Supplement

Table S1. Hyperparameters used and the Grid search ranges tested in the ML model

	Tested ranges	**Final value**
Learning rate	0.1, 0.25, 0.35, 0.5, 0.8	0.35
Max_depth	3, 6, 9, 12	12
subsample	0.4, 0.6, 0.8, 1	1
nrounds	100, 150, 200, 250	150

Table S2. Standard deviation of meteorology and slopes of for the dependence of annual mean PM2.5 fire emissions on meteorology for the southeastern US (SEUS) and western US (WUS)

	RH_SEUS	**Temp_SEUS**	**RH_WUS**	**Temp_WUS**
Standard deviation	1.594	1.385	2.038	1.982
GFED_slope	-0.014	0.017	-0.017	0.049
CLM_slope	-0.042	0.119	-0.036	0.064
JULES_slope	-0.038	0.160	-0.11	0.162

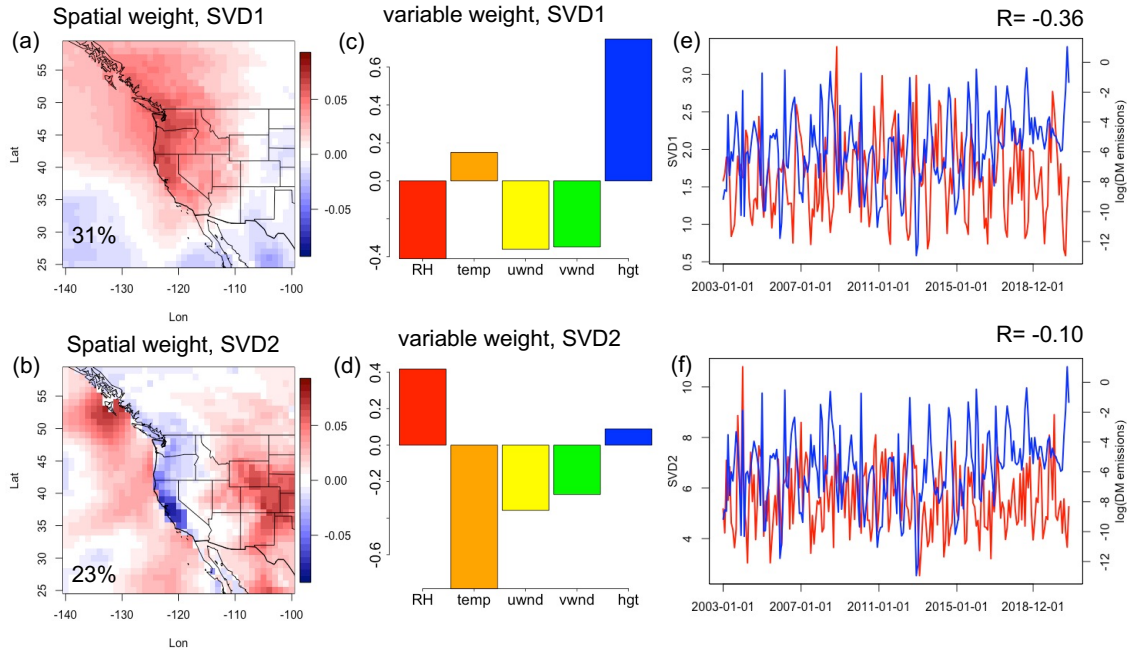

Figure S1. The spatial and variable weights of the first (a, c) and second (b, d) singular value decomposition (SVD) modes describing the spatial correlations between daily mean burned area over NCA and meteorological variables in the grid boxes in the western US from 2000 to 2017.

The meteorological variables include temperature, relative humidity, precipitation, u and v wind speed. (e) Time series of monthly standard deviation of daily SVD1 (red) and logarithm of monthly total burned area (blue) for NCA. (f) Time series of monthly standard deviation of daily SVD2 (red) and logarithm of monthly total burned area (blue) for NCA.

