6.9 CREATING A LIGHTNING MOS FOR SUMMER IN SOUTHWESTERN CALIFORNIA AND EXTREME NORTHERN BAJA CALIFORNIA

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1. Introduction

Summer thunderstorms occur every year over the mountains and deserts of southern California and extreme northern Baja California. These typically occur when high pressure aloft moves north from Mexico into the southwestern United States and results in moisture central and southern Mexico moving north into the southwestern United States and Baja California, Mexico. This is a western extension of the North American Monsoon, centered over Arizona and Sonora. During the summers of 2005 and 2006, there was an average of 26 days where at least one lightning strike occurred over southwestern California (shown in purple in Figure 1) and an average of 34 days over extreme northern Baja California (shown in red in Figure 1). Approximately 29,000 lightning strikes occurred over southwestern California and extreme northern Baja California during summer 2005 (Figure 2), while nearly 16,000 lightning strikes occurred during summer 2006 (Figure 3). This averages approximately one lightning strike every 2 square kilometers per summer. However, the lightning strike distribution is very uneven. Most of the lightning strikes occurred in mountain and high desert terrain, with the high deserts of the Apple and Lucerne Valleys (California Zone 60) and the mountains of northern Baja California (“Zone 98”) receiving the greatest frequencies of lightning where local areas exceeded 5 lightning strikes per square kilometer per summer.

Most of the lightning occurred during the afternoon due to convection which forms from daytime heating. This was especially the case over the mountains, since very unstable conditions normally occur there due to heating of an elevated surface. However, lightning occasionally occurred at other times of day or night when an easterly wave moves west or northwest over southern California or northern Baja California or other dynamics (often mesoscale) play a role. The largest negative impact of lightning in this region is fires. Since evapotranspiration exceeds precipitation in southwestern California and northern Baja California during summer (even with the thunderstorms, which typically have small cores), vegetation is very dry and burns rapidly. Lightning started the Coyote Fire in San Diego County in July 2003 which burned 18,000 acres (73 square kilometers).

2. Development of Lightning MOS

Model Output Statistics (MOS) have been developed, at least rudimentarily (since more years of data will be needed for a reliable MOS), for the sections of the study area with the greatest frequency of lightning. This includes the San Bernardino County Mountains (Zone 55), the San Diego County Mountains (Zone 58), the Apple and Lucerne Valleys (Zone 60) and the mountains of northern Baja California (fictional Zone 98).

The probability of lightning in a 24-hour period (defined as 1200 UTC to 1200 UTC the following day) has been determined based on variables from the1200 UTC model runs of the GFS model from the summers of 2005 and 2006. Statistics have been collected for the NAM; however, due to NAM’s change from the Eta to the WRF between 2005 and 2006 and better performance of relative humidity in the GFS relative to the NAM in 2006, GFS has been used in the MOS presented here. The model variables which correlated most strongly with the occurrence of lightning included:

1. 600-700-mb Average Relative Humidity
2. Surface Convective Available Potential Energy (CAPE)
3. 600-mb Wind Direction (Easterly Wind)

These model variables will appear in the “Category MOS” tables, based on ranges of values for the 3 variables. Other variables which could be promising for MOS included 600-mb wind velocity (negative correlations; lower wind velocities result in greater likelihood of lightning) and surface pressure gradients (albeit over western Arizona and probably due to movement of the thermal trough, which might already be accounted for by CAPE). In all cases, 6-hourly

