Differences in Winter Lighting Activity over Land and Sea across the Eastern Coast of the Mediterranean

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ABSTRACT: The changes in the electrical activity of thunderstorms, crossing the eastern coast of the Mediterranean into central and northern parts of Israel are reported. This four-year study (1995-1999) is based on LPATS measurements of ground lightning strikes during winter storms associated with Cyprus Low synoptic systems. The spatial distribution of flash density shows a maximum over Mount Carmel, possibly due to topographical forcing. The annual variation shows a major maximum in January with two minor peaks, in November and March, which can be explained by changes in the static instability of the lower atmosphere. The average fraction of positive ground flashes was found to be 6% and their average peak current +41 kA. The average peak current of negative ground flashes was –27 kA. Larger frequencies of ground flashes were detected over the sea than over land during the study period. This is probably due to the large heat and humidity fluxes from the sea surface, which destabilize the colder air above and drive cloud convection. The annual distribution shows that during midwinter (D-J-F) there is higher flash density over the sea, while during autumn and spring the flash density is similar above the two regions. The diurnal variation shows a maximum in maritime lightning activity at 0500 LST and over land at 1300 LST.

INTRODUCTION

Global studies showed that most lightning activity takes place over land (Turman and Edgar, 1982, Orville and Henderson, 1986), but they also showed that a considerable amount of lightning activity takes place over the oceans and along coastal areas. There are maritime regions such as the Gulf Stream in the Atlantic and in the South Pacific Ocean near Australia, where lightning activity appears frequently.

As one of the major centers of electrical activity in the Northern Hemisphere winter (Christian et al., 1999), the Mediterranean Sea provides an exceptional and interesting region for studying the differences between land and sea lightning characteristics. This paper describes the electrical activity in Israel during the passage of the most common synoptic setting of Cyprus Lows. The cyclones originate in southern Europe and travel over the northern part of the eastern Mediterranean Sea. The cold air masses are modified by the influence of the warmer water of the Mediterranean Sea, leading to an increase in moisture and in static instability. Almost all thunderclouds develop at the cold front and, after its passage, within the cold air mass. The thunderclouds in these cases develop over the sea and are driven eastward past the coastline by the westerly flow. Mechanical interactions (e.g. friction) between this westerly flow and the coastline and the topographic features over land, together with thermal effects related to the sea-land interaction, are expected to shape a unique spatial and temporal distribution of lightning intensity over the study area (see Altaratz et al, 2003).

DATA DESCRIPTION

Observations of ground lightning strikes including time, location, polarity and peak currents were obtained from the Lightning Positioning and Tracking System (LPATS) operated by the Israeli Electrical Company. During the study period (1995-1999), the system was based on five antennas located in Eilat, Ashkelon, Tiberias, Nahariya and Jerusalem (see figure 1). Evaluations of similar systems in the world gave an overall detection efficiency of 70-90% for ground flashes (Finke and Hauf, 1996 and Pinto et al., 1996). We focused on the northern and central parts of Israel and on an equal area over the Sea bounded by latitudes 31.3ºN and 33.1ºN. The total area is 27,075 km^2 and for purposes of comparison, it was equally divided between sea and land. In this analysis we disregarded positive ground flashes with peak currents lower than 10 kA because they could be signals

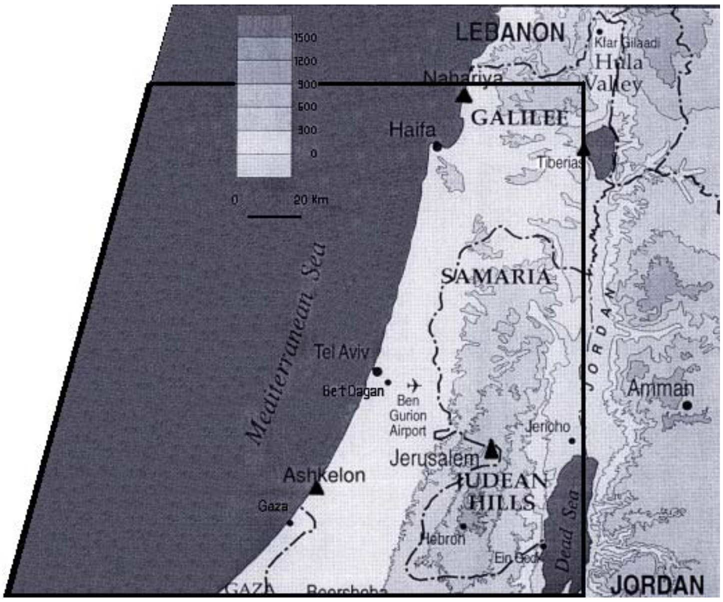

Figure 1: area of interest (inside the polygon). The antennas of the LPATS marked by triangles.

of cloud flashes (Cummins et al., 1998).

