Lightning Climatology for the WFO Los Angeles/Oxnard, California County Warning Area

Jamie Meier and Richard Thompson

National Weather Service Forecast Office

Los Angeles/Oxnard, CA

Introduction

This paper documents cloud-to-ground (CG) lightning activity over the county warning area (CWA) of the National Weather Service Weather Forecast Office (WFO) in Los Angeles/Oxnard (LOX). The area studied encompasses San Luis Obispo, Santa Barbara, Ventura, and Los Angeles counties of California. In order to create a lightning climatology of the area, twenty-two years of CG lightning flashes were used, from 1987 to 2008. The analysis presents the spatial distribution of cloud-to-ground flashes over the county warning area. Specifically, the annual, seasonal, and diurnal distribution of lightning flashes was investigated, as well as the charge distribution. Possible causes for these distributions are also discussed. As lightning is the cause for almost 60% of all forest fires in the western United States (Rorig and Ferguson 2002), understanding its behavior and distribution is important within fire-weather forecasting.

Data Source

Lightning flash information used in this paper was obtained from the National Lightning Detection Network (NLDN), with equipment maintained by Vaisala. The network is comprised of 106 sensors across the United States (Orville 2008), and records each individual cloud-to-ground stroke of lightning with a temporal resolution of 1 millisecond, and a spatial resolution of 500 m^2. In addition, the flash current (i.e., the charge, negative or positive), multiplicity (number of return strokes per flash), and number of detectors observing a flash are recorded. While data are available back to 1986, our study truncated this to 1987 due to a lack of completeness in data from 1986.

It is important to note that detection efficiency of the network has improved significantly over the past twenty-five years, starting with a detection rate of a mere 60-80% of total CG flashes in the late ‘80s, to a current detection rate of over 99% of total CG flashes. This makes strict year-to-year comparisons difficult, but still allows for overall comparisons in trends.

Geographic Overview

The WFO LOX county warning area presents some of the most dramatically varied topography in the United States. Within the span of 20 to 30 miles, the elevation can rise from sea level to over 8,000 feet, as seen in Figure 1. This stark contrast in topography has a significant influence upon the weather, including thunderstorm formation. In addition, the proximity to the cold Pacific Ocean waters limits thunderstorm activity along the coast, while moisture intrusion from Mexico and the southwestern states can enhance thunderstorms over the mountains and deserts.

Figure 2 shows the four coastal counties that constitute the WFO LOX area of responsibility. From north to south, this includes the counties of San Luis Obispo, Santa Barbara, Ventura, and Los Angeles. Figure 2 also outlines some of the more significant mountain ranges located within each county, each of which help to shape seasonal storm and precipitation patterns. In San Luis Obispo County, the largest mountain range is the Santa Lucia range, whose tallest peaks top out at around 5,000 feet. In Santa Barbara County, there are three major ranges: the Santa Ynez range, the San Rafael range, and the Sierra Madre range. The Santa Ynez range, which tops out at around 4500 feet, runs east-west across the southern portion of the county, a mere 5 to 10 miles from the coastline. The San Rafael and Sierra Madre ranges run northwest-southeast across the interior portion of the county, and have highest peaks over 6,000 feet. Across Ventura County, there are numerous small ranges which are collectively referred to as the Western Transverse ranges, with some peaks over 8,000 feet. Across Los Angeles County, the two major mountain ranges are the Santa Monica Mountains, which run east-west just north of Malibu, and the San Gabriel Mountains, which run northwest to southeast through the interior portion of the county. The highest peaks in the San Gabriel range are the highest in the CWA, with peaks over 10,000 feet.

The Antelope Valley, in the northeast corner of Los Angeles County, contains the highest non-mountain elevations in the county, generally ranging between 2,500 and 3,500 feet. As this is on the leeward side of the San Gabriel range, the Antelope Valley is highly rain-shadowed in the general westerly flow that occurs for most of the year. It does, however, have one of the highest incident rates for flash flooding during the late summer months.

Analysis of Lightning Data

Annual

Figure 3 shows the mean annual flash density across the WFO LOX county warning area. It is immediately evident that the highest flash density is observed over the mountains, as well as eastern sections of the Antelope Valley. These lightning “hot spots” can be further pinpointed as the eastern San Gabriel Range, far eastern sections of the Antelope Valley, and the Mount Pinos area in northern Ventura County.

The cause for these “hot spots” has been rather well-established. The high-elevation mountain terrain lies above the very stable marine inversion that dominates the coastal and valley areas south and west of the mountains. This area of decreased stability is often a focus for convective initiation. Additionally, the mountainous areas are more readily influenced by the summertime monsoon pattern which increases the atmospheric moisture and instability. This monsoon pattern will be discussed in further detail in the seasonal breakdown.

The likely major contributor for the hot spot in the eastern Antelope Valley is the phenomenon known as the Eastern Antelope Valley Eddy (EAVE, Danielson 2004). The EAVE is a lee-side eddy that develops along the convergence line from the westerly sea breeze winds that pass through the San Gabriel Mountains, and the southerly sea breeze that moves through the Cajon Pass. As these winds converge, an eddy circulation is formed, pooling available low level moisture and in turn enhancing thunderstorm development under sufficient instability.

One area of note is the flash density maximum over south-central Los Angeles County. The main contributor to this small bulls-eye was a single convective event that occurred on November 12, 2003. A nearly-stationary thunderstorm formed during the afternoon hours over the Watts area, producing 5 inches of rainfall in less than two hours and several inches of small hail accumulation. During the time period from 20Z on November 12th to 03Z on November 13th, 382 lightning flashes were recorded over the area (Fig. 4). This 7 hour period produced six times the amount of lightning that, on average, occurs during the entire month of November.

Seasonal

Figures 5a through 5d show the seasonal variations in flash density across the WFO LOX county warning area. Easily seen is a very distinct maximum in lightning activity occurring during summer (Fig. 5c), decreased activity in the fall (Fig. 5d), and a sharp minimum during the winter and spring (Figs. 5a and 5b, respectively).

During the summer months, the mountains and the Antelope Valley show the greatest flash density across the area. As mentioned previously, these maximums are due to the summertime monsoon and the EAVE. The monsoon pattern sets up over the area as a ridge of high pressure aloft develops over the Four Corners region of the desert Southwest (Small and Dandrea 2006). Southeast to south flow around the center of this high pressure system can funnel tropical moisture from Mexico and the Gulf of Mexico, which often spawns summertime convection over those areas. Oftentimes this tropical moisture takes the form of tropical storm remnants, which Garza et al (1999) found affect the area on average at least once per year. When this moisture interacts with an unstable air mass over higher terrain, thunderstorms can, and often do, develop. Given the weak southerly atmospheric flow, the majority of thunderstorms that develop do not drift over the coastal and valley regions, but rather intensify over the mountains and end up drifting north and northeastward into the Antelope Valley and Mojave Desert. A further investigation notes that, on average, two-thirds of the lightning that occurs over the LOX area of responsibility occurs during the “monsoon season”, which is commonly accepted as the months of July, August, and September. Figure 6 shows the flash density for this period, which is most pronounced over the mountains and Antelope Valley.

During the winter and spring (Figs. 5a and 5b, respectively), the lack of lightning activity can be surprising to some, as this is when Southern California receives its most significant rainfall. The characteristics of winter and spring precipitation in Southern California can explain the lack of lightning activity. A majority of the rainfall events during this time period are stratiform variety, the result of deep, cold-core, upper-level low pressure systems traveling down the coast from as far north as the Gulf of Alaska. The atmosphere is generally stable and extended periods of moderate rainfall occur. Any convection that does occur with these events remains fairly shallow and capped by the marginally unstable atmosphere. This lack of any deep convection results in significant rainfall, but little if any lightning.

When looking at the charge distribution of lightning on a monthly basis, a clear pattern emerges. The ratio of flashes which occurred over marine zones to those which occurred over land was computed and graphed (Fig. 7). The ratio peaks during the winter months, where almost twice as many flashes occurred over the water than do over land. The pattern is reversed during the summer, where nearly twice as many flashes occur over land than do over the water. The month of July is an anomaly, likely skewed by a highly energetic single storm.

Daily

Finally, the diurnal distribution of flash density is presented in figures 8a through 8h. For simplicity's sake, the data are broken down into three hour blocks, corresponding to synoptic time (21Z-00Z, 00Z-03Z, etc.).

