Supporting Information for "The Character and Changing Frequency of Extreme California Fire Weather"

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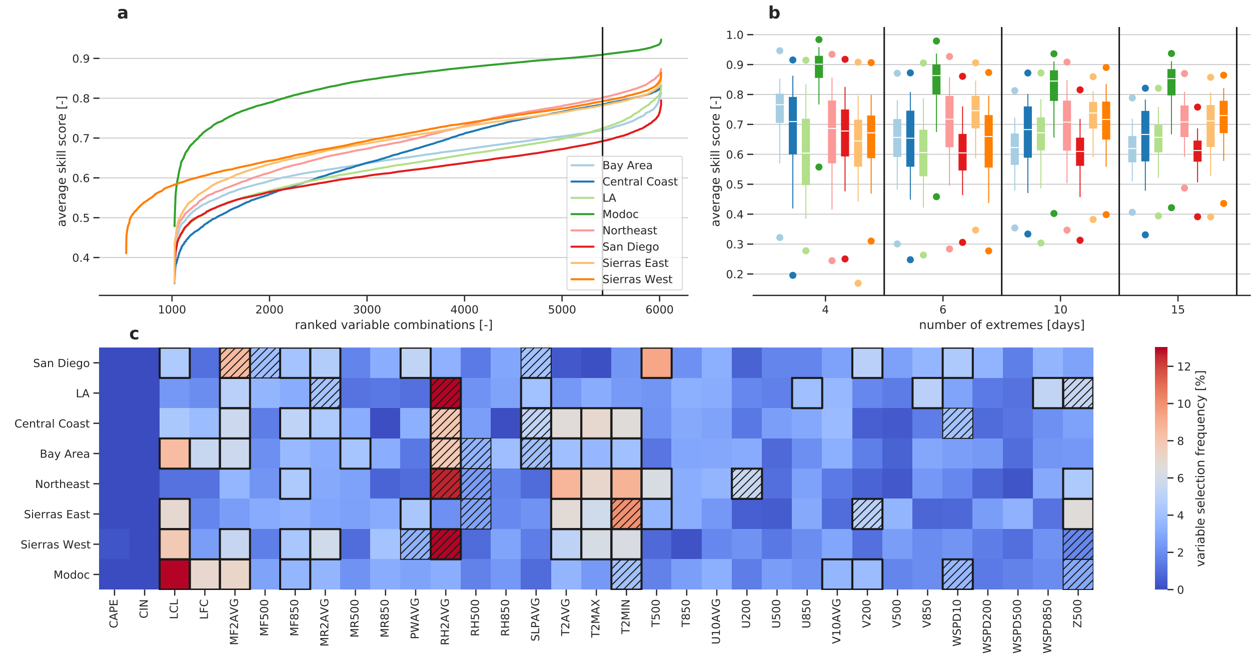

Figure S1: Optimization of the XWT in each of the 8 fire regions. a) Tested variable combination ranked according to their average split sample skill score (zero is perfect). The vertical line shows the 10th percentile of the best performing combinations. b) Box-whisker plots show the skill score spread according to the variable uncertainty. c) Probability frequency heatmap showing how often a variable was picked in the top 10 percent of the best performing variable combinations. The 8 variables that were selected most frequently in the top performing settings are highlighted in black boxes. These are the variables that were used in the testing shown in panel b. The variables that were used in the final XWT are hatched. The tested variables are (from left to right) convective available potential energy (CAPE), convective inhibition (CIN), lifting condensation level (LCL), level of free convection (LFC), moisture flux at 2 m (MF2AVG), 500 hPa (MF500), and 850 hPa (MF850), vapor mixing ratio 2 m (MR2AVG), 500 hPa (MR500), and 850 hPa (MR850), precipitable water (PWAVG), relative humidity at 2 m (RH2AVG), 500 hPa (RH500), and 850 hPa (RH850), sea level pressure (SLPAVG), 2 m average (T2AVG), maximum (T2MAX), and minimum (T2MIN) temperature, mean temperature at 500 hPa (T500), and 850 hPa (T850), zonal wind at 10 m (U10AVG), 200, hPa (U200), 500 hPa (U500), and 850 hPa (U850), meridional wind at 10 m (V10AVG), 200, hPa (V200), 500 hPa (V500), and 850 hPa (V850), wind speed at 10 m (WSPD10), 200, hPa (WSPD200), 500 hPa (WSPD500), and 850 hPa (WSPD850), and geopotential height at 500 hPa (Z500).

