Global Distribution of Midnight Lighting—September to November 1977

RICHARD E. ORVILLE

Department of Atmospheric Science, State University of New York at Albany, Albany, NY 12222

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ABSTRACT

The first significant results of a long detailed lightning study are reported in which the distribution of global midnight lightning is plotted from 60°S to 60°N for the months of September, October and November 1977. Lightning positions obtained from DMSP photographic data are plotted with an accuracy of ~100 km and the cumulative plots show a remarkable agreement with features of the general circulation. Land-ocean lightning flash ratios are calculated to range from 1.5 to 2.0 for the three months, September (1.6), October (1.5) and November (2.0).

1. Introduction

In recent years, the need for a more precise estimate of the global lightning distribution has been emphasized by several authors. Tuck (1976) noted the potential importance of lightning as a source of nitric oxide. The nitrogen oxides are part of many important photochemical reactions and may exert a controlling influence on the atmospheric ozone content (Crutzen, 1970; Johnston, 1971). Consequently, the satellite studies of lightning by Vorphal (1967), Sparrow and Ney (1971), Turman (1976, 1978), and Orville and Spencer (1979) are important, but fail to give a complete record of global lightning for a particular time of day. A major step to fill this gap has been taken recently by Turman and Edgar (1981) in a paper now under review which reports on the global lightning distributions at dawn and dusk. Our own studies complement this work in that we are engaged in a detailed effort to analyze all global midnight lightning locations recorded by a DMSP satellite for 365 consecutive days, beginning in September 1977. This project will take approximately two years to complete. Our initial analyses, however, reveal significant information on the midnight global lightning distribution which is reported in this note.

2. Data source

The data consist of photographs recorded by the high-resolution scanner on the block 5D series F1 satellite. This satellite is in a midnight-noon sun-synchronous orbit; i.e., the orbit precesses around the earth once a year and passes overhead near the same local time each day. The orbit is circular with an altitude of 830 km and inclined 98.7° to the equator on the northbound pass. The orbital period is 101 min and the highest latitude reached by the subpoint track is about 81°.

The sensors in the block 5D series satellites have photomultiplier tube (PMT) detectors with less red response than the radiometer (silicon diode) detectors used in the block 5C series and described by Orville and Spencer (1979). Although the quantum efficiency of photomultipliers (peak ~ 25%) is much lower than that of silicon diodes, the signal/noise characteristics at low light levels are far superior. Eather (1979) has published normalized response curves for the 5D series detectors in the F1–F3 satellites. The F1 satellite has a modified S-20 photocathode and, with the optical system, a peak sensitivity at ~600 nm.

The DMSP satellites have gain controls which allow the satellite to record in light levels ranging from daylight to one-quarter moonlight. A change in the gain will change the saturation threshold of the system. At night the threshold is low enough so that cities, gas and brush fires, and lightning flashes saturate the system. Since the typical response to lightning is a 100 km horizontal streak (Orville and Spencer, 1979, Fig. 4a) the spatial accuracy of the plotted lightning position is ~100 km. This accuracy will be an important consideration when the results are discussed in a later section. The differential sensitivity of the satellite detector, if any, to cloud-to-ground or intracloud lightning is unknown.
3. Data reduction

The lightning data consist of a series of positive transparencies which are archived at the University of Wisconsin-Madison Space Science and Engineering Center. The entire globe between 60°S and 60°N is covered by these data; some areas receive more coverage than others. At latitudes poleward of ±60° the transparencies are generally of poor quality because the satellite is passing through a daylight-night transition period. Consequently, lightning at latitudes higher than 60° is neglected.

Our analysis begins with the photographs collected on 1 September 1977, and will cover 365 consecutive days. The first three months, September, October and November, have been analyzed in the following way. Maps are generated by computer which contain only longitude and latitude lines and the orbit tracks for one day. Continental outlines, oceans, etc., are not on these maps. Each lightning streak in a DMSP photograph is marked on a map as near as possible to the location where it occurred with an error which we estimate to be no larger than 1°. When this phase is completed in Wisconsin, the maps are sent to New York where we mount them on a digitizer board and the coordinates of the lightning flashes and orbital paths are entered into a computer. The resulting data can then be plotted for one day or any number of days under software control.

4. Results and discussion

An example of a plot for one day, 4 September 1977, is shown in Fig. 1. The world is graphed as a Mercator projection from 60°S to 60°N. The diagonal rhumb lines represent the approximate orbit path of the DMSP satellite over the earth near local midnight. Gaps in the tracks indicate where photographic coverage was not obtained for that day. It is apparent that on 4 September there are areas of the North Pacific, North and South Atlantic, and southern Africa for which photographic data were not archived. With the exception of the South Atlantic, the data gaps appear to be randomly distributed. Over the South Atlantic region there frequently are no data or the existing photographs are of poor quality. The problem has been noted by previous authors (e.g., Croft, 1977, p. 29) and is caused by the impact of the satellite's entry into the inner radiation belt which dips nearest the earth over the South Atlantic. Short streaks may be produced in the DMSP image when the satellite penetrates the belt. Lightning can easily be differentiated from these short streaks. On other occasions the data are of such poor photographic quality that they are not archived and a gap in the orbit path appears.

Small plus marks are plotted in Fig. 1 to show the location of each flash recorded by the DMSP satellite—a total of 59 flashes for the 24 h period shown. Where several flashes are in proximity to each other, the plotting marks overlap. A plot of the local midnight data for one 24 h period is of little use except to check the accuracy of the digitization process. Only a small percentage of the flashes occurring near local midnight are recorded on any given day. Consequently, significant data can be generated only by summing the lightning flash locations for one month and plotting the result.

