

Supplemental information

A. Comparison of meteorology between FAMWEB and NARR

As noted in section 2.3, we use site-based measurements from FAMWEB for the fire regressions and the gridded data from NARR for the parameterization. We find large mean differences between the two datasets (Fig. S1), partly because FAMWEB provides weather conditions at local noon while the meteorological variables from NARR daily reanalyses shown here are diurnal averages. To test the consistency between the two datasets in terms of interannual variability, we correlate the deseasonalized time series of monthly data for 1979 to 2009. For temperature and precipitation, we find that the correlation r ranges from 0.83 to 0.97 ($p < 0.001$) in all three ecoregions; r is somewhat less for RH, with the smallest r of 0.71 ($p < 0.001$) in the Sierra Nevada. However, for wind speed, we do not find significant ($p < 0.1$) correlations. Hughes and Hall (2010) reported that the NARR cannot capture the Santa Ana winds due to its coarse resolution relative to the complicated local topography. The differences between FAMWEB and NARR meteorology do not influence our results because we develop and evaluate the two fire schemes independently. We do not use wind speed from NARR in this study.

B. Relationships between area burned and meteorology in the parameterization

Yue et al. (2013) calculated logarithmic monthly area burned [$\ln(AB)$] and averages of the North American Regional Reanalysis meteorological variables for each $1^\circ \times 1^\circ$ fire cell (area burned > 10 ha) in the western U.S. during 1980-2004. We found that $\ln(AB)$ is linearly correlated with T , $(1-RH/100)^2$, and $(R+0.2)^{-1}$, where T is surface air temperature ($^\circ\text{C}$), RH is relative humidity (%), and R is precipitation (mm day^{-1}) (see Fig. 4 in Yue et al. 2013). In this study, we apply a similar approach with $0.5^\circ \times 0.5^\circ$ monthly area burned over southern California during 1980-2009. To increase the sample size, we select those grid squares with area burned larger than 1 ha, yielding 5932 cells.

Figure S2 shows the probability distribution of meteorological variables in all cells and in those cells with area burned larger than 1 ha. Fire cells generally have higher temperature and lower relative humidity. We do not find significant differences for precipitation (Fig. S2c), probably because the rainfall is already very low in southern

California. In a result similar to Yue et al. (2013), we find that more than 75% of the fire cells have temperatures greater than 15 °C and rainfall less than 2.5 mm day⁻¹. For temperature (Fig. S2a), the maximum probability of fire occurrence peaks at ~21.5 °C, beyond which the frequency of fires decreases. More than 70% of non-fire cells (area burned < 1 ha) with temperatures higher than 21.5 °C are located outside the three subregions in our study (Fig. 2a), in areas where fuel load or constraints from agriculture limit fire activity. For similar reasons, the probability in fire occurrence also decreases when relative humidity is lower than 30% (Fig. S2b).

Although fire probability is influenced by factors other than weather conditions, $\ln(AB)$ generally shows linear relationships with the meteorological functions $F(T) = T/15$, $G(RH) = (1-RH/100)^2$, $H(R) = 1/(R+0.2)$, and their product (Figures S2e-h). However, the correlation coefficients of $\ln(AB)$ with these functions (0.63-0.88) are lower than those for all fire cells in western U.S. as shown in Fig. 4 of Y2013. This result for southern California underscores the challenge in capturing the interannual variability of area burned in this region, especially given the influences from topography and the Santa Ana winds here. It is these challenges we attempt to address through inclusion of geographical factors and the Santa Anas in our parameterization of area burned.