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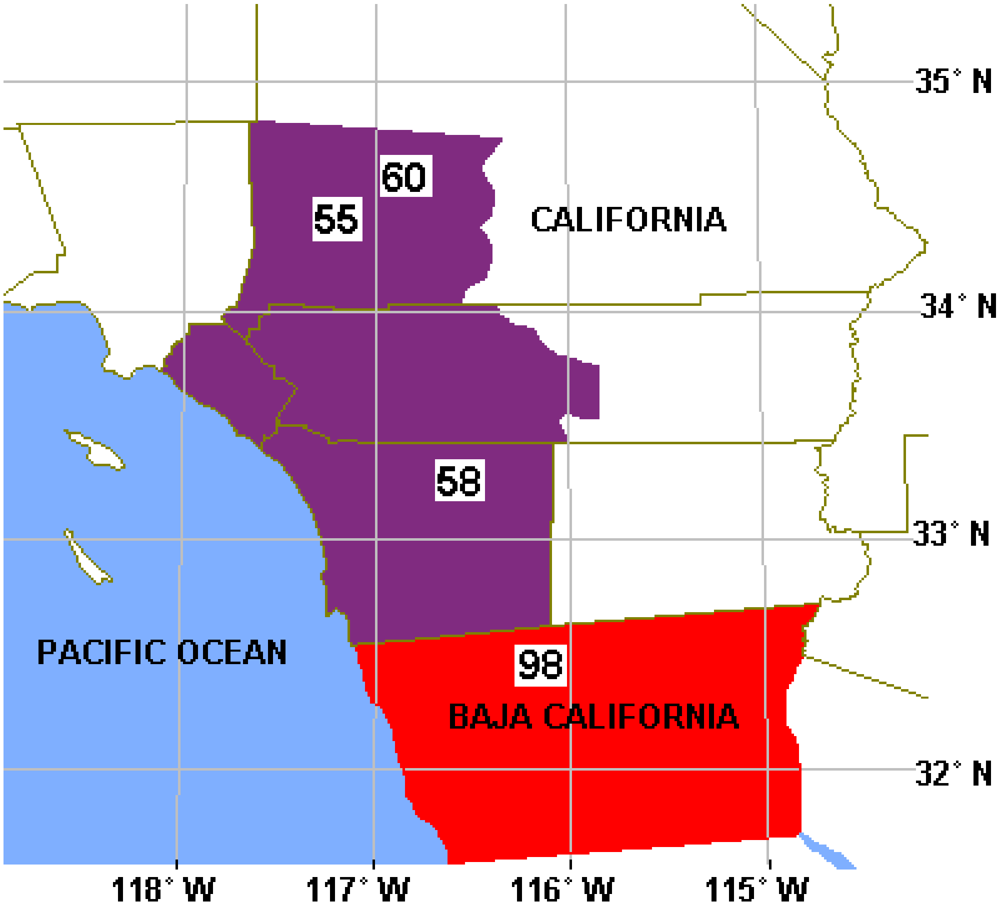


Figure 1: Domain of the Lightning MOS study. The purple area consists of the San Diego National Weather Service Forecast Office (NWSFO) County Warning and Forecast Area (CWFA), and the red area consists of the section of northern Baja California included in this study. National Weather Service zone numbers (plus the fictional "Zone 98" for the Northern Baja California mountains) are posted in their approximate locations. Latitudes and longitudes are included since these will be referenced for model output.

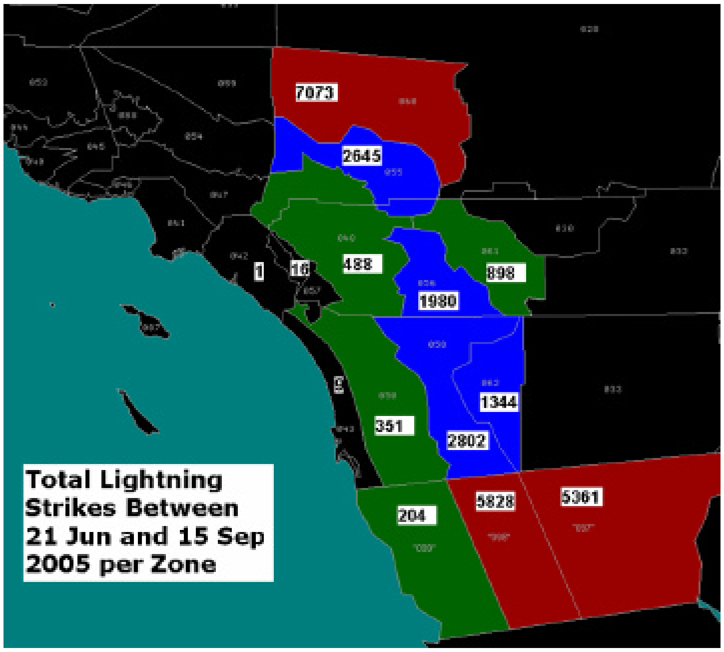


Figure 2: Total number of lightning strikes by forecast zone (including fictional northern Baja California zones) during the summer of 2005. The period of data is from 21 June through 15 September