Our initial analysis has been completed for the months of September, October and November, and the results plotted as Figs. 2a, 2b and 2c, respectively. Each plot shows the location of approximately 2000 flashes in respect to the major land areas. Satellite orbit paths have been omitted.

![Diagram](image-url)
In Fig. 2a, we note the obvious concentration of lightning in Indonesia, Central and South America, and Africa. An apparent lack of lightning over the oceans is a curious result, but agrees with previous reports (e.g., Sparrow and Ney, 1971). Note that lightning is concentrated in central Africa in a pattern which appears to coincide with the Intertropical Convergence Zone. This lightning pattern, however, does not continue to the west over the Atlantic Ocean where the ITCZ is observed. Other lightning concentrations appear in eastern India and Bangladesh in association with the monsoon, and off the east coast of Australia in association with a region of cyclogenesis. An area of intense midnight lightning activity occurs over Uruguay. It appears at first strange that no lightning flashes are recorded over Florida, but frequent flashes appear over the midwestern part of the United States. This result is consistent with the diurnal variability of convection over Florida which reaches a maximum in the afternoon, more than 6 h before the DMSP satellite passes overhead. Our observations are also consistent with the known maximum frequency of thunderstorms over the Midwest around midnight which has been documented, for example, by Wallace (1975). Several areas without lightning are of interest in addition to Florida. The west coasts of South America and Africa are influenced by the cold waters of the Humboldt and Benguela currents, respectively, resulting in suppressed convection and a lack of thunderstorms. The absence of lightning is apparent in the Atacama desert region of South America and the Kalahari desert in Africa. In fact, the Kalahari is almost outlined in a closer inspection of southern Africa in Figs. 2b and 2c.

The midnight lightning distribution for October
(Fig. 2b) and November (Fig. 2c) supports many of our conclusions derived from Fig. 2a, but a comparison of the lightning activity in each of the three months reveals the following. The major areas of activity remain in Indonesia, South America and Africa, but there is a definite shift of the lightning activity to the south as the summer season in the Southern Hemisphere approaches. The monsoon retreats from Bangladesh and midnight lightning activity is concentrated in southern India. The lightning activity increases significantly in Australia as summer approaches as does the frequency of lightning off the east coast of Australia. The accuracy of the lightning position is apparent in Fig. 2b in the delineation of the Andes mountains in Peru, to the west of which no lightning is plotted. In Africa, the southern retreat of the lightning is impressive from September to November as is the increase of activity over South Africa and Madagascar. Some variation in the oceanic lightning activity is obvious where it is relatively near coasts, such as Central America, or more generally in the North Pacific where the activity decreases from September to November.

A calculation has been made of the land-ocean flash ratio as a function of month. It is not possible with the present minicomputer to classify coastal lightning in the “land category” if it is within 50 or 300–400 km of a coast as was done by Vorphal (1967) and by Orville and Spencer (1979). A computer search of our lightning data base classifies each flash location as to whether it is over land or water and then calculates the ratio. The results are given in Table 1. A significant increase occurs in November which may reflect the southward progression of increased activity in Australia, South American and Africa. It will be interesting to have the analysis for a complete year.

The land-ocean flash ratios reported here are in apparent conflict with the value of 10 reported by Vorphal et al. (1970) and the average values of 8 and 4 reported by Orville and Spencer (1979). The conflict is largely resolved when we realize that the above values of 10 and 8 resulted from classifying the ocean flashes within 300–400 km of a coast as land flashes; the value of 4 resulted from classifying the ocean flashes within 50 km of a coast as “land flashes” and the present results of 1.6–2.0 result from a strict separation at the coastline. I believe that all the above results are correct and that they merely emphasize the importance of the land-ocean interface in producing thunderstorms.

It would be desirable to calculate the global lightning frequency to check the values reported by Orville and Spencer (1979) that ranged from 40–150 s⁻¹. However, the only information missing at this time is the sensitivity of the F1 satellite to lightning. That is, what is the area of the earth’s surface to which the PMT detector will respond to lightning? In the DMSP 5C series, Orville and Spencer (1979) reported that the area corresponded to a rectangular area with dimensions 3.8 km × 185 km. The DMSP 5D satellites are more sensitive to lightning, but this factor has not yet been determined.

TABLE 1. Land-ocean lightning flash frequency as a function of month.

<table>
<thead>
<tr>
<th>Month</th>
<th>Total flashes recorded</th>
<th>Land-ocean ratio*</th>
</tr>
</thead>
<tbody>
<tr>
<td>September</td>
<td>1813</td>
<td>1.58</td>
</tr>
<tr>
<td>October</td>
<td>2121</td>
<td>1.53</td>
</tr>
<tr>
<td>November</td>
<td>2178</td>
<td>1.95</td>
</tr>
</tbody>
</table>

* The estimated errors in these values are ±7% due to the algorithm used to classify flashes. We are continuing our efforts to reduce this error to near zero percent.
5. Conclusions

These data are only the first results of a detailed mapping of the global distribution of lightning near local midnight. Monthly maps are now being generated for the remaining nine months and will result in the cataloging of over 25,000 flash locations. These results should be available in one to two years. For the present, however, we see land-ocean flash ratios ranging from 1.5 to 2.0 with an increase apparently associated with the onset of summer in the Southern Hemisphere. The lightning flash locations for September, October, and November for local midnight show a remarkable, but not surprising, agreement between the geographical flash distribution and the features of the general circulation.

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REFERENCES