C. Sensitivity tests for parameterization with different resolutions and schemes

In Table S2 we present the results from a series of sensitivity tests demonstrating how our improvements to the parameterization model affect its performance in southern California. We find that with 1°×1° resolution and without consideration of the Santa Ana winds, the model fails to capture the spatial pattern and interannual variability of observed area burned. Increasing the horizontal resolution to 0.5°×0.5° yields a slightly higher correlation r of 0.44 ($p < 0.05$) between the time series of modeled and observed annual area burned. However, the spatial correlation for the long-term average area burned is poor, -0.33 for 116 grid squares with this resolution. If we then include the impact of Santa Ana winds on area burned in the model, the temporal correlation increases to 0.69 ($p < 0.001$), but with no improvement in spatial correlation. Implementation of fire probability, which takes into account the elevation, population distribution, and fuel load, improves the spatial correlation. When we take into account

both fire probability and Santa Anas in the model with fine resolution, the parameterization predicts reasonable area burned, with correlations between model and observations of 0.50 in space ($p < 0.001$) and 0.67 in time ($p < 0.001$). In addition to the changes in the interannual variability, the seasonality of area burned is improved after the inclusion of Santa Anas, due to reproduction of the October peaks in wildfire activity.

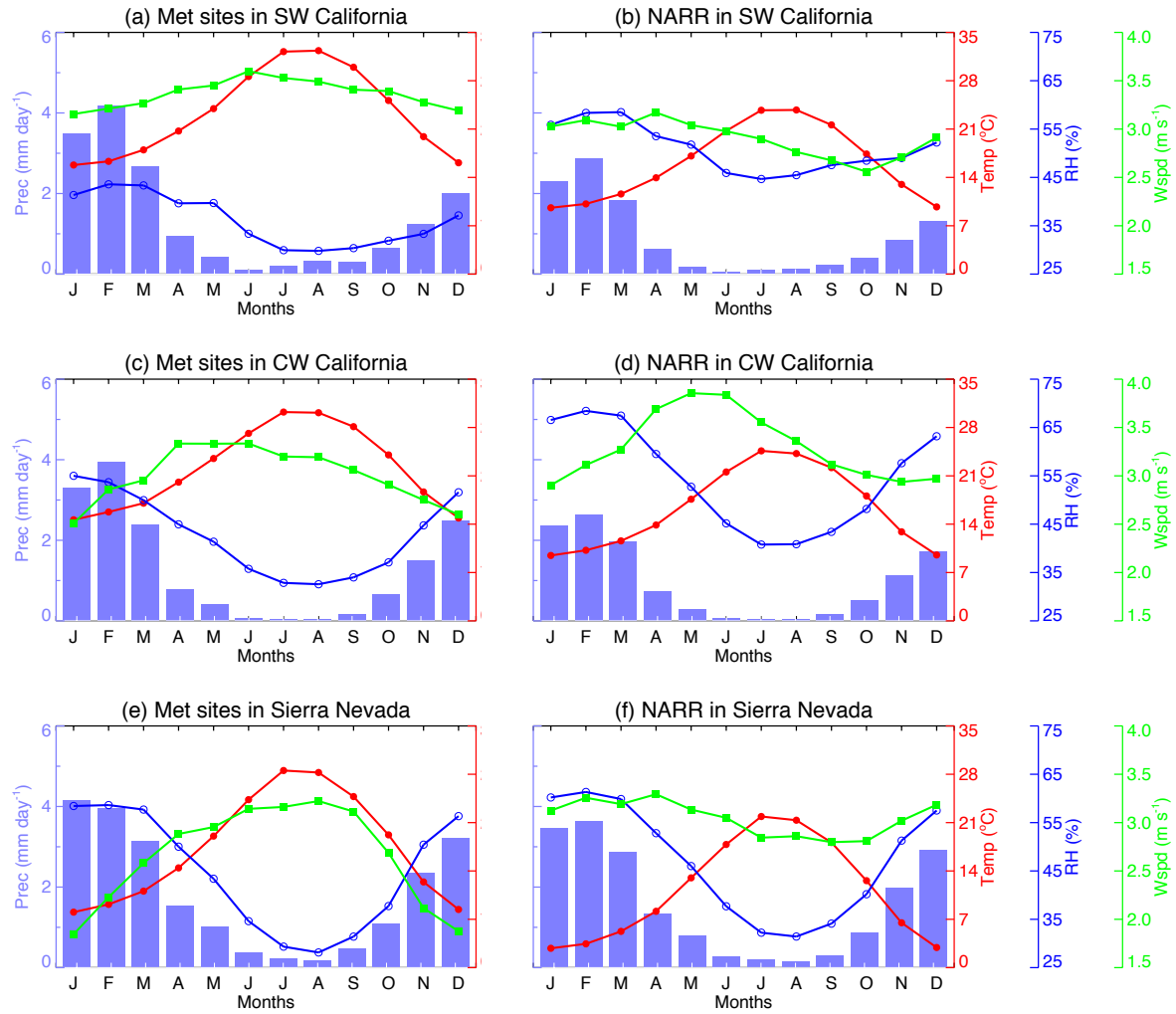


Fig. S1 Monthly mean precipitation rates (Prec, purple bars), temperatures (Temp, red curves) and relative humidity (RH, blue curves) at 2 meters above ground level (AGL), and wind speed (Wspd, green curves) at 10 meters AGL, averaged over the 1980 to 2009 time period in three different ecoregions of Southern California, calculated with data from (a, c, e) FAMWEB weather sites and (b, d, f) NARR reanalyses.