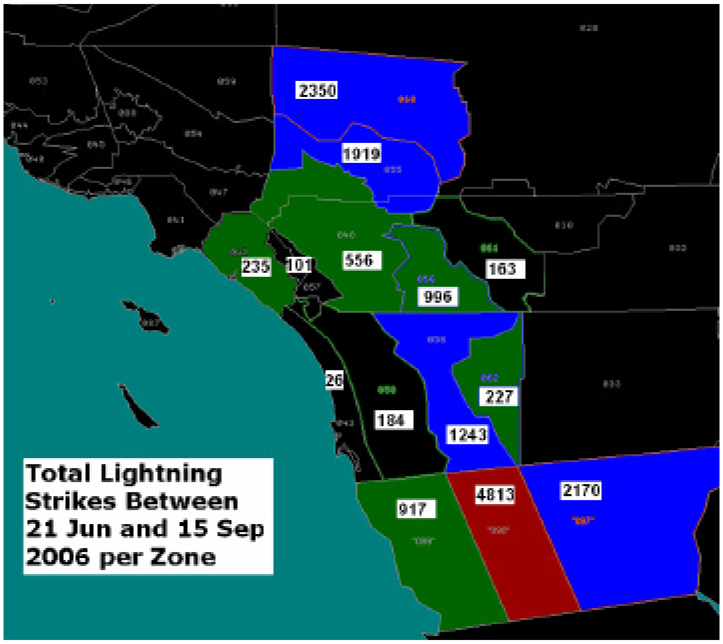


Figure 3: Same as Figure 2, except for 2006.

prognosis were used (1800 UTC output from the1200 UTC model run), but other hours will likely be explored in the future.

The locations of the output from GFS were not necessarily directly over the zone affected by the lightning. While relative humidity values near the zone usually correlated best with lightning frequency for that zone (versus values further away), CAPE and wind values about 100 kilometers east of the zone correlate best. There are at least two possible reasons. First, during the summer monsoon, there is often a low-level surge of moisture over the deserts from the Gulf of California, and this is reflected better by the CAPE over the deserts than the mountains. Second, winds aloft are more steady and indicative of the synoptic pattern over lower terrain than over the mountains, where mesoscale influences are more likely seen over the mountains.

Some model variables were attempted for the MOS, but without success. Since the models typically have difficulty depicting the mechanisms behind the Gulf of California moisture surges into the desert such as low-level (950-mb and 900-mb) temperature gradients and surface pressure gradients across the Gulf of California, those variables did not correlate with lightning over southwestern California or northern Baja California and could not be used in the MOS.

3. MOS Tables

Because the statistics have been collected for only 2 years, linear regression techniques have not yet been applied. Therefore, tables are created based on intervals of the variables. Relative humidity values are split between “low”, “medium” and “high”, where low values are less than 50 percent, medium values are between 50 and 70 percent and high values are greater than 70 percent for all zones. CAPE values are likewise split between the same three categories, but the threshold values between the categories vary (but are usually 100 and 1000 J kg^{-1}). Wind values are split between two categories, easterly versus westerly, but the breakpoints are not always 180? (south) and 360? (north) as they can deviate slightly; for example, 196? and 336? are the breakpoints for Zone 60 (Apple and Lucerne Valleys) because when the 600-mb wind used for that zone (from 34? N, 115? W) is southerly or northerly, thunderstorms are almost as frequent as with an easterly wind.