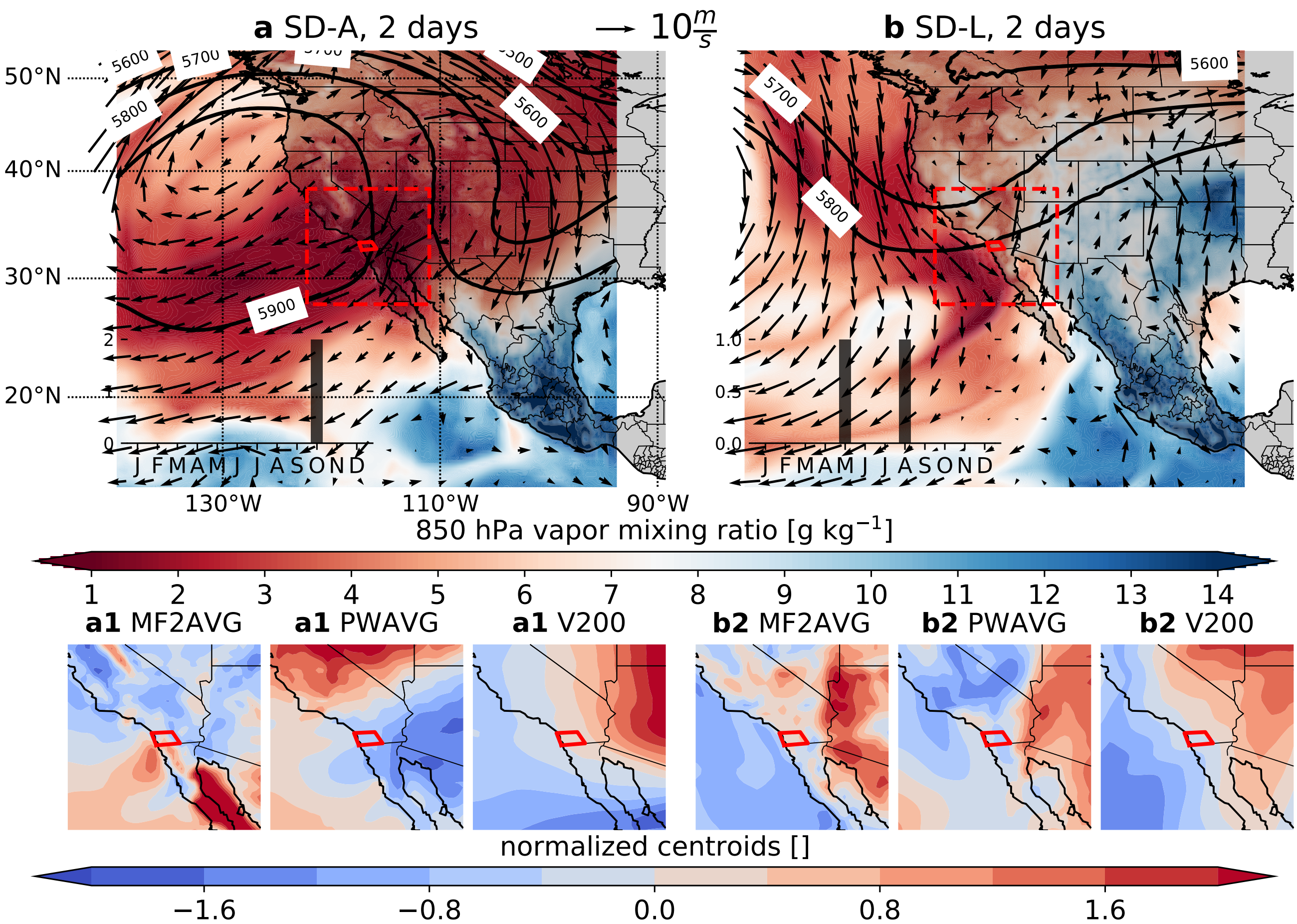

Figure S2: a,b) Two XWTs are identified in the San Diego region. SD-A is associated with strong Santa Ana winds that occur on the west-side of a mid-level trough causing very strong, dry offshore winds. SD-L is related to fires that develop under low-pressure anomalies (thermal lows) in the intermountain West causing onshore advection of moisture at mid-levels. The centroids of the three variables that characterize these XWTs are shown in (a1, b2). These variables are 2 m above ground moisture flux (MF2AVG), daily average precipitable water (PWAVG), and 200 hPa nothward wind speed.

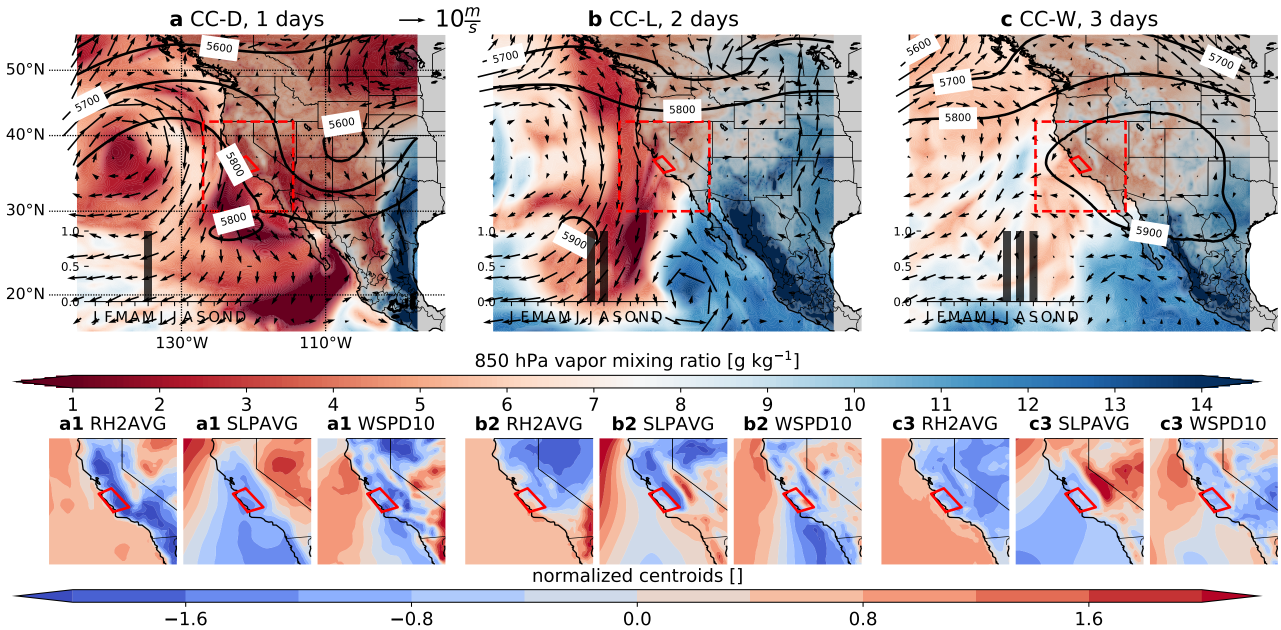

Figure S3: Similar to Supplementary Fig. S2 but showing the 3 identified XWTs in the Central Coast region. CC-D is associated with strong ridging in the west and Diablo Winds along the coast, CC-L features a thermal low and onshore wind advection, and CC-W is associated with weak large-scale forcing and is likely dominated by local scale processes. The XWT centroids are defined by daily average 2 m relative humidity (RH2AVG), sea level pressure (SLPAVG), and 10 m above ground wind speed (WSPD10).

