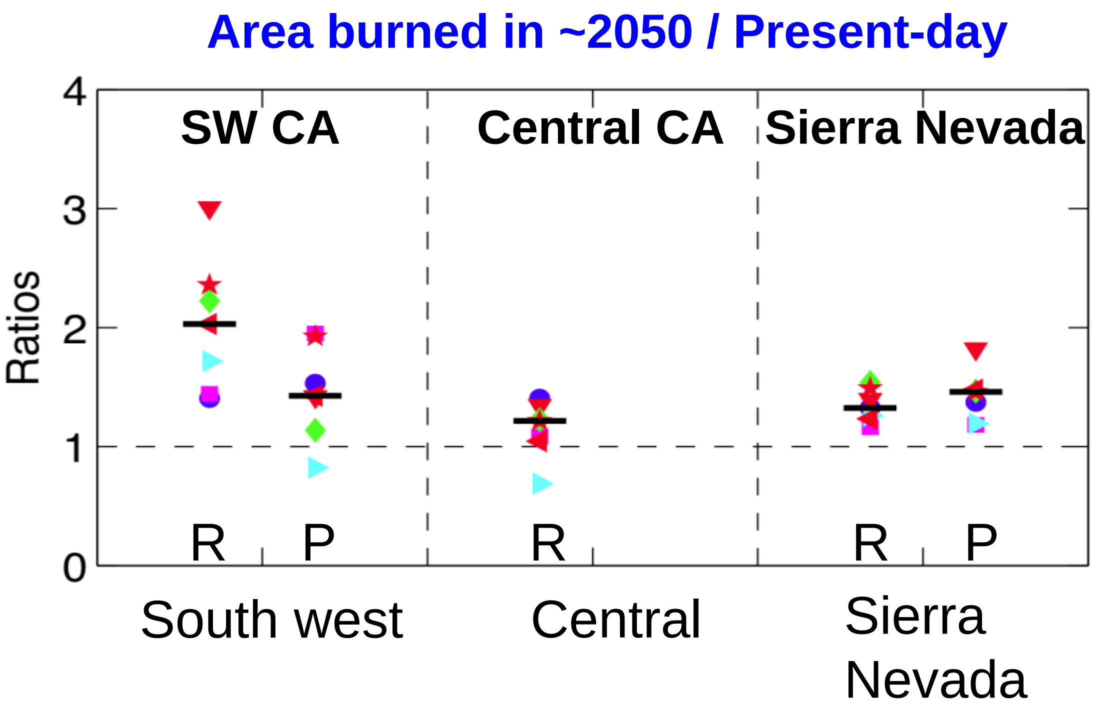


Only 7 of 15 GCMs predict a maximum in area burned in October for the present day



- Sept/Oct: 4 GCMs predict increases, 3 decreases
- Nov: All predict increases, but much less burned area in November than October

Smaller increases in CA fires with parameterization than with regression approach



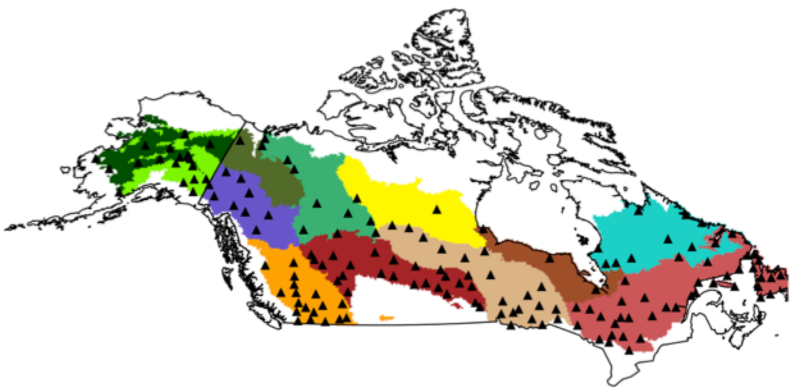
~45% increase in area burned with parameterization