It is immediately evident that the highest flash densities occur during the 18Z-21Z, 21Z-00Z, and 00Z-03Z time blocks. This peak in activity from 18Z to 03Z coincides with peak heating over the area, the time where warmest temperatures occur over land and as a result the maximum thermal destabilizing of the atmosphere. When coupled with sufficient mid-level moisture, the added instability can incite thunderstorm activity over the area.

During the remaining time periods (from 03Z to 18Z), thunderstorms require another method of initiation in lieu of afternoon peak heating. These triggers often take the form of a passing cold front or another type of atmospheric disturbance.

Also interesting to note is how the peak lightning activity differs when dividing the area up by marine and land areas of responsibility, as seen in figure 9. The NLDN maintains high detection efficiency out more than 300 nm offshore, which more than covers our area of marine responsibility, which extends 60 nm. Over marine areas, lightning activity is at a maximum during the 11Z to 15Z time frame, while the maximum occurs between 21Z to 01Z over land. This is a very interesting feature, and one that we witness frequently. While the previously mentioned diurnal heating mechanism clearly explains the peak time frame over land, the reasoning for the marine maximum is less clear. It is likely that thunderstorm activity (and hence lightning activity) over the coastal waters is more driven by synoptic-scale patterns, such as the position of the upper-level jet, and its interaction with the cold pool aloft associated with upper-level low pressure systems. Whether there is a physical reasoning as to why these factors more often align during the early morning hours is unclear, but the effect on the marine lightning distribution is quite evident.

Charge Distribution

Since the NLDN records the charge of any given lightning flash, the data can be classified as either positive or negative. Figure 10 shows a chart that details the number of positive and negative flashes detected between 1987 and 2008, divided up by land zones and marine zones. Over 90% of all lightning that occurred over the WFO LOX CWA were negative flashes. This data corresponds with other analyses done on a country-wide scale (Ely and Orville 2005). It is interesting to note, however, the slightly higher percentage of positive flashes that occur over the marine zones (12%) than over the land zones (8%). This phenomenon has also been identified by researchers, with some West Coast regions even seeing up to 50% of the annual lightning to be of a positive charge (Ely and Orville 2005). It is thought that the areas which receive this anomalously high percentage of positive lightning flashes do so because of the increased number of winter storms contributing to the lightning totals, which are more likely to contain positive flashes. In the case of LOX, the annual percentage of positive flashes is likely dampened by the fact that the dominant electrical time frame for the area is the monsoon season rather than winter.

Ely and Orville (2005) found a correlation between the dominant polarity of a storm and the height of the -10^{o} C temperature level, a good estimation of where the charged layers are in a typical thunderstorm. The lower the charged layer was to the surface, the more likely a storm was to be dominated by positive flashes. During the winter months at LOX, when colder storms affect the area, bringing the charge layer closer to the surface, positive flashes make the highest contribution to seasonal totals, accounting for 38% of total lightning (Fig. 11). Spring storms fall at a close second (23%), and also tend to be cold-core systems.

The differentiation between positive and negative lightning flashes has become very important in recent years in regards to fire weather. Research indicates that positive lightning flashes are 10 times more powerful (hotter) than negative flashes (JetStream 2010). With this increased intensity, positive flashes can be more damaging and lethal, igniting wildfires and striking power lines.

Conclusions

This paper presents the cloud-to-ground lightning activity over the WFO Lox Angeles/Oxnard county warning area. The dataset, which covered the period from 1987 to 2008, was obtained from the National Lightning Detection Network.

The most striking observations from this study were the flash density maximums over mountainous areas and the eastern Antelope Valley. These maximums were observed during the summer and early fall time frame (June through September). On a diurnal scale, lightning activity over land peaked in the afternoon and early evening hours, coinciding with the period of peak solar heating, as well as during the summer months. Lightning activity over the coastal waters, however, peaked in the pre-dawn hours, and during the winter months. Overall, the summertime monsoon pattern and the Eastern Antelope Valley Eddy were deemed to be the driving force for lightning activity on both a seasonal and diurnal scale.

Additionally, the distribution of positively and negatively charged lightning flashes was examined. Based on the data, over 90% of all of the lightning flashes were negatively charged which agrees with accepted research. When comparing water vs. land, marine areas were slightly more likely to experience positively charged lightning flashes than land. Positive lightning flashes are also more likely to occur during the winter months, when cold-core storms affect Southern California.

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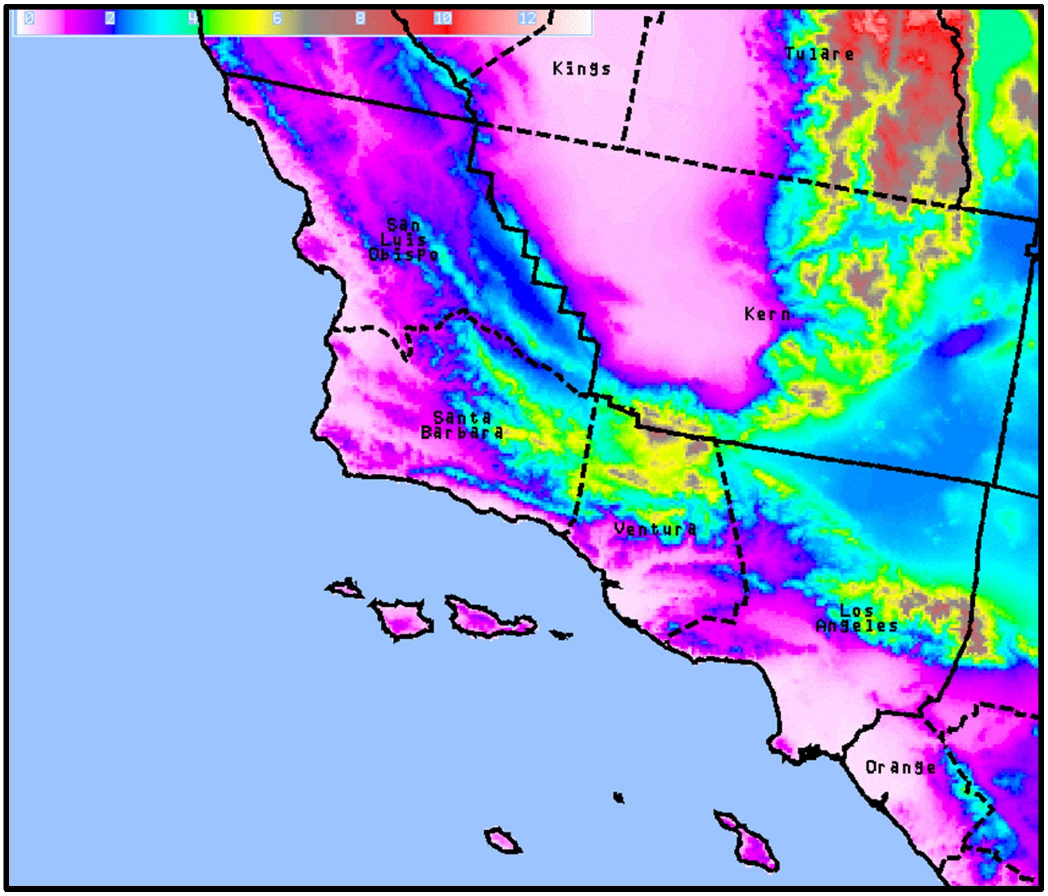


Fig. 1. Topographic map of the LOX county warning area. The scale (elevation in kft), on the top left portion of the image, shows that elevations within the area range from sea level along the coasts to over 10,000 feet over portions of the Ventura and Los Angeles county mountains.