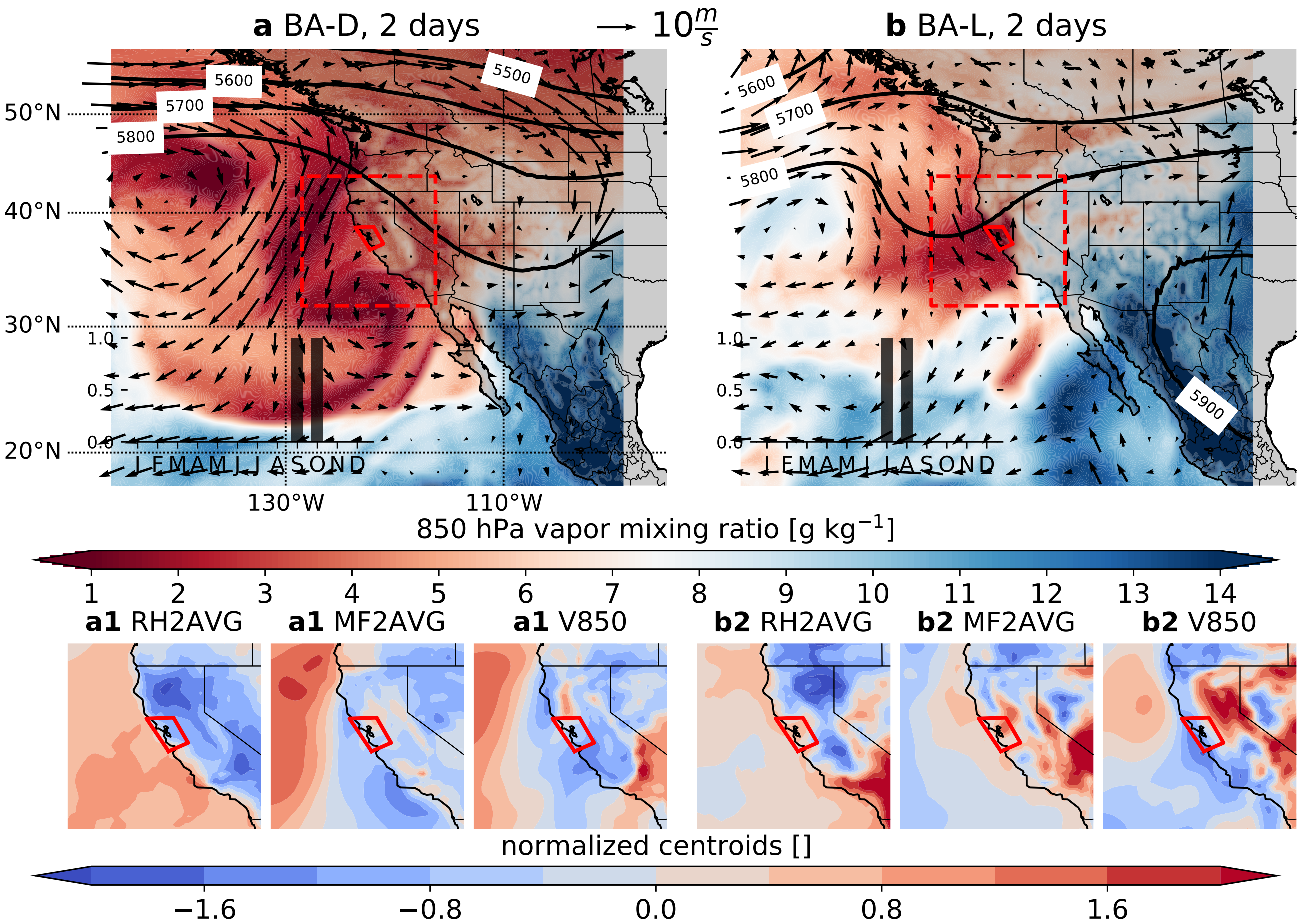

Figure S4: Similar to Supplementary Fig. S2 but showing the 2 identified XWTs in the Bay Area. BA-D is associated with strong offshore, Diablo winds, BA-L features a thermal low and onshore dry wind advection. The XWT centroids are defined by daily average 2 m relative humidity (RH2AVG), 2 above ground moisture flux (MF2AVG), and 850 hPa northward wind speed (V850).