100% incr. in SW CA with regression

20-30% in Central CA and Sierras

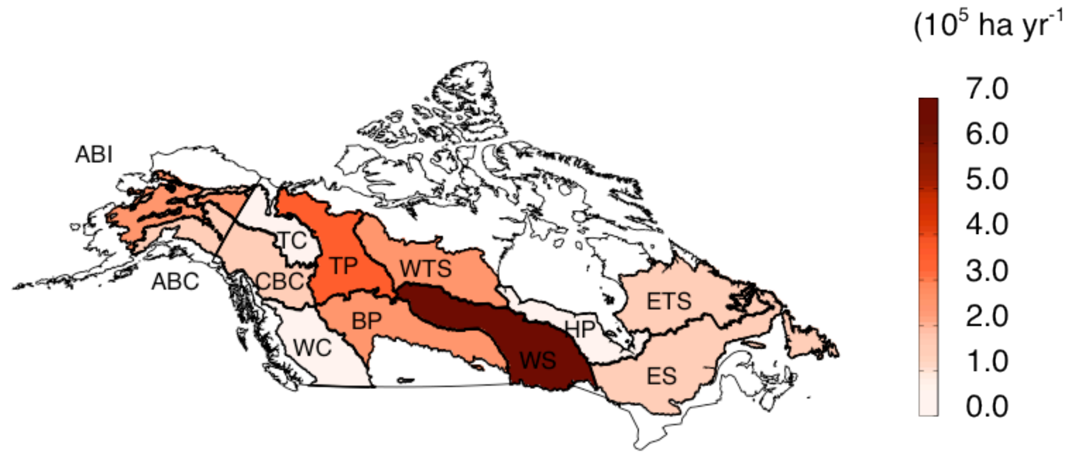
Fires in Alaska and Canada: area burned data for 1980-2009.

Ecoregions and sites with met. data

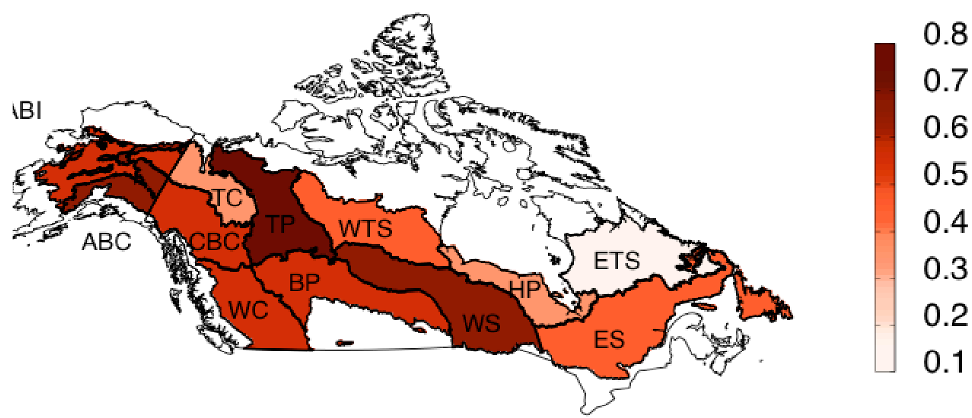


- Alaska Boreal Interior (ABI)
- Alaska Boreal Cordillera (ABC)
- Taiga Cordillera (TC)
- Taiga Plain (TP)
- Western Taiga Shield (WTS)
- Eastern Taiga Shield (ETS)
- Hudson Plain (HP)
- Western Mixed Wood Shield (WS)
- Eastern Mixed Wood Shield (ES)
- Boreal Plain (BP)
- Canadian Boreal Cordillera (CBC)
- Western Cordillera (WC)