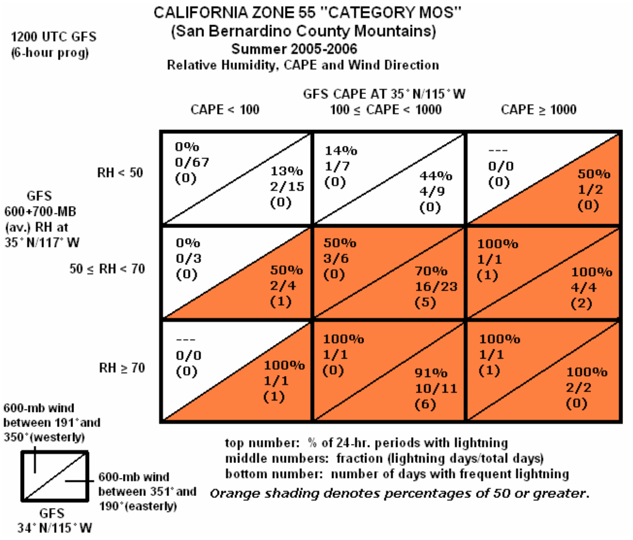
The tables are shown below in Figures 4 through 7. Within each box, CAPE is on the x-axis (higher values to the right), and relative humidity is on the y-axis (higher values to the bottom). Within each smaller box is a diagonal line, which splits westerly winds (upper-left diagonal) with easterly winds (lower-right diagonal). Within each segment in the boxes are the percentage chances of lightning in the 24-hour period, the fraction (lightning days/total days) and the number of days with frequent lightning (defined as 100 strikes or more in a zone).

For California Zone 55 (San Bernardino County Mountains, Figure 4), the probability of lightning was much greater for CAPE values at 35? N, 115? W of at least 100 J kg^{-1} (66 percent) than less than 100 J kg^{-1} (6 percent). For model values greater than 1000 J kg^{-1}, that probability increased to 90 percent. Note that the GFS values for CAPE are usually less than the actual values for CAPE (and values in the NAM), so while values of 100 J kg^{-1} might seem insubstantial, they can occur in GFS with thunderstorms in the region. For lightning, the 50-percent threshold was important for the 600-700-mb average relative humidity at 35? N, 117? W, as the probability was 8 percent for lower values versus 60 percent for higher values. For 600-mb wind at 34? N, 115? W, the westerly winds were associated with an 8- percent probability of lightning, while easterly (plus some northerly and southerly winds) resulted in a 59-percent probability.

The cases with GFS CAPE greater than 1000 J kg^{-1} and 600-700-mb RH being greater than 50 percent always resulted in lightning, regardless of the wind direction. However, only 8 days had this scenario in the summers of 2005 and 2006, and more data will be needed to reliably suggest a 100% chance of lightning with these weather elements.

For frequent lightning (in parentheses in the graphic) where 100 or more strikes occurred in a zone, the relationship was not as strong, partly because there were fewer days when frequent lightning occurred (about 1/6th of the lightning cases were “frequent lightning”).

Figures 5 through 7 (for the San Diego County Mountains, Apple and Lucerne Valleys and northern Baja California Mountains, respectively) show similar results, where higher values of CAPE and relative humidity and easterly winds were associated with a greater probability of lightning. The CAPE thresholds were lower for the northern



CALIFORNIA ZONE 55 "CATEGORY MOS"
(San Bernardino County Mountains)
Summer 2005-2006
Relative Humidity, CAPE and Wind Direction

1200 UTC GFS
(6-hour prog)

GFS CAPE AT 35°N/115°W

GFS 600+700-MB (av.) RH at 35°N/117°W

	CAPE < 100	100 ≤ CAPE < 1000	CAPE ≥ 1000
RH < 50	0% 0/67 (0) 13% 2/15 (0)	14% 1/7 (0) 44% 4/9 (0)	--- 0/0 (0) 50% 1/2 (0)
50 ≤ RH < 70	0% 0/3 (0) 50% 2/4 (1)	50% 3/6 (0) 70% 16/23 (5)	100% 1/1 (1) 100% 4/4 (2)
RH ≥ 70	--- 0/0 (0) 100% 1/1 (1)	100% 1/1 (0) 91% 10/11 (6)	100% 1/1 (1) 100% 2/2 (0)

600-mb wind between 191° and 350° (westerly)