By examining sea level pressure maps and wind dataset we selected only those Cyprus Low events in which the centers of the lows were found to the north west of Israel and with a southwest to northwest wind at the 925 mb level.

RESULTS

General coastal lightning characteristics

The LPATS detected 32,383 ground flashes over the study area during 425 thunderstorm days in four winter seasons. A 'lightning year' is defined from July to June of the following calendar year, so each lightning year contains an entire winter season.

The spatial distribution of flash density, using 20 km^2 grid boxes, for the study area showed a peak in the flash density (2.5 km^{-2} $year^{-1}$) over Mount Carmel near the coastal city of Haifa (see the map in figure 1). There are a few possible reasons for this finding: 1) the mountain acts as a topographical obstacle, which enhances the convection through orographic lifting 2) the airflow convergence due to the urban heat island effect caused by the industrial area of Haifa Bay 3) the air pollution produced in that area, which is one of Israel’s major petrochemical centers (Orville et al. 2001 showed high flash density near the urban area of Houston Texas).

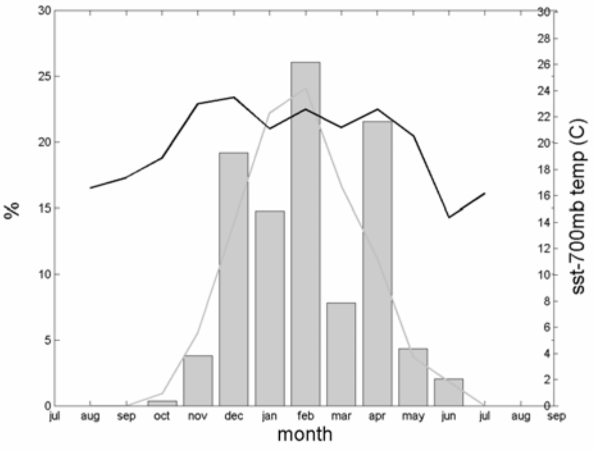

Figure 2: Lightning monthly distribution during Cyprus Low events (columns) and accumulated rain distribution (gray curve) and the difference between SST and 700 mb temperature (black curve).

The monthly ground flash density distribution for the whole area is shown in figure 2 (gray columns). The Cyprus Lows thunderstorm season is well defined between the months of October and April, with little activity in the border months. The monthly flash density distribution has a maximum in January and two secondary maxima, in November and in March. Trying to explain this pattern we calculated instability index (black curve), which is the average temperature difference between the sea surface and the 700mb pressure level (for the thunderstorm days included in the study period). A large index reflects an unstable lower-mid atmosphere. The gray curve is the average long-term monthly precipitation distribution calculated for Hafetz-Haim (a meteorological station 15 km from the coast) between 1961-1990 (Goldreich, 1998). The lightning density histogram differs from the distribution of average monthly precipitation, which forms a bell shaped distribution with 15% of the annual rainfall in the fall (September-November) and in the spring (March-May). The monthly flash density on the other hand shows two secondary maximums, in November and in March. This can be explained by the variation of the above mentioned instability index during the year. This emphasizes the crucial role of the lower level instability for electrical activity. Regarding the distribution along the year, 26% of the annual amount of lightning flashes occurs in the fall season and only about 11% in the spring months. Since the seawater is colder in spring than in the fall, it produces weaker vertical atmospheric instability in the former than in the latter. It is interesting to point out that the relative part of the autumnal electrical activity (26%) is larger than that of the precipitation during these months (15%). This means that the amount of rain per lightning flash is smaller during the autumn thunderstorms compared to the midwinter storms. A possible explanation for this observation may be related to the difference in the degree of vertical development of convective clouds in autumn and winter, which results from the difference in the height of the tropopause (in autumn the tropopause is higher).

The peak of electrical activity over the whole region, along the day, is at 0200 LST (0000 UTC).

The average percentage of positive ground flashes for the lightning season is 6%, which is lower than the 16% reported by Yair et al. (1998) for the Tel Aviv area. The reason for this difference may be the inclusion of only Cyprus Lows storms in the present study.

The average peak current of negative ground flashes, which were detected over the entire study area, is -27 kA (the median peak current is –24 kA). For positive ground flashes, the average is +41 kA but the median peak current is only +23 kA. These values are comparable to measurements in other places around the world (Ezcurra et al. 2002, Hojo et al. 1989).