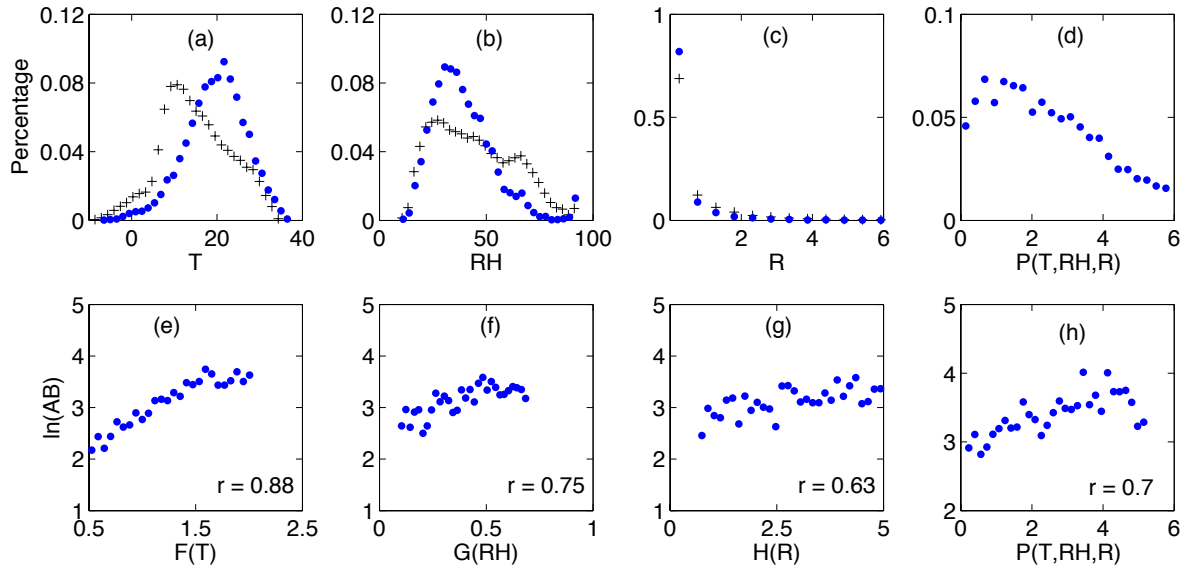


Fig. S2 Probability distributions of monthly mean (a) surface air temperature ($^{\circ}\text{C}$), (b) relative humidity (%), and (c) precipitation (mm day^{-1}) for all grid cells in southern California (plus signs) and for those cells that have observed monthly area burned larger than 1 ha (blue points) during 1980-2009. Panels (e)-(g) show the relationships between the logarithmic monthly area burned ($\ln(\text{AB})$, ha) and these functions: (e) $F(T) = T/15$, (f) $G(\text{RH}) = (1-\text{RH}/100)^2$, and (g) $H(R) = 1/(R+0.2)$, where T is surface air temperature, RH is relative humidity, and R is rainfall. Panel (d) shows the probability distribution for the function $P(T, \text{RH}, R) = F(T) \times G(\text{RH}) \times H(R)$ over the same fire cells as in Panels (a)-(c). Panel (h) shows the relationship between $\ln(\text{AB})$ and the function $P(T, \text{RH}, R)$. In all panels, the range for each meteorological variable or function has been divided into 30 equal-size bins, and the symbols represent the average of the cell values within each bin. For panels (e)-(h), the correlation coefficient between $\ln(\text{AB})$ and the individual function is shown at the right bottom of each panel.

Table S1. Description of Canadian Fire Weather Index System

Code	Full Name	Description	Input ^a
FFMC	Fine Fuel Moisture Code	Moisture content of litter and fine fuel	T, RH, wind, rain
DMC	Duff Moisture Code	Moisture content of moderate duff and woody materials	T, RH, rain
DC	Drought Code	Moisture content of deep and compact organic layers	T, rain
ISI	Initial Spread Index	Measure of fire spread rate	FFMC, wind
BUI	Build-up Index	Measure of fuel availability for combustion	DMC, DC
FWI	Fire Weather Index	Measure of fire intensity	ISI, BUI
DSR	Daily Severity Rating	Measure of the difficulty to control fires	FWI

^a The meteorological variables and/or fire indexes used as input in the calculation of a specific fire index. The meteorological variables include temperature (T), relative humidity (RH), wind speed, and precipitation (rain).