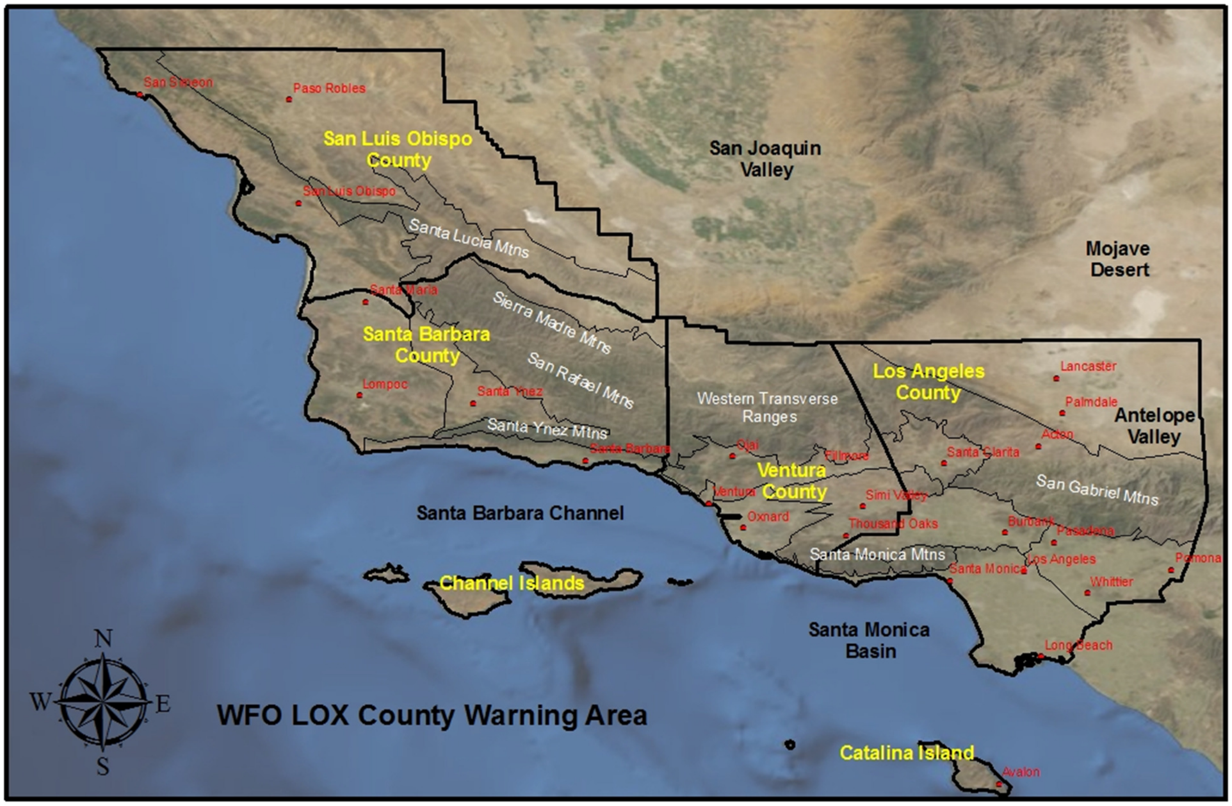


Fig. 2. Map of Los Angeles/Oxnard county warning area. Highlighted are the counties within the CWA, public forecast zones, and significant mountain ranges and geographical reference points.

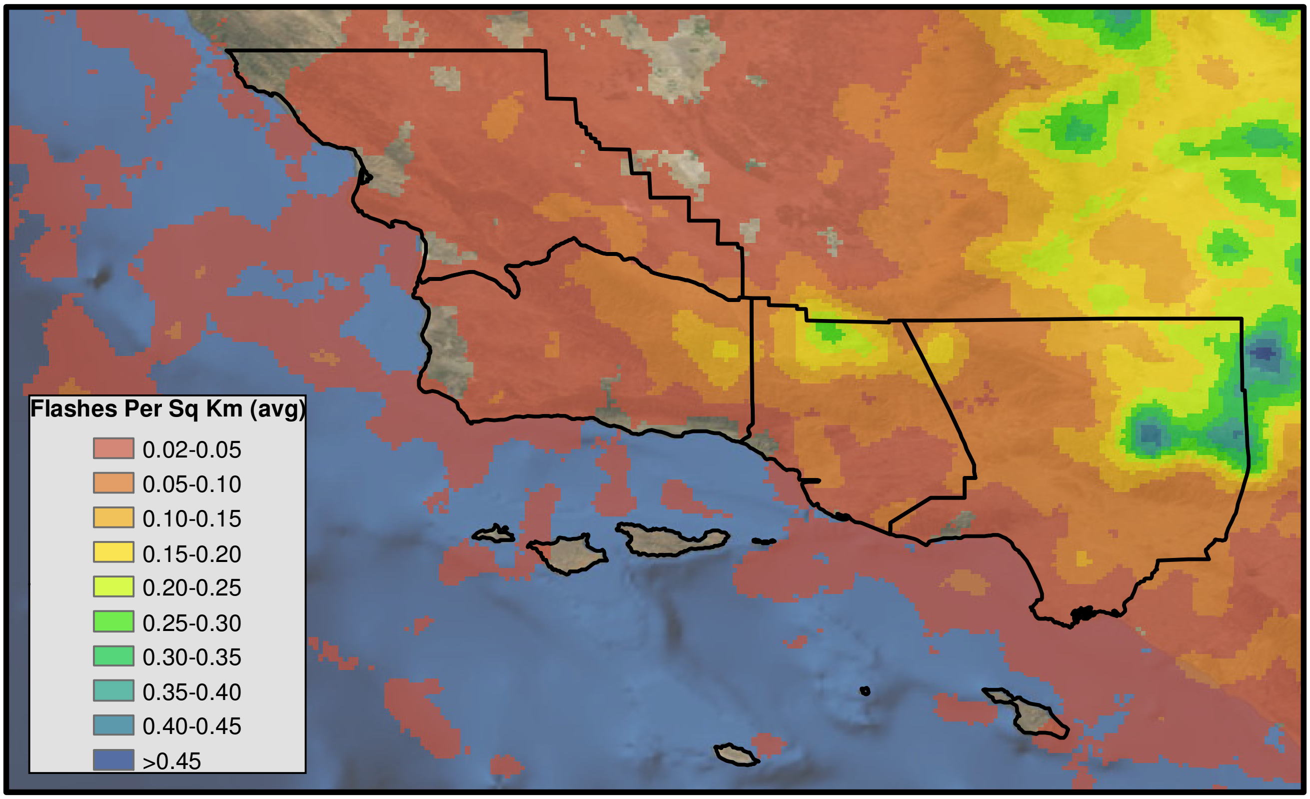


Fig. 3. Average annual lightning flash density over WFO LOX. Flash density ranges from less than 0.02 lightning flashes per square kilometer over coastal and marine areas to over 0.45 flashes per square kilometer over areas of the mountains. Local maximums in flash density can be found over the Mt Pinos area in Ventura County, and over the eastern San Gabriel Mountains and Antelope Valley in Los Angeles County. (Data from 1987 to 2000)

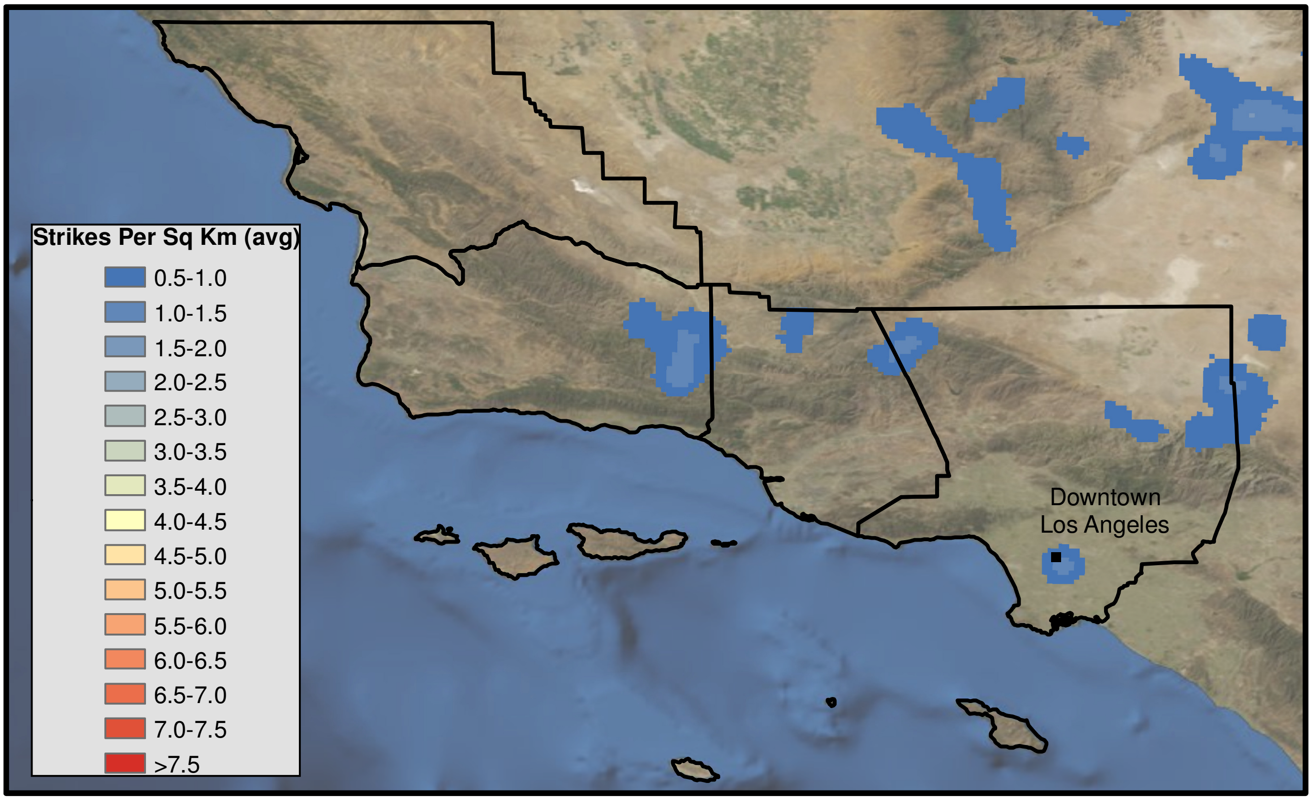


Fig.4. Density map of lightning flashes over the area during a period from 00Z November 12th to 00Z November 14th. Note the maximum of lightning activity over the Downtown Los Angeles area, which skews the 22-year average for that region.