Lightning characteristics over land compared to over sea

During the study period, the LPATS detected 20,121 flashes over the sea and only 12,262 flashes over land. In all four years the annual ground flash counts were higher over the sea. This is rather unusual compared to oceanic and continental lightning activity around the globe. Several studies of winter lightning in Japan also showed that ground strikes occur primarily to the sea surface (Hojo et al., 1989). Biswas and Hobbs (1990) reported similar results for the Gulf Stream.

The calculated monthly flash densities in mid winter are considerably higher over the sea. On the other hand, during the fall and spring, the flash densities over land and sea are almost equal or even slightly higher over land. This difference may be explained by the temperature contrast between the cold air masses originating from Europe and the relatively warm surface of the Mediterranean Sea. This contrast is maximal in midwinter. As a result, the instability that is built-up within these air masses as they move over the water increases rapidly and the thunderclouds develop at an earlier stage while they are still far from the coastline. In the transition seasons this thermal contrast is weaker and the convection develops much slower and at a later stage, when the clouds are closer to the coastline or over the land itself.

In Fig. 3 we compare the variation of the activity during the day over the sea (solid line) and over land (dotted line). The peaks of the continental and maritime activity occur at 1300 LST (1100 UTC) and at 0500 LST (0300 UTC), respectively. A few factors may contribute to the existence of the early morning maritime peak: 1) the curved shape of the south-eastern Mediterranean coastline leads to a convergence of eastern and southeastern land breezes over the sea 2) the maximal intensity of the land breeze occurs in the early morning hours, enhancing the lifting mechanism 3) the convergence of the prevailing synoptic wind (which is normally westerly in these synoptic situations) with the continental breeze (easterly-southeasterly) above the sea, enhances convection.

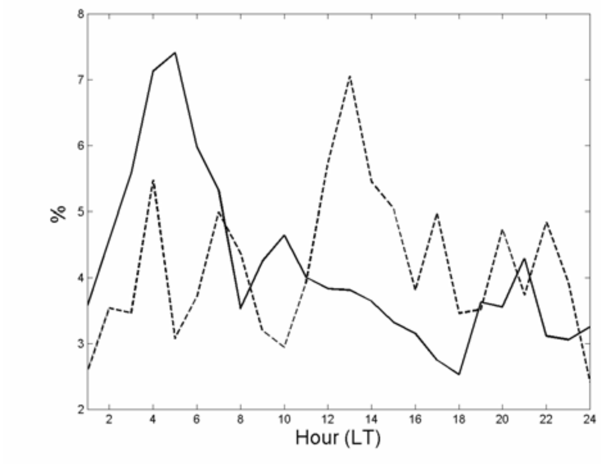

Figure 3: The percentage of ground flashes duri Low events, as a function of local time for the s line) and for land (dotted line).

The average peak current of negative ground flashes is -28 kA over the sea (the median is –25 kA) and -25 kA over land (the median is –22 kA). For positive ground flashes, the mean peak current is +38 kA for lightning over the sea (the median is +20 kA) and +49 kA for land (the median is +32 kA). It seems that the mean peak current of positive ground flashes is higher over land and for negative ground flashes it is higher over the sea.

CONCLUSION

Most of the planetary lightning activity in the tropics is driven by solar-heating induced convection, and hence follows a pronounced diurnal cycle that peaks in the local afternoon (reflected in the Carnegie Curve). On the other hand, winter lightning activity in the Eastern Mediterranean, is found to peak at night suggesting that it may be driven by specific local factors, 1) the synoptic scale factor, i.e., the timing of the passage of cold fronts associated with Cyprus Lows 2) the thermodynamic factor, i.e., the lapse rate between the sea surface temperature and the temperature at the 700mb pressure level (around 3,000 m), which reflects the degree of static instability. This is especially expressed in mid winter when the maximal temperature contrast between the cold European air masses and the warm surface of the sea leads to early development of thunderclouds and intense lightning activity over the sea.

In addition, there are mesoscale factors that modulate the spatial and temporal distribution of the electrical activity: 1) Orography – the Carmel Mountain ridge exerts a constraint that forces the westerly flow to ascend, and to amplify the updraft and enhance the convection 2) Sea-land temperature contrast – the nocturnal distinct maximum in lightning frequency over the sea, which is not found over land (figure 3).

ACKNOWLEDGMENTS: The Basic Research Foundation of the Israeli Academy for Science and the Humanities, Jerusalem, supported this research. NCEP Reanalysis data provided by the NOAA-CIRES Climate Diagnostics Center, Boulder, Colorado, US, is from their Web site at http://www.cdc.noaa.gov/. LPATS data was obtained courtesy of the Israeli Electrical Company. We wish to thank Colin Price for his helpful remarks.

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