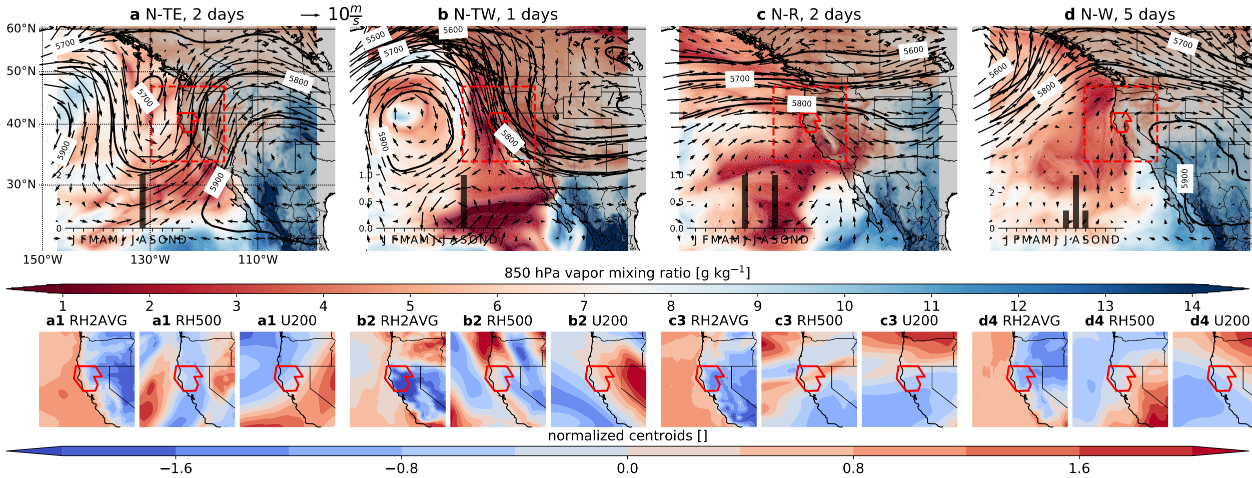

Figure S5: Similar to Supplementary Fig. S2 but showing the four identified XWTs in the Northern region. N-TE is associated with strong south westerly wind advection on the eastern side of a trough, N-TW features strong northerly winds on the western side of a trough, N-R is associated with westerly wind in a ridge, and N-W features northerly wind due to a high pressure ridge over the continent. The XWT centroids are defined by daily average 2 m and 500 hPa relative humidity (RH2AVG), and 200 hPa westward wind speed (U200).

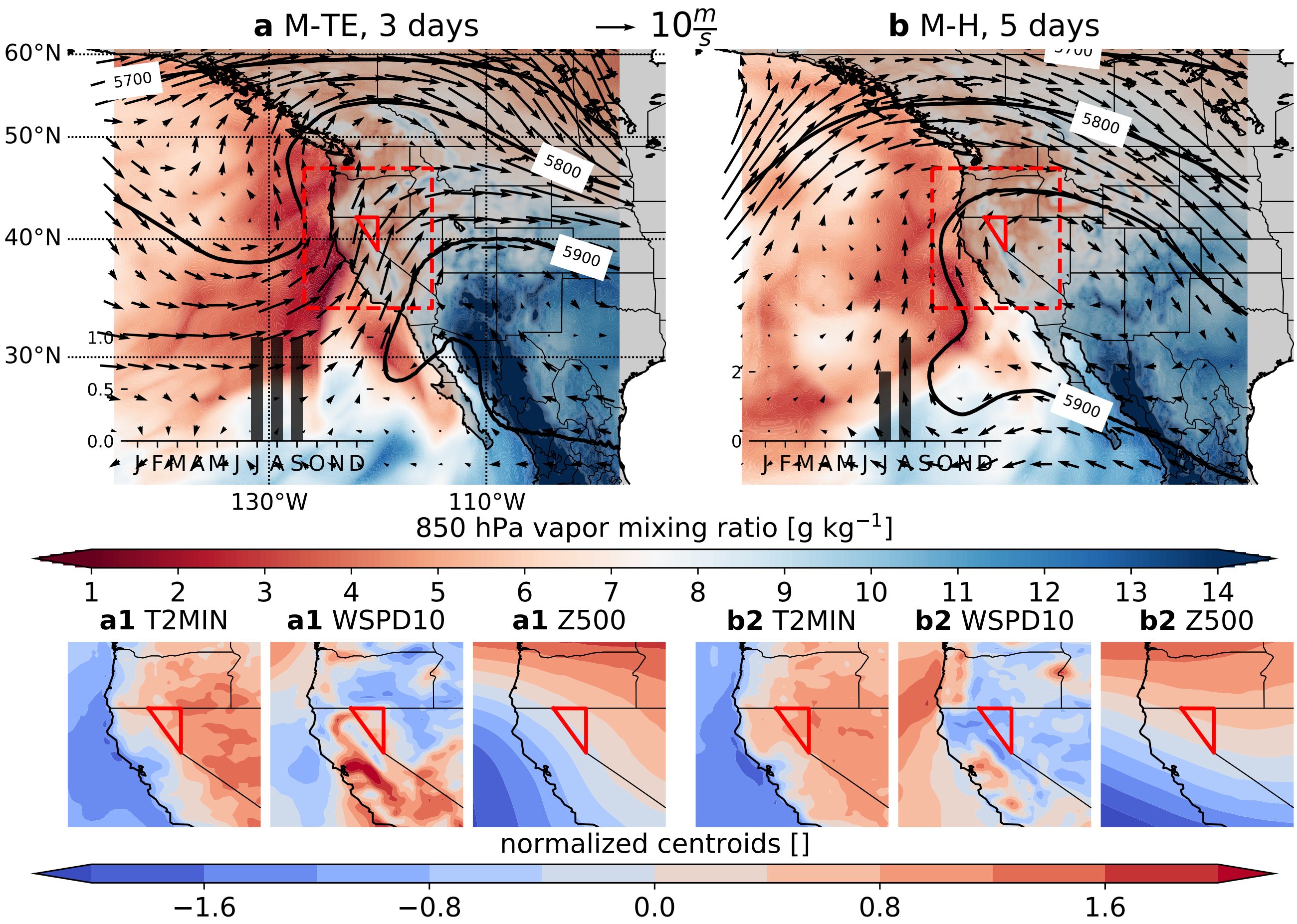

Figure S6: Similar to Supplementary Fig. S2 but showing the two identified XWTs in the Modoc region. M-TE is associated with strong south westerly winds on the eastern side of a trough, and M-H features anticyclonic circulation due to high pressure system over the intermountain west. The XWT centroids are defined by daily minimum 2 m air temperature (T2MIN), 10 m above ground wind speed (WSPD10), and 500 hPa geopotential heights (ZG500).