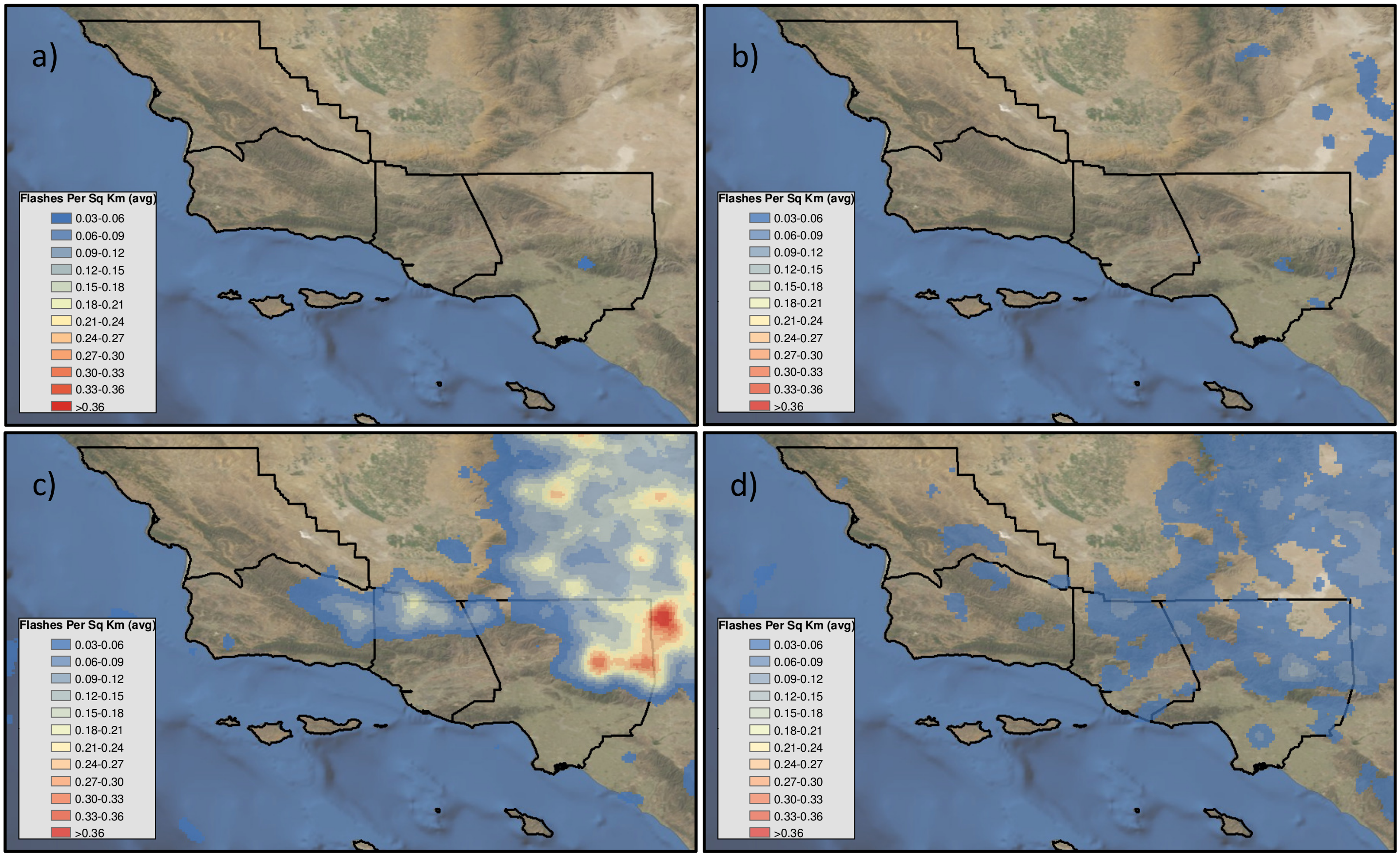


Fig. 5. Lightning flash density, by season for: a) Winter - December, January, and February, b) Spring- March, April, and May, c) Summer- June, July, and August, and d) Fall- September, October, and November. (Data from 1987 to 2000)

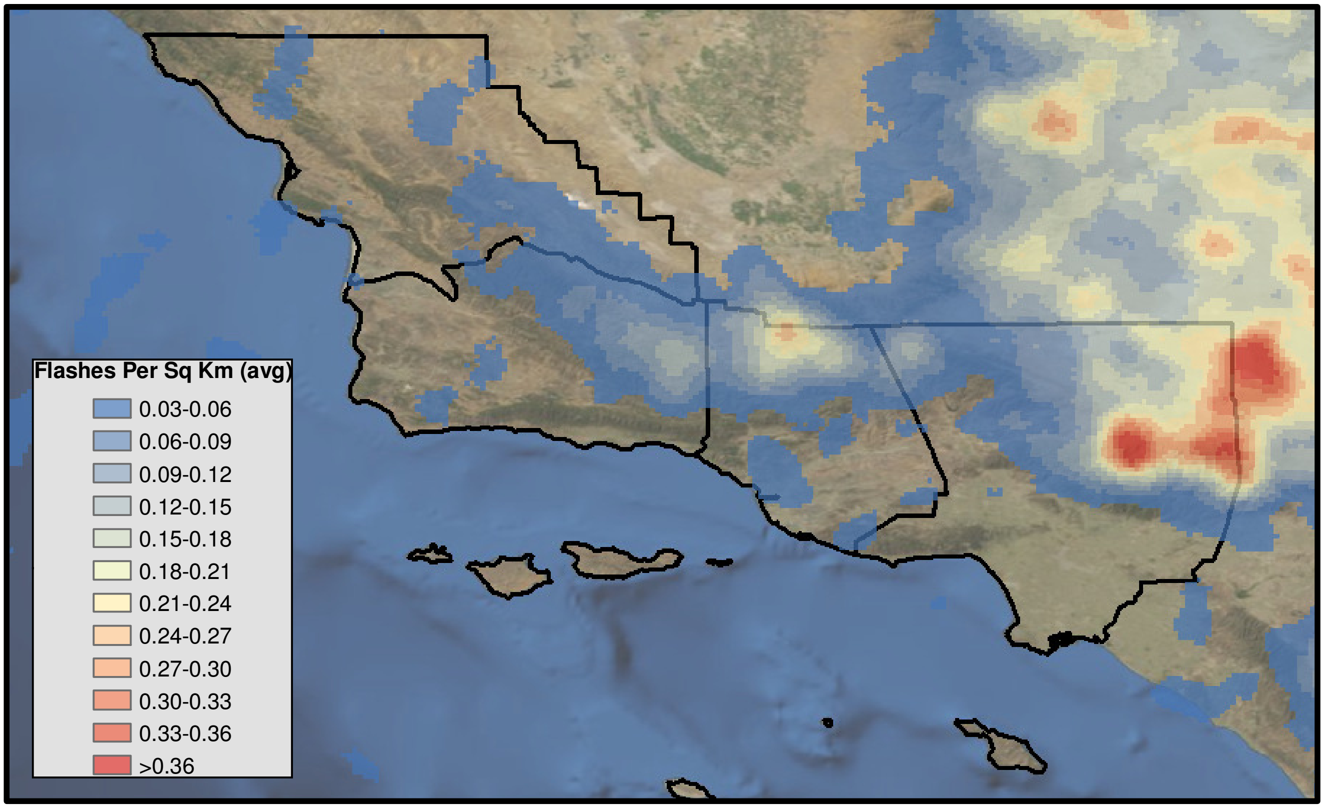


Fig. 6. Lightning flash density over the Monsoon Season- July, August and September. This is the most active period for lightning flashes over the county warning area, with two thirds of all lightning occurring during this time frame. (Data from 1987 to 2000)