Area burned

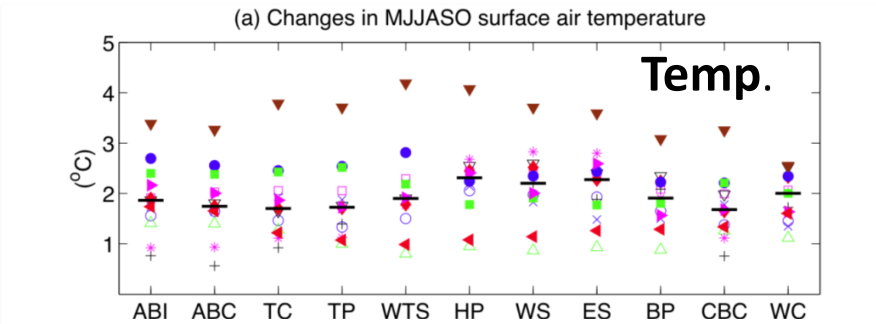


R^2 for regressions

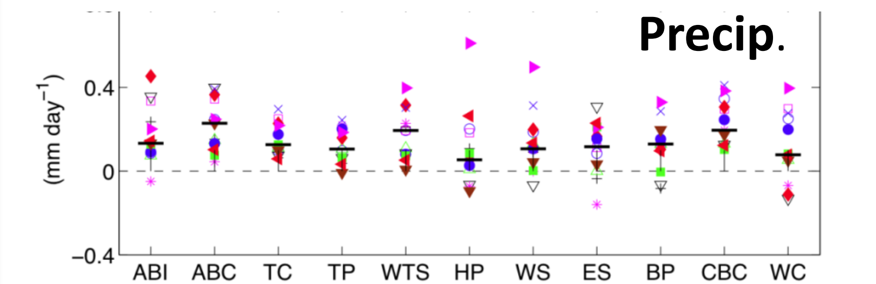


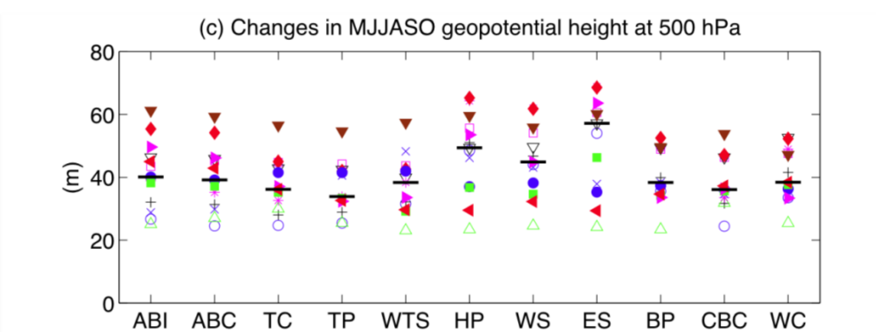
By ~2050, summer will be warmer and wetter in boreal North America

All GCMs predict an increase in temp.

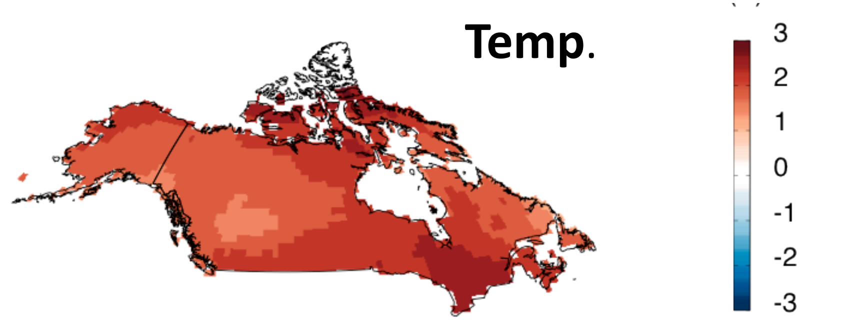


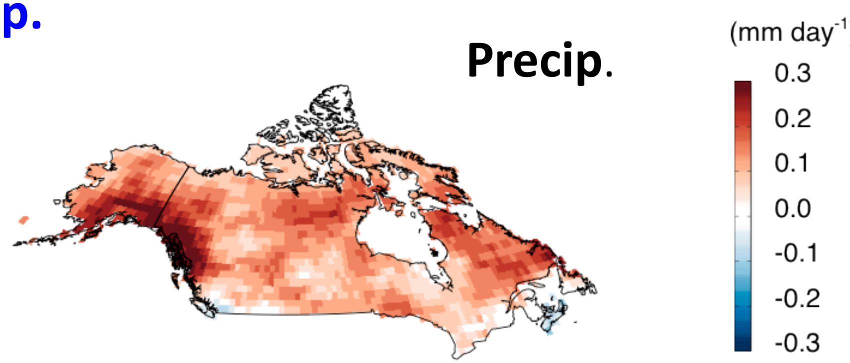
Most GCMs predict an increase in precip.