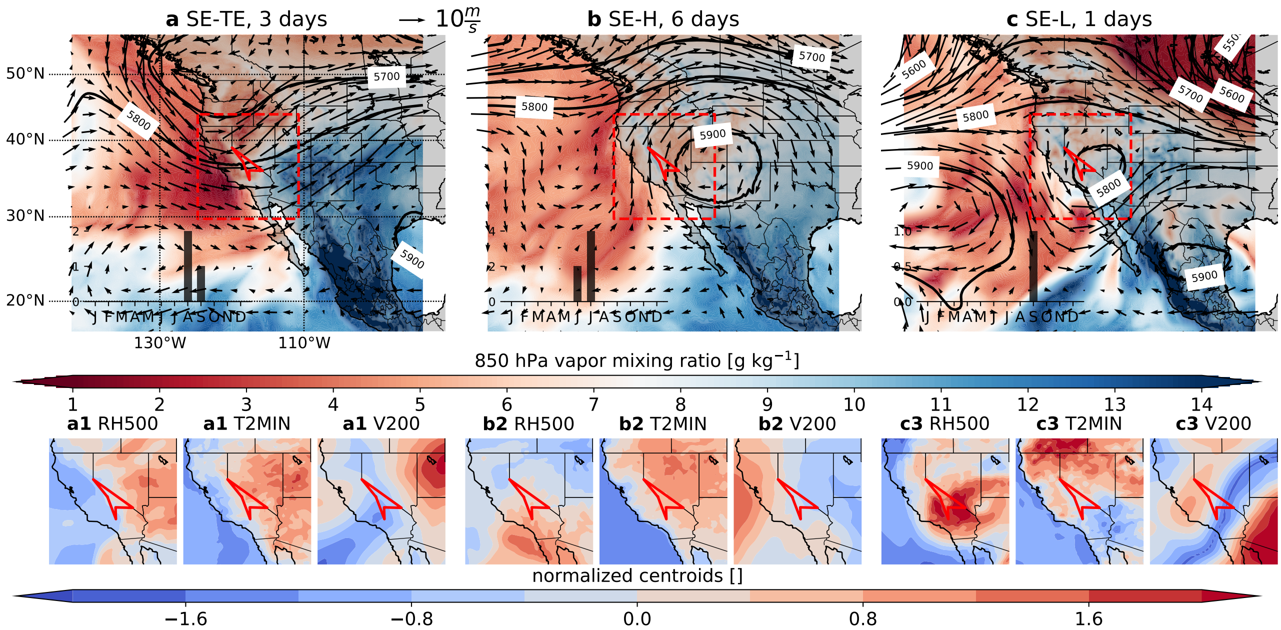

Figure S7: Similar to Supplementary Fig. S2 but showing the three identified XWTs in the Sierra East region. SE-TE is associated with strong westerly winds within a trough, SE-H features strong southerly winds caused by an anti-cyclone over the Four Corners Region, and SE-L is characterized by northerly winds caused by a cutoff low. The XWT centroids are defined by 500 hPa relative humidity (RH500), daily minimum air temperature (T2MIN), and 200 hPa northward wind speed (V200).