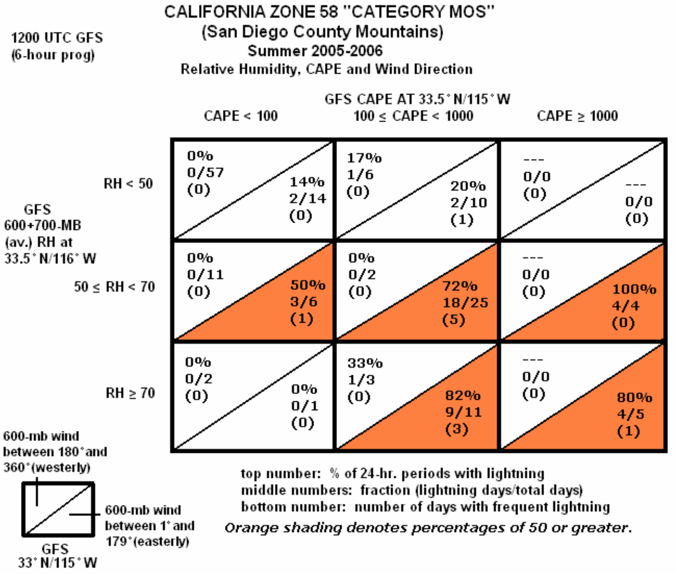
600-mb wind between 351° and 190° (easterly)

GFS
34°N/115°W

top number: % of 24-hr. periods with lightning
middle numbers: fraction (lightning days/total days)
bottom number: number of days with frequent lightning

Orange shading denotes percentages of 50 or greater.

Figure 4: Table of probabilities for lightning based on GFS surface cape, 600-700-mb relative humidity and 600-mb wind direction at 1800 UTC (based on 1200 UTC model run) for California Zone 55 (San Bernardino County Mountains).



CALIFORNIA ZONE 58 "CATEGORY MOS"
(San Diego County Mountains)
Summer 2005-2006
Relative Humidity, CAPE and Wind Direction

1200 UTC GFS
(6-hour prog)

GFS CAPE AT 33.5°N/115°W

GFS 600+700-MB (av.) RH at 33.5°N/116°W

	CAPE < 100	100 ≤ CAPE < 1000	CAPE ≥ 1000
RH < 50	0% 0/57 (0) 14% 2/14 (0)	17% 1/6 (0) 20% 2/10 (1)	--- 0/0 (0) --- 0/0 (0)
50 ≤ RH < 70	0% 0/11 (0) 50% 3/6 (1)	0% 0/2 (0) 72% 18/25 (5)	--- 0/0 (0) 100% 4/4 (0)
RH ≥ 70	0% 0/2 (0) 0% 0/1 (0)	33% 1/3 (0) 82% 9/11 (3)	--- 0/0 (0) 80% 4/5 (1)

600-mb wind between 180° and 360° (westerly)

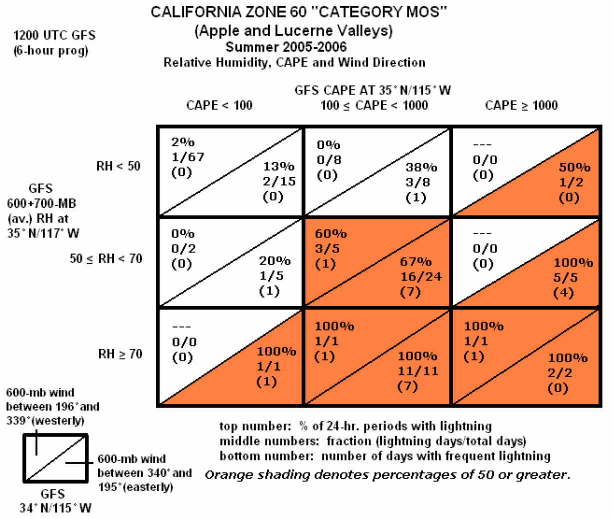
600-mb wind between 1° and 179° (easterly)

GFS
33°N/115°W

top number: % of 24-hr. periods with lightning
middle numbers: fraction (lightning days/total days)
bottom number: number of days with frequent lightning

Orange shading denotes percentages of 50 or greater.

Figure 5: Same as Figure 4, except for California Zone 58 (San Diego County Mountains).