Table S2. Comparison of modeled with observed annual total area burned in southern California from 1980-2009. Shown are the results from a series of sensitivity simulations using the parameterization ^a.

Horizontal Resolution	Inclusion of fire probability	Inclusion of Santa Ana	Spatial corr. coef. r^b	Interannual corr. coef. r^c	Seasonal corr. coef. r^d
1.0° × 1.0°	No	No	-0.06 (26)	0.32	<u>0.84</u>
0.5° × 0.5°	No	No	-0.33 (116)	<u>0.44</u>	<u>0.86</u>
0.5° × 0.5°	No	Yes	-0.31 (116)	<u>0.69</u>	<u>0.98</u>
0.5° × 0.5°	Yes	No	<u>0.41</u> (116)	0.33	<u>0.88</u>
0.5° × 0.5°	Yes	Yes	<u>0.50</u> (116)	<u>0.67</u>	<u>0.97</u>

^a The functional form of the parameterization is:

$$\ln(AB) = \begin{cases} \frac{\alpha \cdot T \cdot (1.0 - RH/100)^2}{T_t \cdot (R + 0.2)} & \text{if } T > T_t \text{ and } R < R_t \\ \text{no fire} & \text{otherwise} \end{cases}$$

where AB is area burned, T is temperature, R is precipitation, and RH is relative humidity. α is a scaling coefficient dependent on the fire probability. Two threshold values are $T_t = 15.0$ °C and $R_t = 2.5$ mm day⁻¹.

^b Correlation between observed and modeled values for the 30-year mean area burned across all grid squares. Values in parentheses show the number of grid squares used in calculating the correlation. The correlation r is underlined if significant at $p < 0.05$.

^c Correlation between observed and modeled values for the annual total area burned in three ecoregions of Southern California during 1980-2009. The correlation r is underlined if significant at $p < 0.05$.

^d Correlation between observed and modeled values for the long-term mean monthly total area burned in three ecoregions of Southern California during 1980-2009. The correlation r is underlined if significant at $p < 0.05$.

References

- Hughes M, Hall A (2010) Local and synoptic mechanisms causing Southern California's Santa Ana winds. *Clim Dyn* 34:847-857
- Yue X, Mickley LJ, Logan JA, Kaplan JO (2013) Ensemble projections of wildfire activity and carbonaceous aerosol concentrations over the western United States in the mid-21st century. *Atmos Environ* 77:767-780