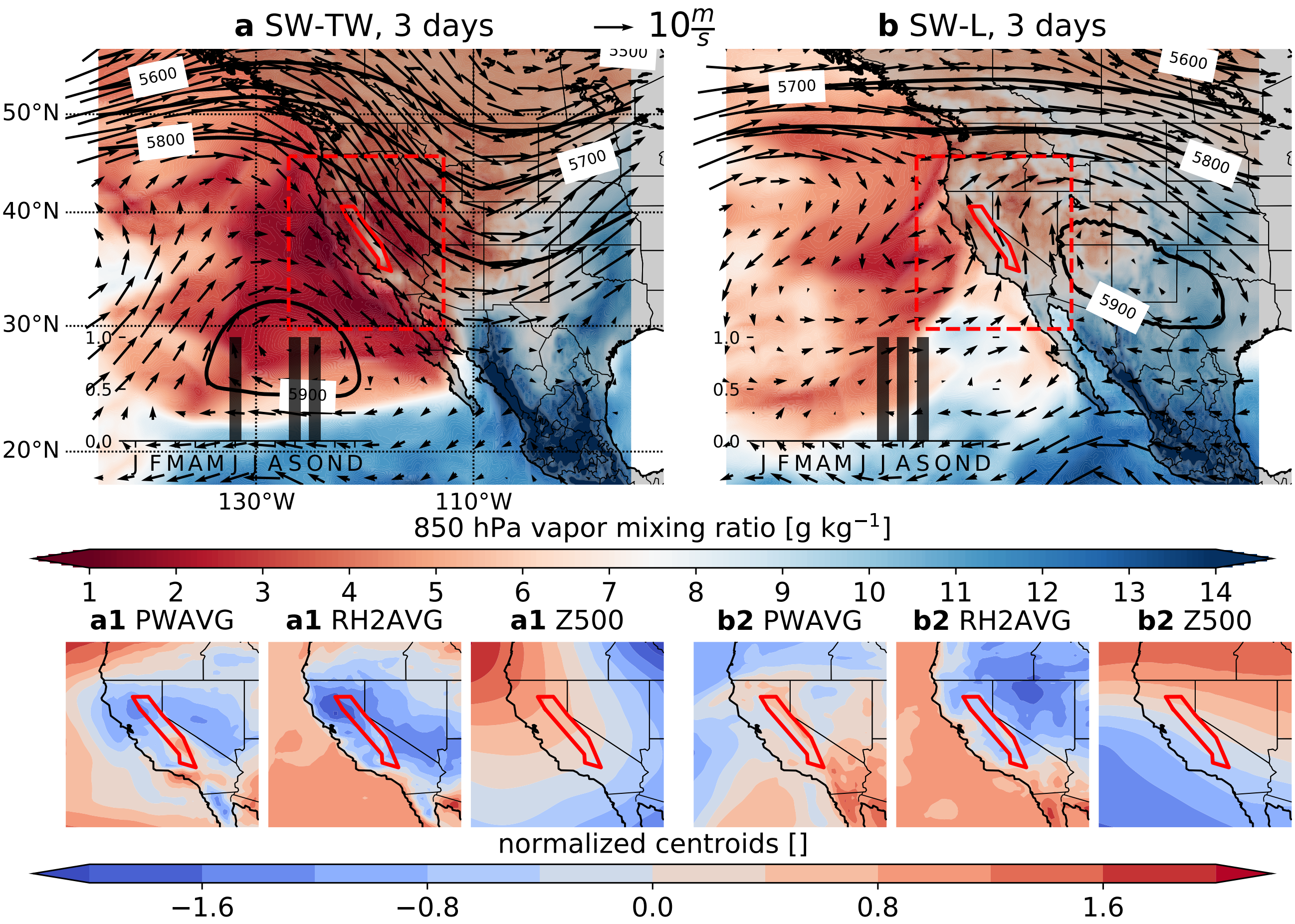

Figure S8: Similar to Supplementary Fig. S2 but showing the two identified XWTs in the Sierra West region. SW-TE is associated with strong northwesterly winds on the west-side of a trough, SW-L is characterized by northeasterly winds within a thermal low pressure system. The XWT centroids are defined by precipitable water (PWAVG), 2 m above gorund relative humidity (RH2AVG), and 500 hPa geopotential height (Z500).

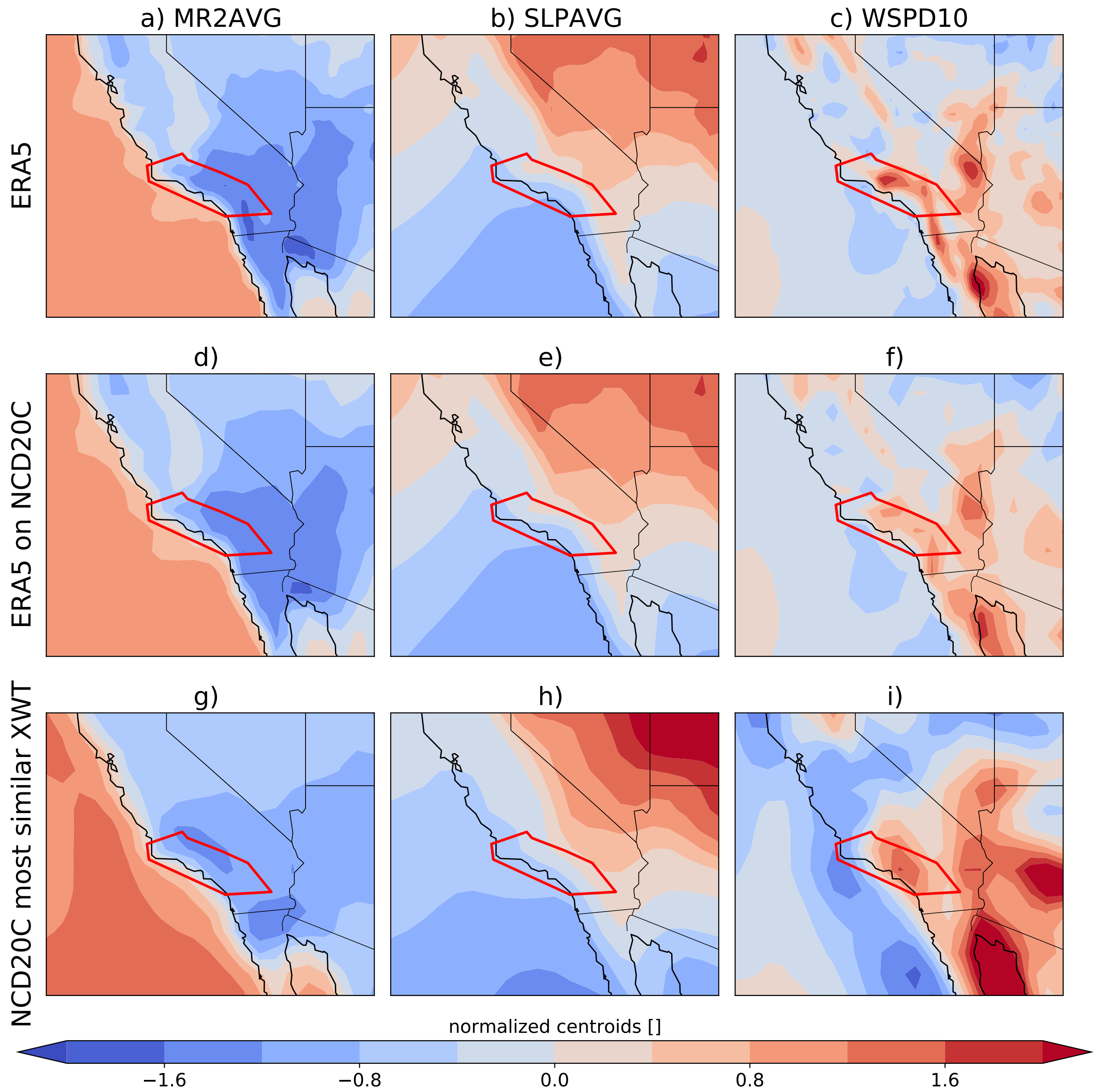

Figure S9: Example for detecting XWTs in the NOAA-CIRES-DOE 20th Century Reanalysis (NCD20C). The original LA-A XWT centroids (a–c) are regrided to the NCD20C grid (d–f). Euclidean distances are calculated between these patterns and all days in the NCD20C dataset. The normalized anomaly fields for the day with the lowest Euclidean distance (14.6 on October 20, 1904) is shown in (g–i).