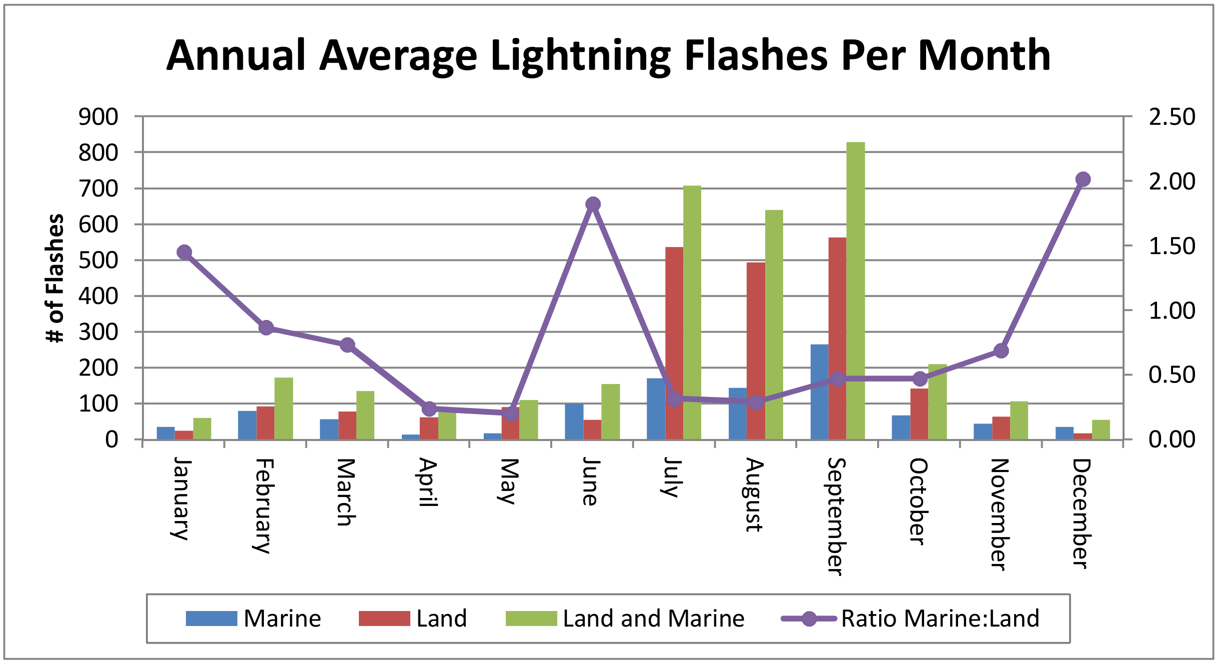


Fig. 7. Annual average lightning flashes per month. The results are divided up by those that occurred over WFO LOX marine zones, land zones, and a combination of both. The line graph represents the ratio of flashes which occurred over marine zones to those which occurred over land, with values greater than one representing months where more lightning flashes occurred over water than did over land. This occurred during only three months- December, January, and June. (Data from 1987 to 2000)

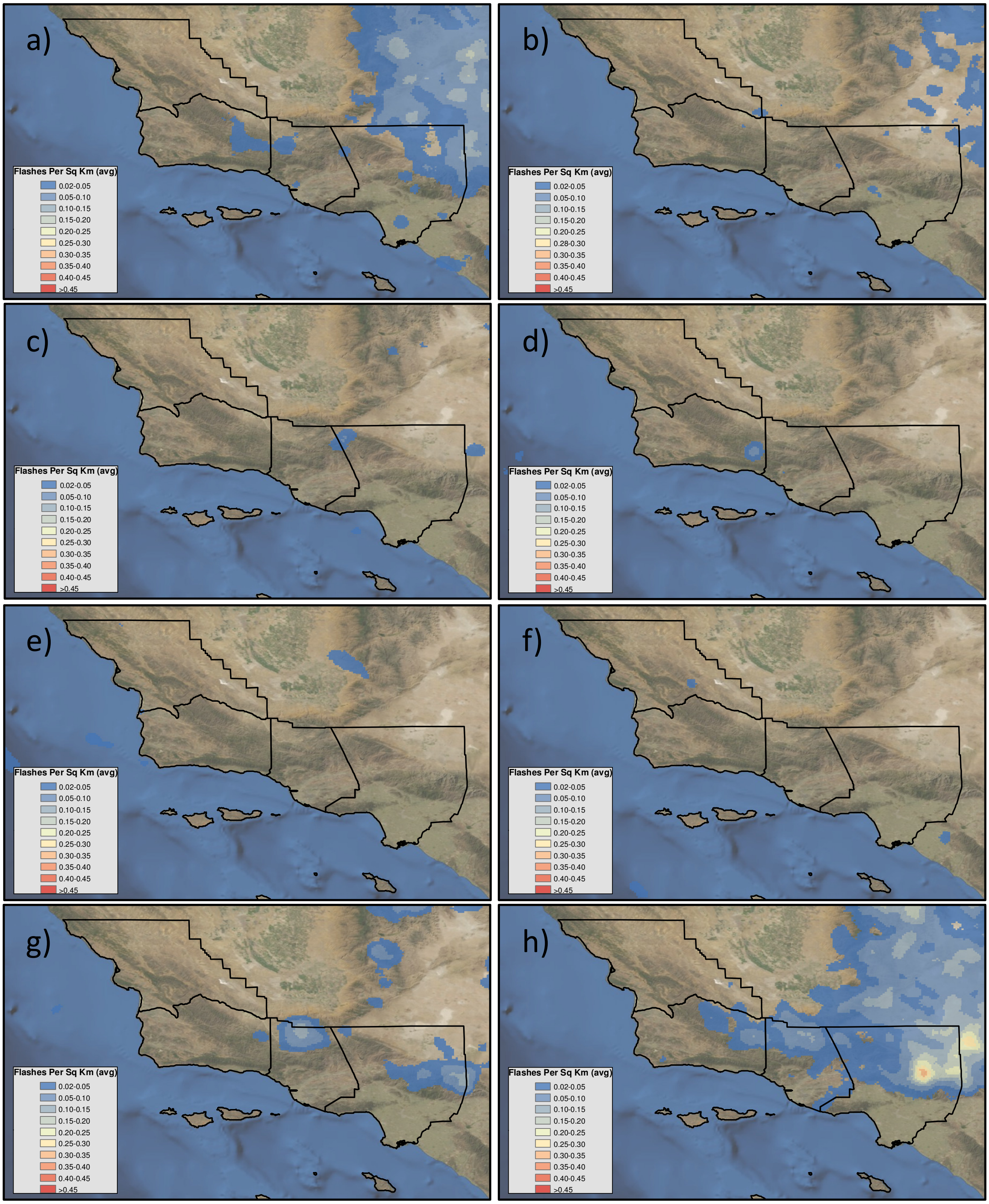


Fig. 8. Lightning flash density, by time of day, for a) 00Z-03Z, b) 03Z-06Z, c) 06Z-09Z, d) 09Z-12Z, e) 12Z-15Z, f) 15Z-18Z, g) 18Z-21Z, h) 21Z-00Z. (Data from 1987 to 2000)