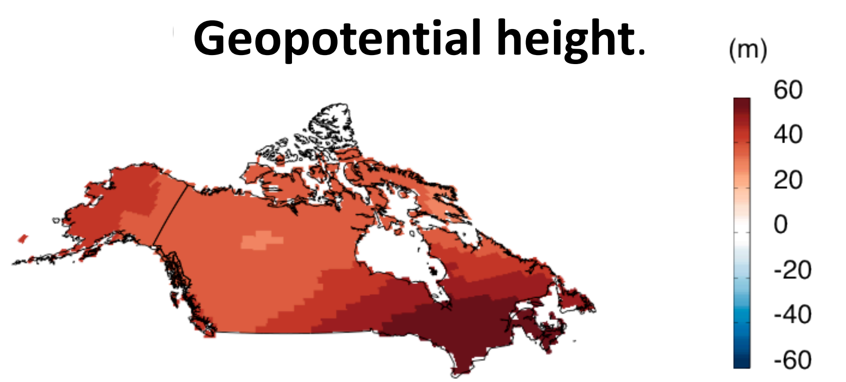




Mean changes in meteorology

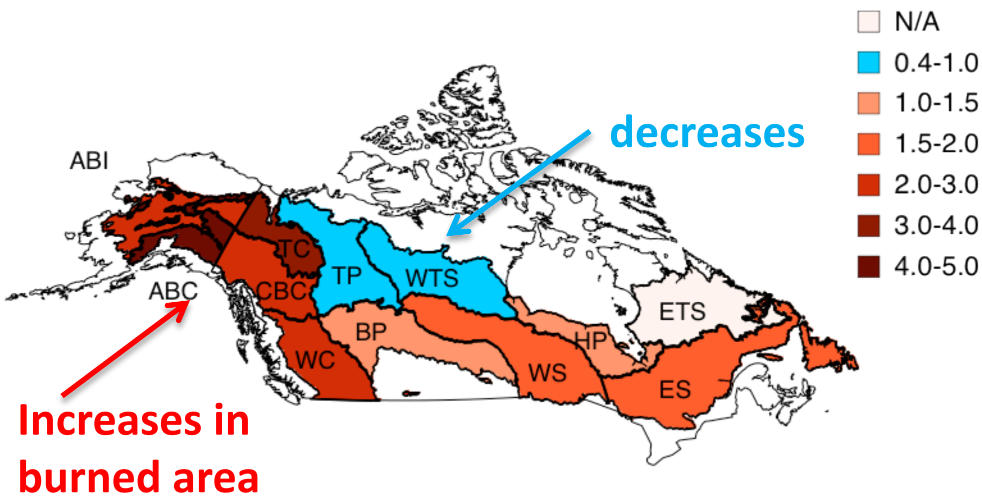






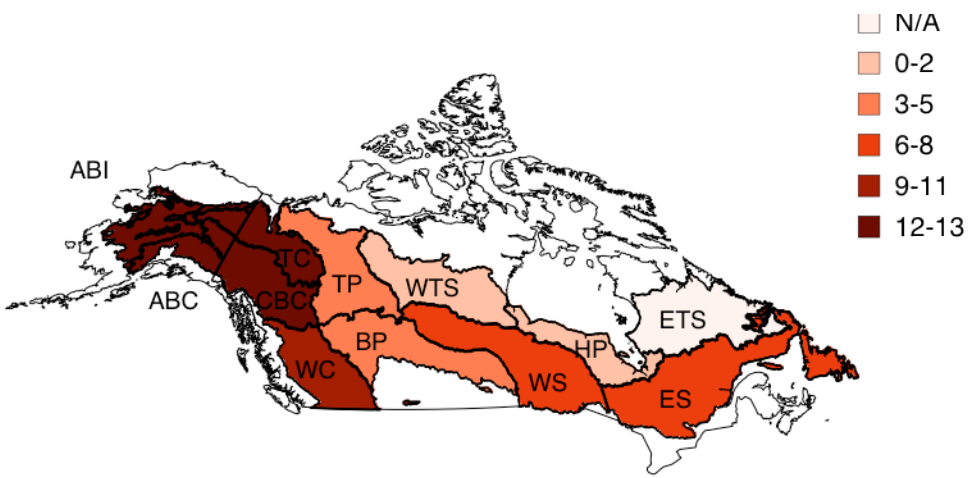
Increases in area burned in most ecoregions, but some decreases, as precip. increases.