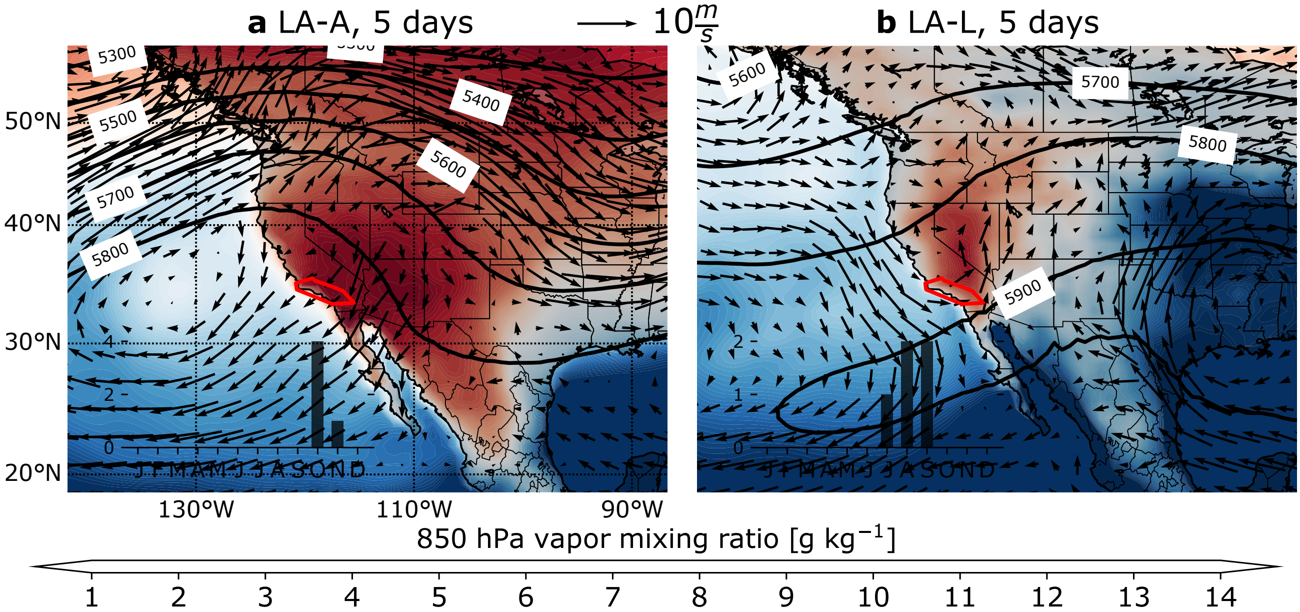

Figure S10: Average synoptic scale conditions for the five most similar days (lowest Euclidean distance) in the NCD20C member-1 compared to LA-A. The map shows the same variables as Fig. 2a,b except for the filled contour which shows Q2 instead Q850 since the latter is not available for NCD20C.