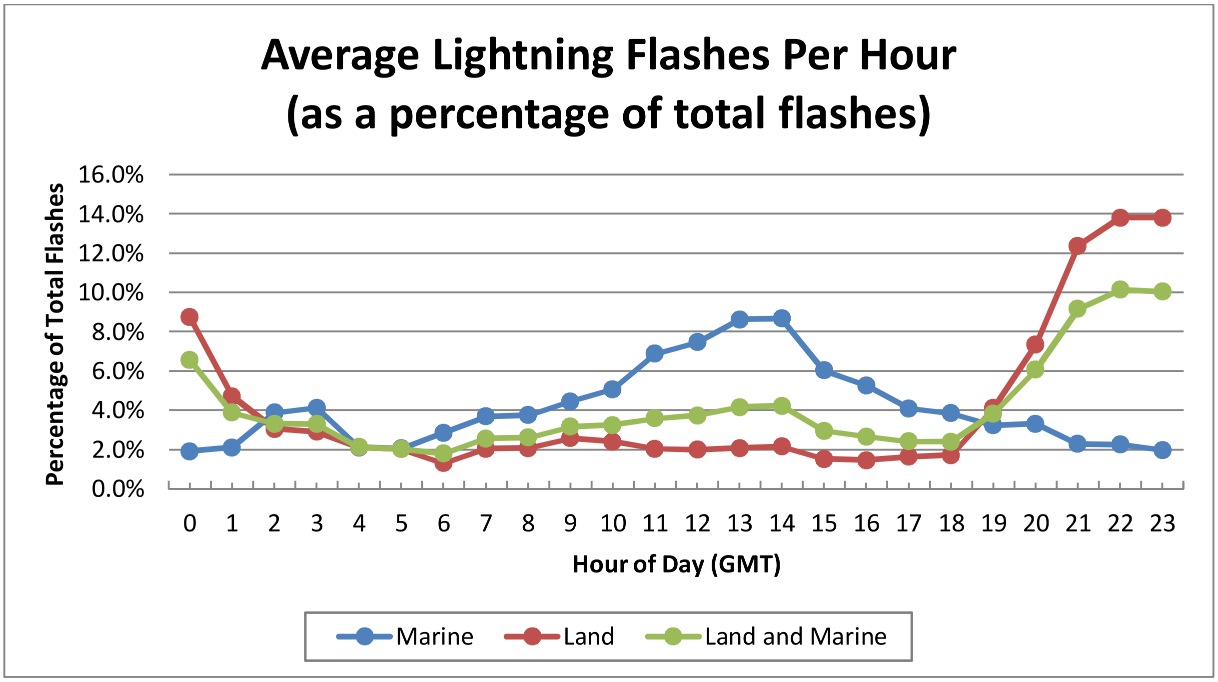


Fig. 9. Average lightning flashes per hour, as a percentage of total flashes. The results are divided up by those that occurred over WFO LOX marine zones, land zones, and a combination of both. Of interest is the difference in timing for the peak period of lightning activity over the marine zones vs. land zones. Peak lighting activity over land occurs between 21Z and 01Z, while peak activity over water occurs between 11Z and 15Z. (Data from 1987 to 2000)

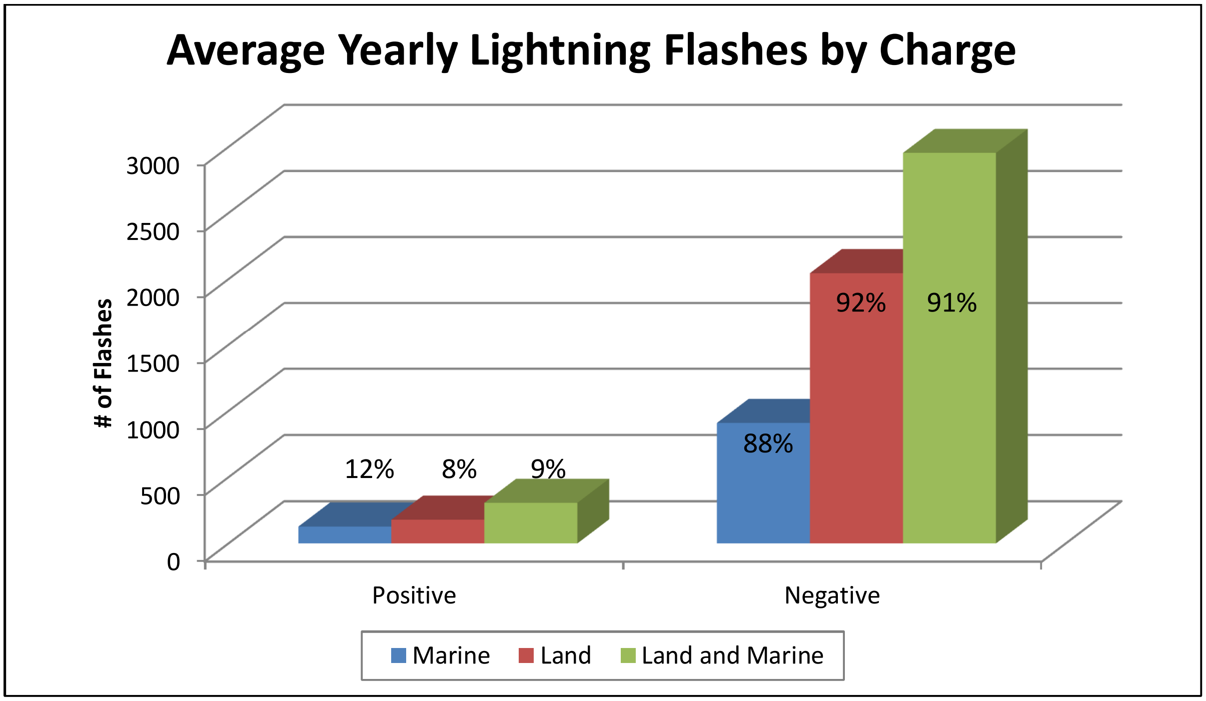


Fig. 10. Distribution of annual lightning flashes by charge (positive or negative). Results are divided into three categories- those that occurred over WFO LOX marine zones, those that occurred over WFO LOX land zones, and a combination of land and marine. Bars represent the average number of flashes that occur annually, while the overlain numbers are the percentage of total lightning, positive or negative. While the vast majority of lightning flashes over the area that occur are negative (~91%), there is a slightly higher percentage of positive flashes that occur over water (~12%) than occur over land (8%). (Data from 1987 to 2000)

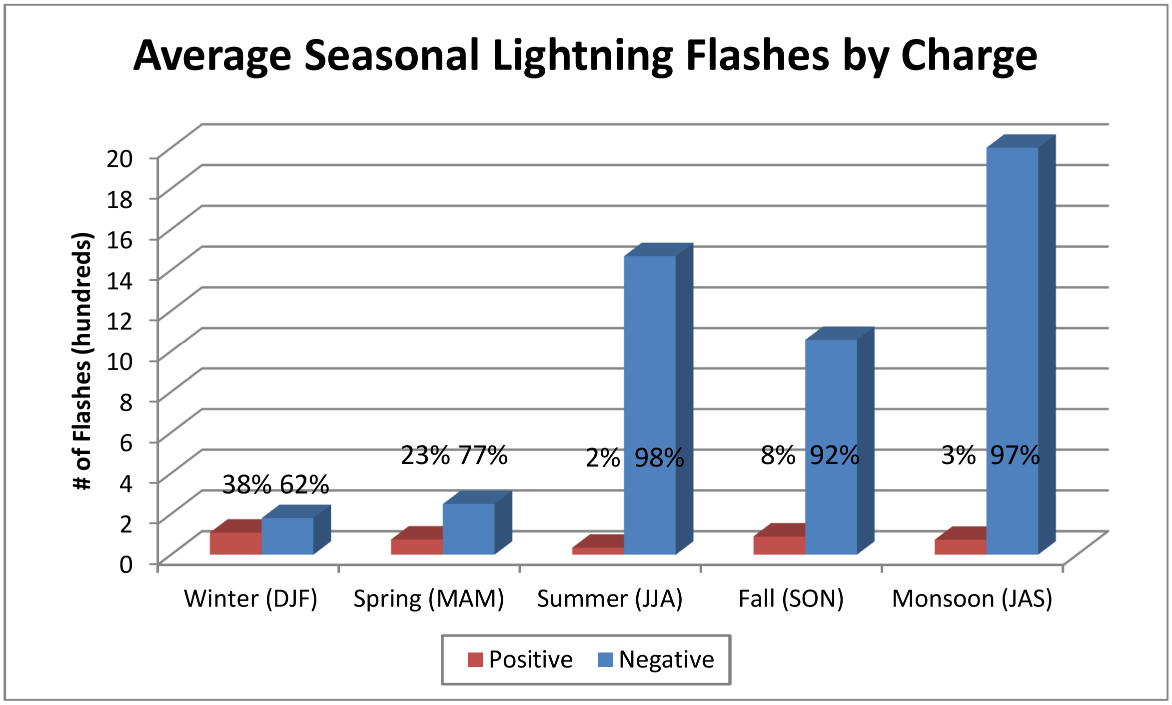
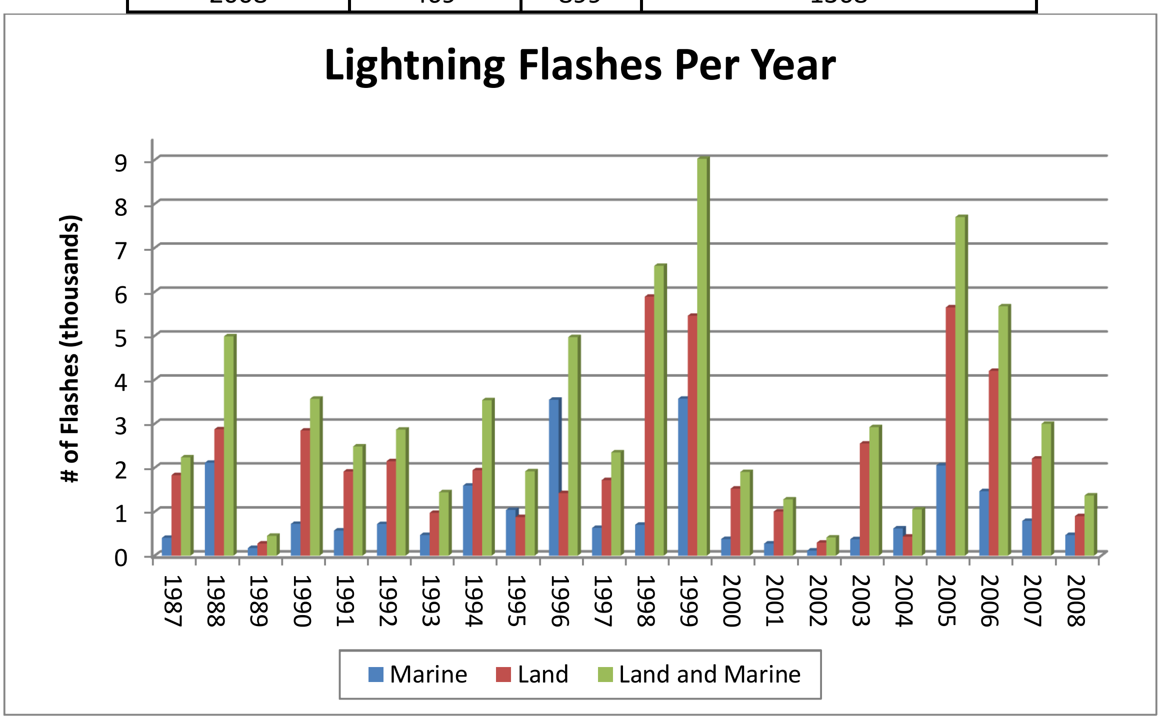