(a) Ratios of midcentury to present day



Larger increases in area burned are predicted in Alaska and western Canada

Number of models with a significant change

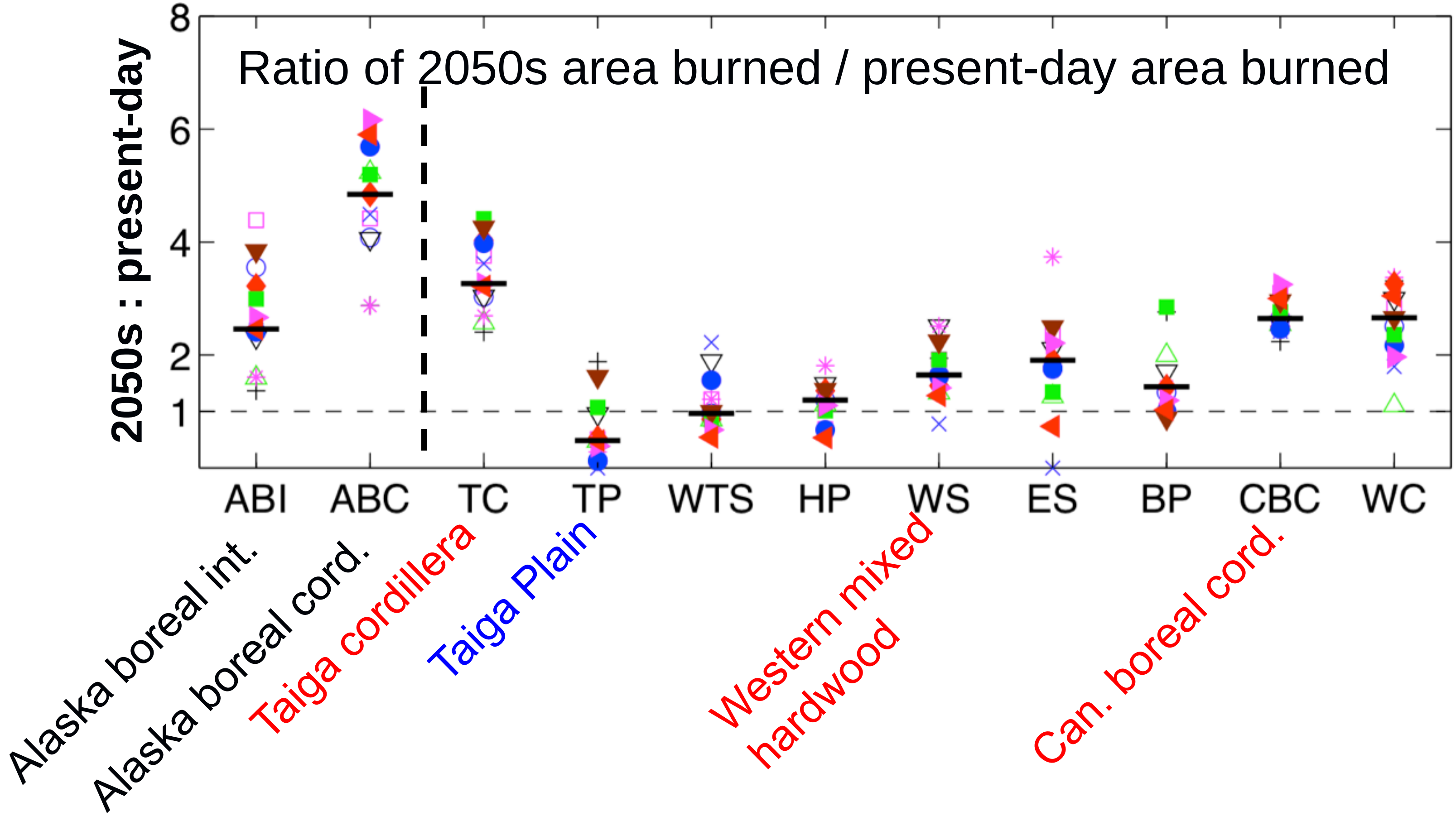


Projections are more robust for Alaska and western Canada but more uncertain for northern Canada.

Large changes in area burned in boreal forests

Alaska: increases of 150-400%, overall, factor of 3

Canada: changes of -50% to +230%, overall increase of ~50%



Summary

Western U.S.