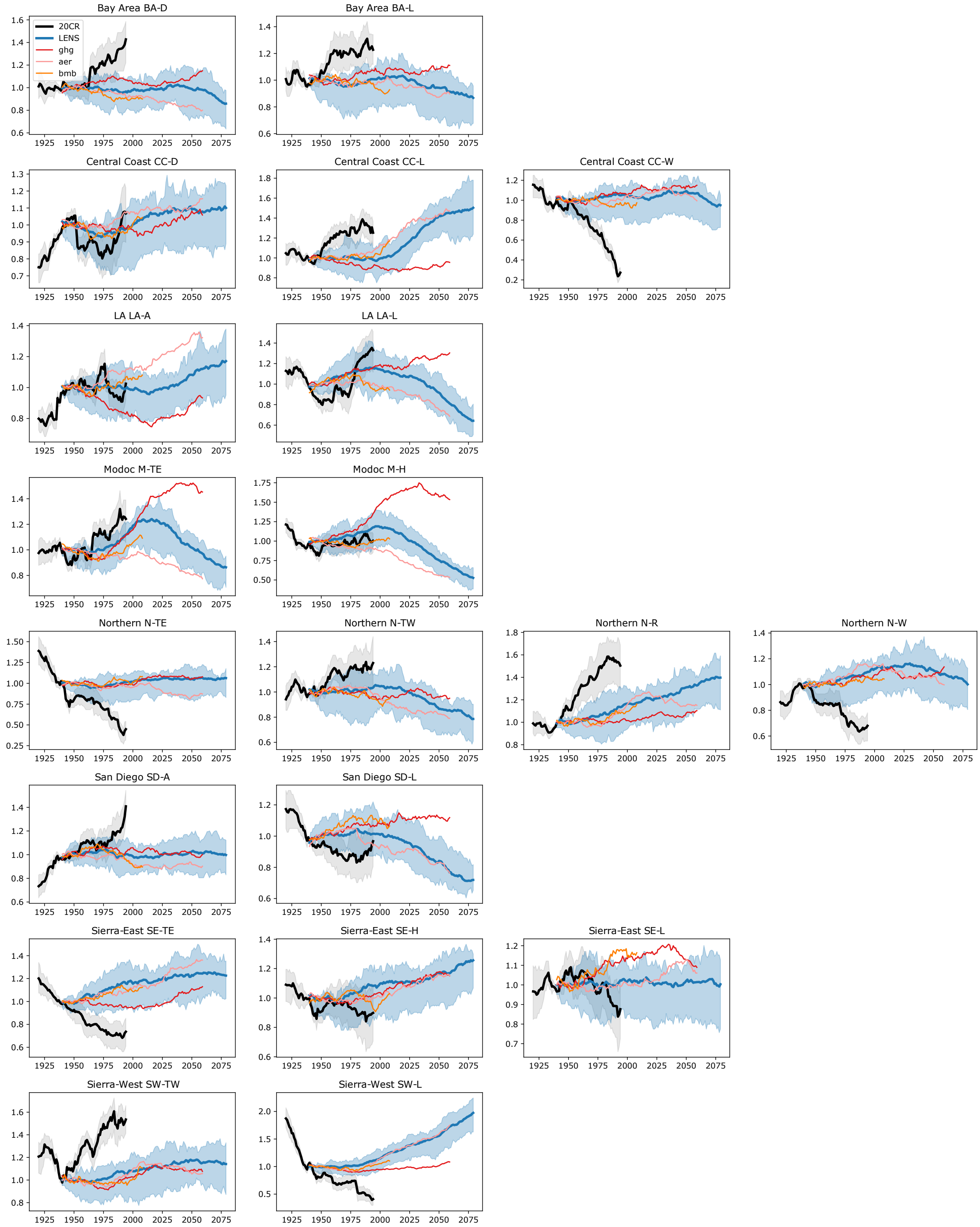

Figure S11: Frequency changes in the annual XWT event relative to the reference period 1975–2015. Shown are time series for each fire region (rows) and XWTs (columns) from the 20CR (black), LENS (blue), simulations without greenhouse gases changes (ghg; red), without aerosols changes (aer; pink), and without landsurface changes (bmb; orange). Thick lines show ensemble median changes. The interquantile ensemble spread is shown for the 20CR and LENS data (contours). All time series are low-pass filtered with a 40-year moving average filter.

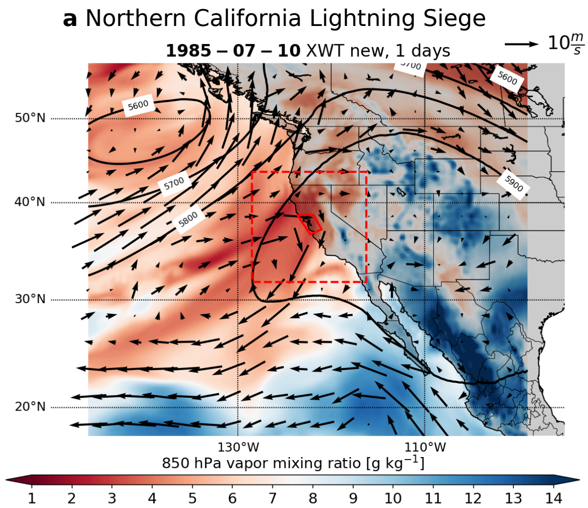

Figure S12: Occurrences of the new Bay Area XWT that was related to the record breaking daily burned area in August 2020. Similar conditions caused large burned areas during the Northern California Lightning Siege of 1985 (a) whereas the same pattern did not cause large burned areas during its occurrence in July 2018 likely due to a smaller number of active fires before its onset.

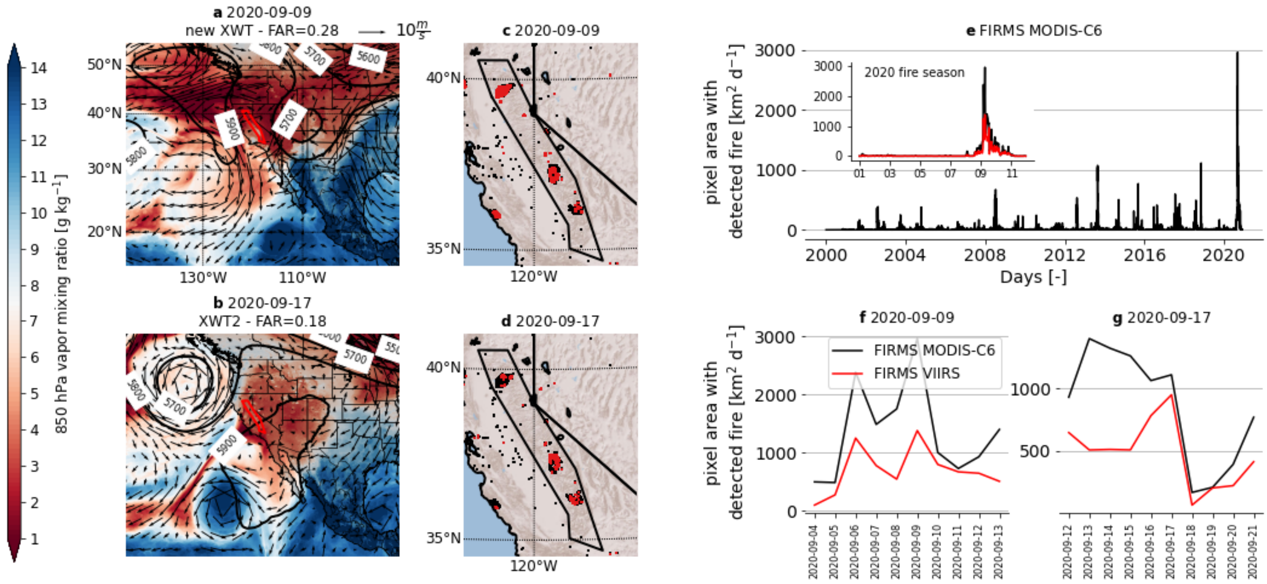

Figure S13: The record-breaking burned area on Aug. 9, 2020, in the Sierra West region was related to a so-far undetected XWT. (a,b) Large-scale weather pattern during the two days with the largest burned area of 2020 in the Sierra West region (a, Aug. 9; b, Aug. 17), based on IFS model analysis. The titles above the maps show the day, the associated XWT, and the false alarm ratio (FAR). (c,d) Pixels with detected fire for the largest fire days (red) and ± 9 days around this day based on VIIRS data (black). (e) Time series of daily pixel area with detected fires in the Sierra West region from the FIRMS MODIS-C6 data. (f,g) Zoom into the time period with the two fire outbreaks showing the MODIS-C6 (black) and VIIRS (red) data.