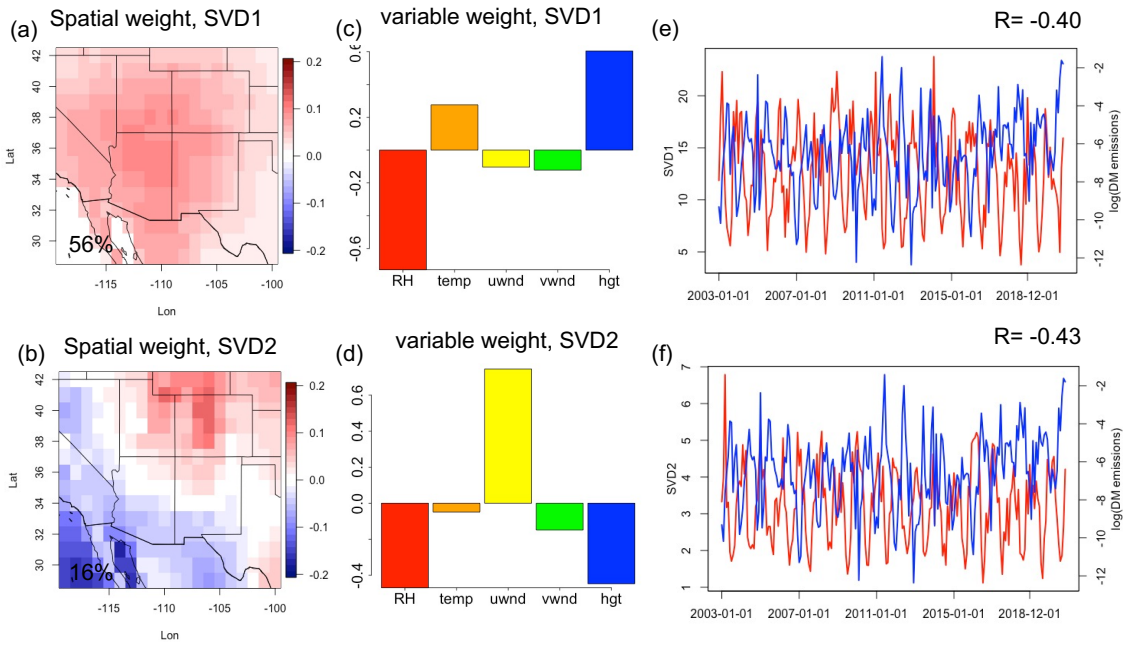

Figure S2. The spatial and variable weights of the first (a, c) and second (b, d) singular value decomposition (SVD) modes describing the spatial correlations between daily mean burned area over southern Rocky Mountains (SRM) and meteorological variables in the grid boxes in the southwestern US from 2000 to 2017. The meteorological variables include temperature, relative humidity, precipitation, u and v wind speed. (e) Time series of monthly standard deviation of daily SVD1 (red) and logarithm of monthly total burned area (blue) for SRM. (f) Time series of monthly standard deviation of daily SVD2 (red) and logarithm of monthly total burned area (blue) for SRM.

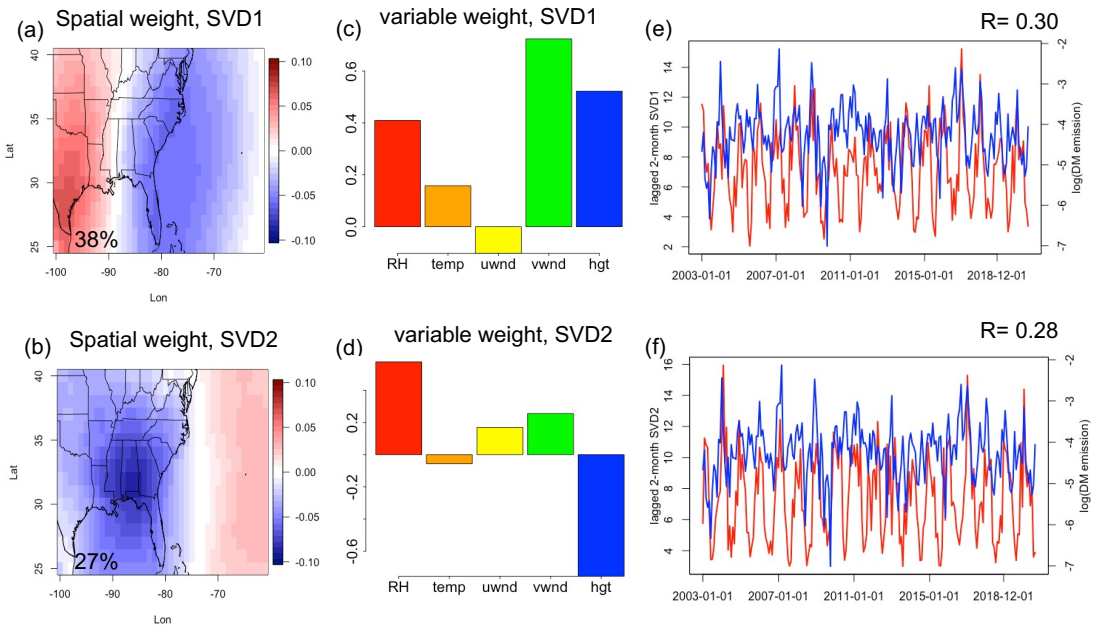

Figure S3. The spatial and variable weights of the first (a, c) and second (b, d) singular value decomposition (SVD) modes describing the spatial correlations between daily mean burned area over southeastern US (SEUS) and meteorological variables in the grid boxes in the SEUS from 2000 to 2017. The meteorological variables include temperature, relative humidity, precipitation, u and v wind speed. (e) Time series of monthly standard deviation of daily SVD1 (red) and logarithm of monthly total burned area (blue) for SEUS. (f) Time series of monthly standard deviation of daily SVD2 (red) and logarithm of monthly total burned area (blue) for SEUS.