- Total area burned increases by 60-120%
- Fire season extends by 3 weeks
- Summer OC concentrations increase by 40-70%, EC by 20-30% in 50 y (Yue et al., 2012, in review)

Southern California

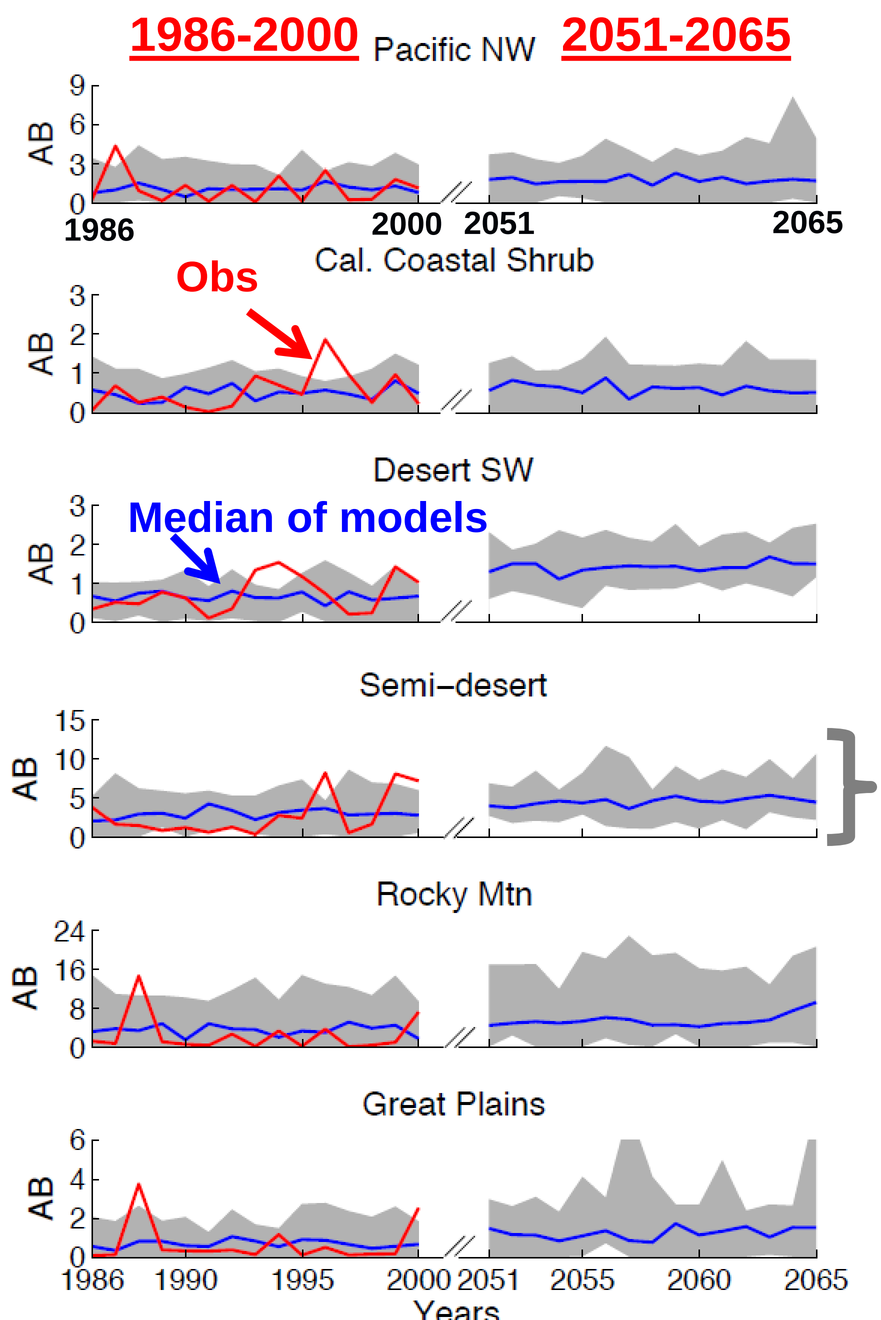
- Area burned increases by 20-100%, depending on ecoregion

Alaska and Canada

- Area burned increases by 150-400% in Alaskan ecoregions, and 160-230% in western Canadian ecoregions
- Area burned is some northern Canadian ecoregions may decrease due to increase in precipitation

Increase in fires in all regions predicted by GCMs using median results

Regression results



The GCMs cannot match year to year variability, but match the mean area burned fairly well.

Parameterization is based on empirical relationships of 1°x1° grid cells with fires to Temperature, RH, Precip.

Fires occur at higher temps, lower RH and precip.