Fig. 11. Seasonal distribution of lightning flashes over the WFO LOX area of responsibility. Bars represent the average number of flashes that occur during each season, while the overlain numbers are the percentage of seasonal lightning, positive or negative. It is again clear that the majority of lightning flashes that occur are negatively charged. Negatively charged flashes occur most often (71% of the time) during the monsoon season. The majority of positive lightning flashes, however, occur during the winter months (35% of annual positive flashes). Positive flashes account for the highest percentage of total flashes during the winter and spring months, 38% of total and 23% of total, respectively. (Data from 1987 to 2000)

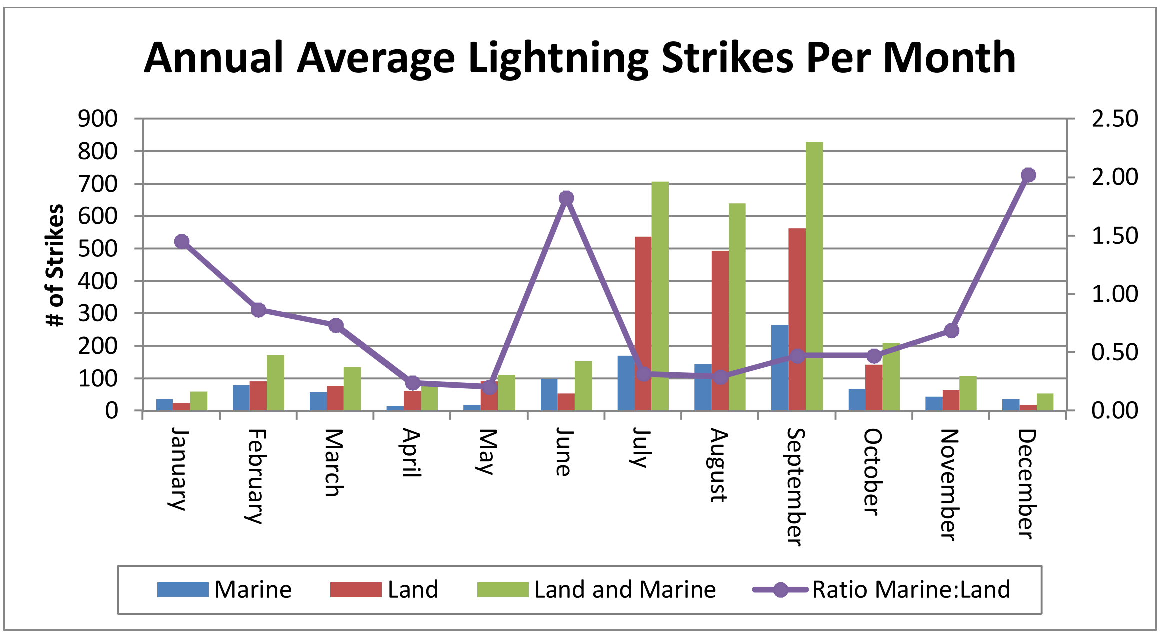
APPENDIX

Data tables and charts, for lightning flashes divided up by:

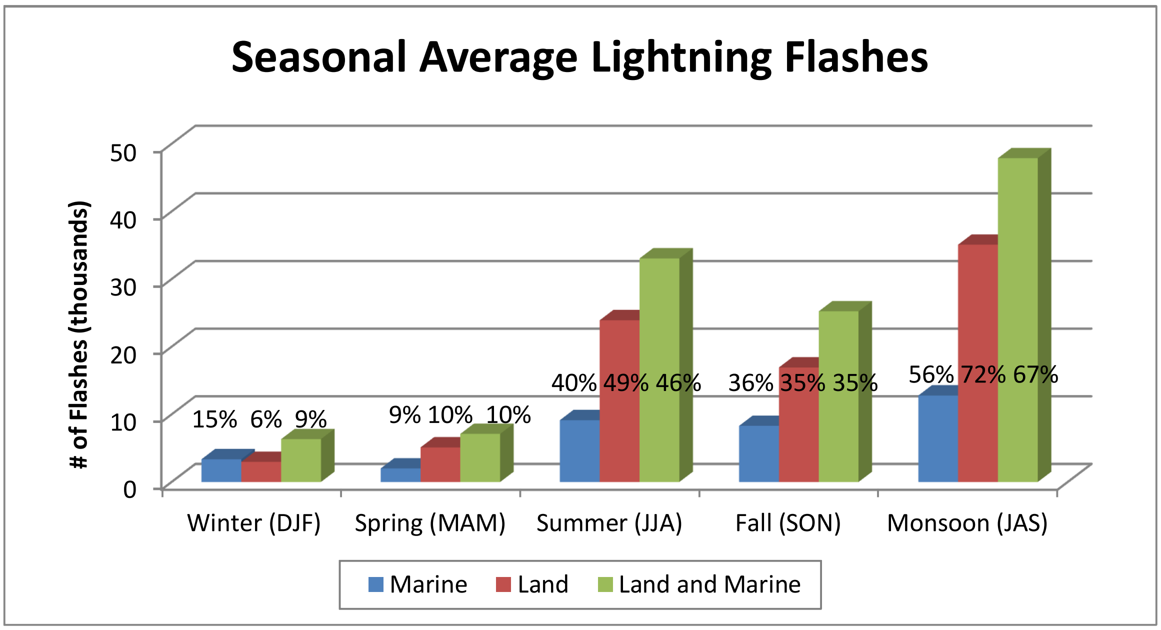
	Lightning Flashes Per Year		
Year	Marine	Land	Land and Marine
1987	405	1831	2236
1988	2114	2875	4989
1989	175	277	452
1990	723	2846	3569
1991	571	1913	2484
1992	719	2149	2868
1993	469	973	1442
1994	1593	1943	3536
1995	1040	878	1918
1996	3547	1423	4970
1997	631	1718	2349
1998	703	5889	6592
1999	3571	5456	9027
2000	378	1525	1903
2001	276	1004	1280
2002	117	296	413
2003	374	2550	2924
2004	618	433	1051
2005	2054	5648	7702
2006	1468	4203	5671
2007	791	2208	2999
2008	469	899	1368