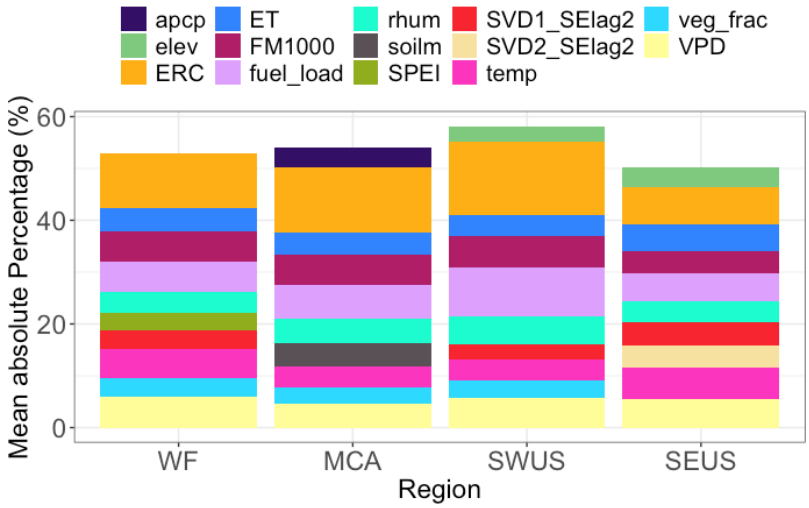

Figure S4. The top 10 variables based on the mean absolute percentage for the selected regions. The mean absolute percentage is calculated by the absolute SHAP value of the variable divided by the sum of the absolute SHAP values of all the variables.

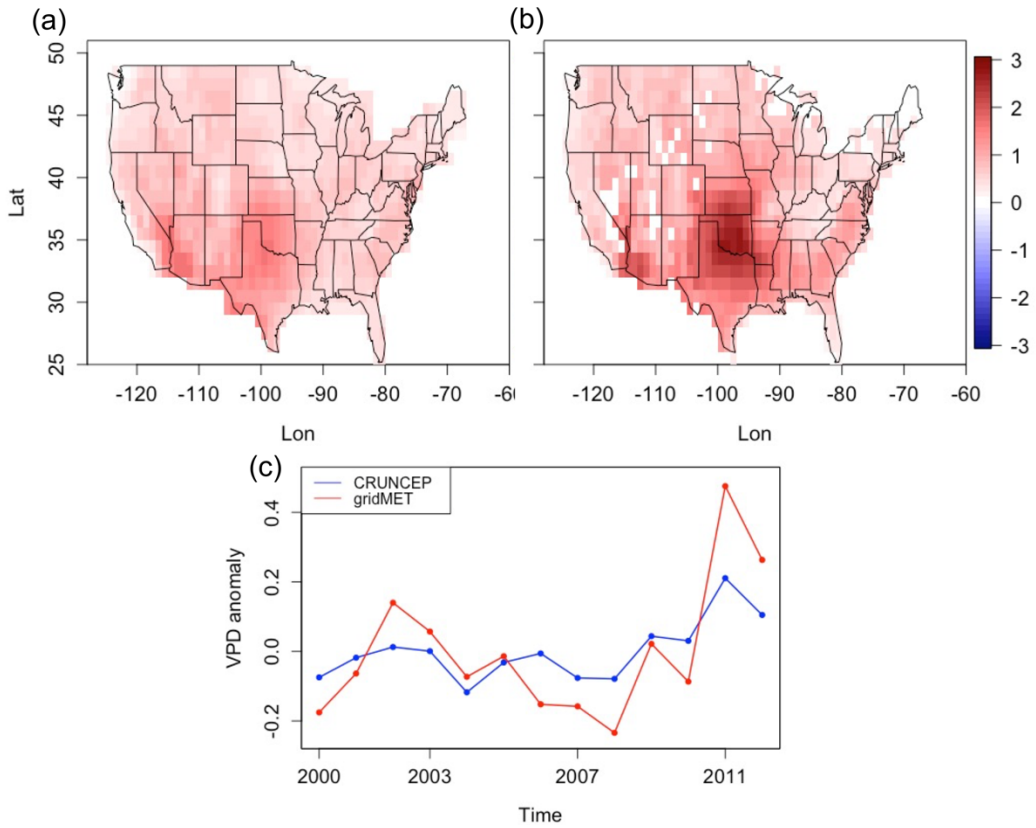

Figure S5. Top panel: Spatial map of VPD anomalies in JJA for (a) CRUNCEP and (b) gridMET. Bottom panel: (c) Time series of VPD anomalies in JJA from 2000 to 2012.