CALIFORNIA ZONE 60 "CATEGORY MOS"
(Apple and Lucerne Valleys)
Summer 2005-2006
Relative Humidity, CAPE and Wind Direction

1200 UTC GFS
(6-hour prog)

GFS CAPE AT 35° N/115° W

GFS 600+700-MB (av.) RH at 35° N/117° W

	CAPE < 100	100 ≤ CAPE < 1000	CAPE ≥ 1000
RH < 50	2% 1/67 (0) 13% 2/15 (0)	0% 0/8 (0) 38% 3/8 (1)	--- 0/0 (0) 50% 1/2 (0)
50 ≤ RH < 70	0% 0/2 (0) 20% 1/5 (1)	60% 3/5 (1) 67% 16/24 (7)	--- 0/0 (0) 100% 5/5 (4)
RH ≥ 70	--- 0/0 (0) 100% 1/1 (1)	100% 1/1 (1) 100% 11/11 (7)	100% 1/1 (1) 100% 2/2 (0)

600-mb wind between 196° and 339° (westerly)

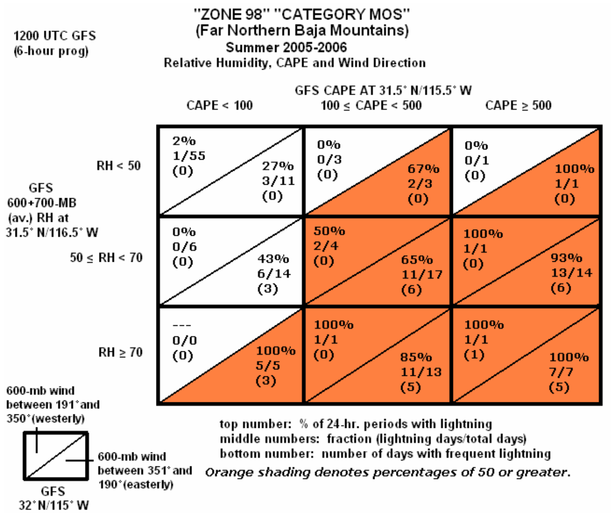
600-mb wind between 340° and 195° (easterly)

GFS 34° N/115° W

top number: % of 24-hr. periods with lightning
middle numbers: fraction (lightning days/total days)
bottom number: number of days with frequent lightning

Orange shading denotes percentages of 50 or greater.

Figure 6: Same as Figure 4, except for California Zone 60 (Apple and Lucerne Valleys).



"ZONE 98" "CATEGORY MOS"
(Far Northern Baja Mountains)
Summer 2005-2006
Relative Humidity, CAPE and Wind Direction

1200 UTC GFS
(6-hour prog)

GFS CAPE AT 31.5° N/115.5° W

GFS 600+700-MB (av.) RH at 31.5° N/116.5° W

	CAPE < 100	100 ≤ CAPE < 500	CAPE ≥ 500
RH < 50	2% 1/55 (0) 27% 3/11 (0)	0% 0/3 (0) 67% 2/3 (0)	0% 0/1 (0) 100% 1/1 (0)
50 ≤ RH < 70	0% 0/6 (0) 43% 6/14 (3)	50% 2/4 (0) 65% 11/17 (6)	100% 1/1 (0) 93% 13/14 (6)
RH ≥ 70	--- 0/0 (0) 100% 5/5 (3)	100% 1/1 (0) 85% 11/13 (5)	100% 1/1 (1) 100% 7/7 (5)

600-mb wind between 191° and 350° (westerly)

600-mb wind between 351° and 190° (easterly)

GFS 32° N/115° W

top number: % of 24-hr. periods with lightning
middle numbers: fraction (lightning days/total days)
bottom number: number of days with frequent lightning

Orange shading denotes percentages of 50 or greater.

Figure 7: Same as Figure 4, except for "Zone 98" (Northern Baja California Mountains).

Baja California Mountains because the location used for the CAPE that best correlated with lightning typically had lower values than the locations used for CAPE for the other zones.

4. Conclusions

When more detail is available in a few years, lightning MOS could become very useful for forecasters in southwestern California during the summer monsoon. The MOS over northern Baja California could potentially be useful to Mexican weather forecasters (whether or not that comes true, the Baja California MOS can help southwestern California forecasters anticipate the onset of the monsoon, which usually arrives from the southeast). Linear regression should be available by then for 600-700-mb relative humidity, surface CAPE, 600-mb wind direction and likely the 600-mb wind speed to create a MOS which will be pragmatic for a variety of conditions. However, MOS will have its limitations; if the model is imperfect, then the MOS will also be imperfect. Also, while the relationships between these variables and whether or not lightning occurred were strong, those between these same variables and lightning frequency were somewhat less strong.