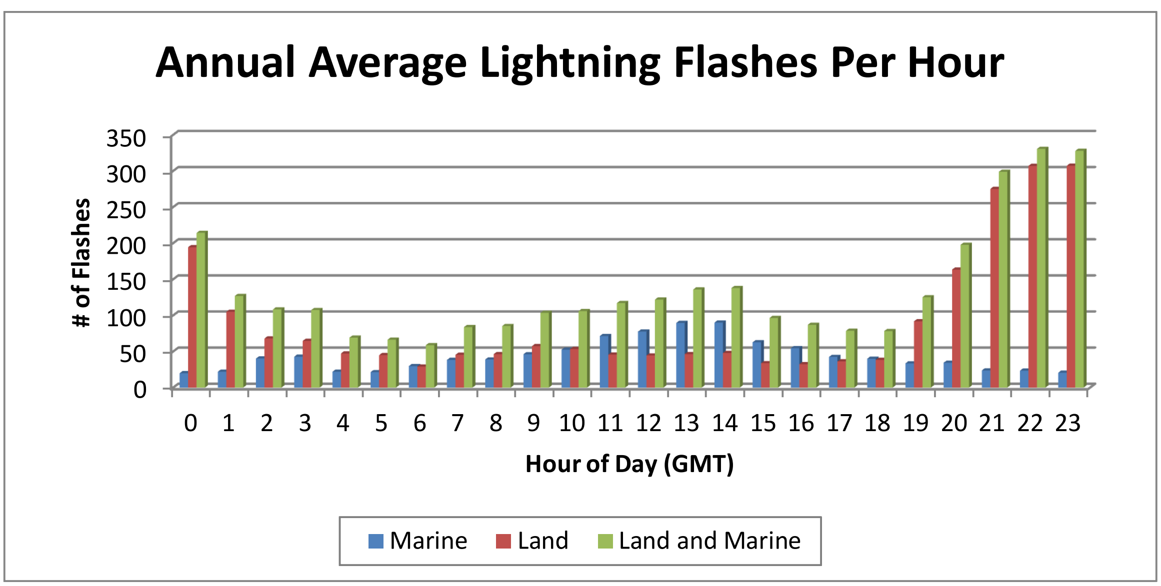
	Average Lightning Flashes Per Month					
	Marine		Land		Land and Marine	
Month	#	%	#	%	#	%
January	36	3.5%	25	1.1%	61	1.9%
February	80	7.7%	92	4.2%	173	5.3%
March	57	5.5%	78	3.5%	135	4.2%
April	15	1.4%	62	2.8%	77	2.4%
May	19	1.8%	92	4.1%	111	3.4%
June	100	9.7%	55	2.5%	155	4.8%
July	171	16.5%	537	24.2%	708	21.7%
August	145	14.0%	495	22.2%	640	19.6%
September	266	25.6%	563	25.3%	829	25.4%
October	67	6.5%	143	6.4%	211	6.5%
November	44	4.2%	64	2.9%	108	3.3%
December	37	3.5%	18	0.8%	55	1.7%



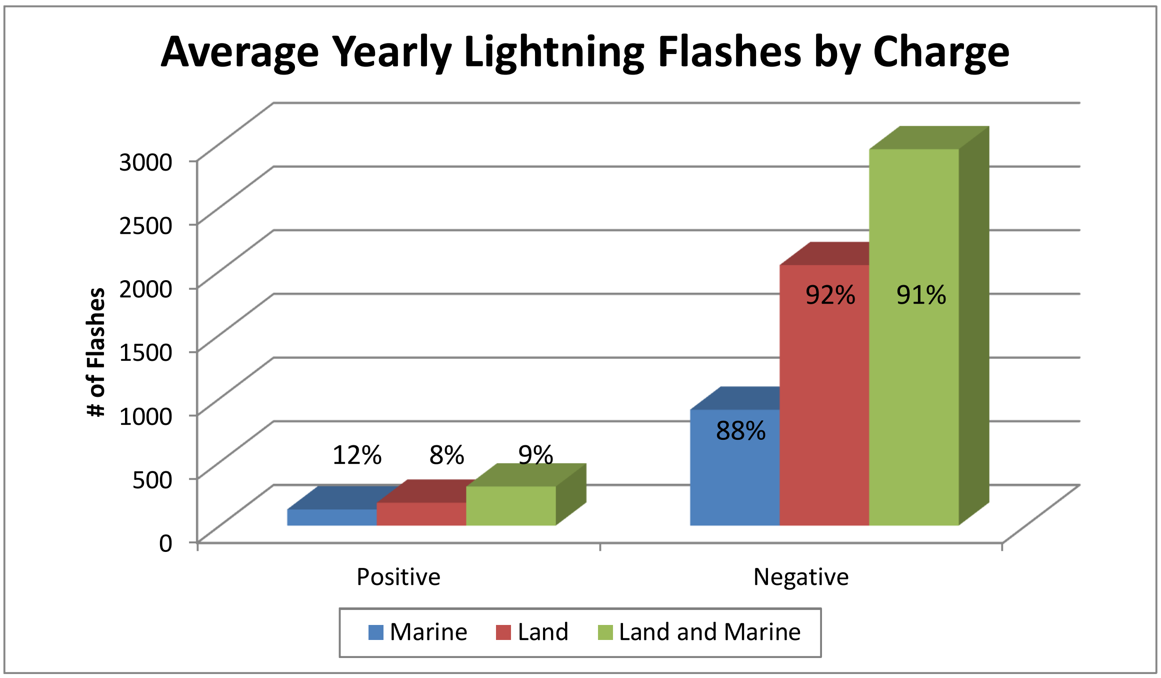
	Average Lightning Flashes Per Season					
	Marine		Land		Land and Marine	
Season	#	%	#	%	#	%
Winter (DJF)	3363	14.7%	2976	6.1%	6339	8.8%
Spring (MAM)	2001	8.8%	5112	10.4%	7113	9.9%
Summer (JJA)	9143	40.1%	23915	48.9%	33058	46.1%
Fall (SON)	8299	36.4%	16934	34.6%	25233	35.2%
Monsoon (JAS)	12785	56.1%	35092	71.7%	47877	66.7%



	Average Lightning Flashes Per Hour					
	Marine		Land		Land and Marine	
Hour (GMT)	#	%	#	%	#	%
0	20	1.9%	194	8.7%	214	6.6%
1	22	2.1%	105	4.7%	127	3.9%
2	40	3.9%	68	3.1%	108	3.3%
3	43	4.1%	65	2.9%	107	3.3%
4	22	2.1%	47	2.1%	69	2.1%
5	21	2.1%	45	2.0%	66	2.0%
6	30	2.9%	29	1.3%	59	1.8%
7	38	3.7%	45	2.0%	84	2.6%
8	39	3.7%	46	2.1%	85	2.6%
9	46	4.4%	57	2.6%	103	3.2%
10	53	5.1%	53	2.4%	106	3.2%
11	71	6.9%	46	2.0%	117	3.6%
12	77	7.5%	44	2.0%	122	3.7%
13	89	8.6%	46	2.1%	136	4.2%
14	90	8.7%	48	2.2%	138	4.2%
15	63	6.0%	34	1.5%	96	3.0%
16	55	5.3%	32	1.5%	87	2.7%
17	42	4.1%	36	1.6%	79	2.4%
18	40	3.8%	38	1.7%	78	2.4%
19	33	3.2%	92	4.1%	125	3.8%
20	34	3.3%	163	7.3%	198	6.1%
21	24	2.3%	275	12.4%	299	9.2%
22	23	2.3%	307	13.8%	330	10.1%
23	21	2.0%	307	13.8%	328	10.0%



	Average Yearly Lightning Flashes by Charge					
	Marine		Land		Land and Marine	
Charge	#	%	#	%	#	%
Positive	127	12.3%	179	8.1%	306	9.4%
Negative	910	87.7%	2045	91.9%	2955	90.6%



	Average Seasonal Lightning Flashes by Charge			
	Land and Marine			
	Positive		Negative	
Season	#	%	#	%
Winter (DJF)	108	35%	180	6%
Spring (MAM)	74	24%	249	8%
Summer (JJA)	34	11%	1469	50%
Fall (SON)	90	29%	1057	36%
Monsoon (JAS)	73	24%	2103	71%

	Average Seasonal Lightning Flashes	
	Land and Marine	
Season	% Positive	% Negative
Winter (DJF)	38%	62%
Spring (MAM)	23%	77%
Summer (JJA)	2%	98%
Fall (SON)	8%	92%
Monsoon (JAS)	3%	97%