Occurrence of positive and negative polarity cloud-to-ground lightning flashes: Case study of CGR4 and GPATS data for Brisbane, Australia

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The occurrences of positive and negative polarity cloud-to-ground lightning flashes were detected by ground-based lightning flash counters CGR4 in Brisbane, Australia. Positive (negative) flashes constituted 2–5 per cent (95–98 per cent) of total cloud-to-ground flashes. These results were compared with data obtained by a GPATS lightning location system over the period 2005–2008. It was found that prior to January 2007 the GPATS lightning location system was reporting an excessive proportion of ground flashes as being positive, with a correspondingly low proportion as negative. Over the same period, the CGR4 lightning flash counter reported positive to negative ground flash ratios consistent with those obtained by other researchers both in Australia and elsewhere using a range of instrumentation. The high proportion of positive ground flashes (up to 50 per cent) recorded by the GPATS lightning location system in Australia prior to 2007 may be attributed to one or more possible factors, including (i) changes in the processing of raw GPATS sensor data implemented in January 2007, (ii) upgrades to sensor firmware, and (iii) the installation of more GPATS sensors.

Introduction

The hazards associated with lightning are common in Australia. In some instances, the effects of lightning-initiated bushfires are so extreme that they are classified as natural disasters. Knowledge about geographical distribution and seasonal variability of lightning activity for the Australian continent are vital for developing adequate lightning protection measures.

In this paper, we present an overview of instrumental methods used for recording lightning activity in Australia, and compare the occurrence of positive and negative polarity cloud-to-ground lightning flashes (ground flashes or GF) obtained from stand-alone ground-based lightning flash counters (LFCs) and a network-based lightning location system (LLS). To describe lightning activity, we use the number of negative GF (NGF), positive GF (PGF), intra-cloud flashes (cloud flashes or CF) and total flashes (TF = NGF + PGF + CF) within a specified radius at a particular locality. Accurate knowledge about occurrences of PGF and NGF are of high importance for lightning protection. PGF are typically more intense than NGF and consequently potentially more damaging.
The first instrumental records of lightning activity using LFCs were made in the 1950s (Pierce 1956); later, several types of LFCs known as CIGRE-500 Hz, CIGRE-10kHz (Barham and Mackerras 1972; Anderson et al. 1979) and CGR3 (Mackerras 1985) were developed and have been used widely around the world. LLSs are also used in most developed countries, beginning in America in the 1980s and then worldwide, including two commercial systems in Australia, GPATS (GPATS website www.gpats.com.au) and Kattron (Kattron website www.lightning.net.au). The GPATS network provides coverage of the Australian continent while spatial coverage of the Kattron network is limited to selected areas in southeast Australia. In this study, we analyse GPATS LLS data.

The role of a LFC differs from that of a LLS. The LFC records the occurrence of local lightning flashes with effective ranges between about 10 and 30 km, whereas the LLS produces information about lightning strokes occurring within the bounds of its network of sensors. In such a network, each sensor is optimally separated by no more than 300 to 400 km from neighbouring sensors. The LFC registrations are more accurate than LLSs data for ranges below 30 km (Kuleshov et al. 2010).

In this study, we examine results obtained by the CGR4 (Cloud-to-Ground Ratio #4) LFC which is a recent modification of the CGR3 LFC. In Australia, long-term records obtained by the CGR3 LFCs are available for Brisbane and Darwin, and short-term records from the CGR4 LFCs are available for Brisbane. We also examine lightning statistics based on data from the GPATS Pty Ltd LLS for storms that occurred in the vicinity of the Brisbane CGR4 LFCs during the period 2005–08.

The instruments that have been used for lightning detection such as CGR3 and CGR4 LFCs, and GPATS LLS, are described in the section Instruments, method and data. The Results section presents the results of deriving lightning parameters from the data obtained by the CGR4 LFC and the GPATS LLS. These results derived for a selected Australian locality (case study for Brisbane) are discussed in the Discussion section.

Instruments, methods and data

Instruments and methods

Lightning flash counters

The CGR3 (Cloud-to-Ground Ratio #3) counter is a modification of the original forms of the instrument (CGR1 and CGR2) developed at the University of Queensland (Brisbane, Australia). The CGR3 instrument was used for lightning research for a number of years and it is described in detail in Mackerras (1985), Baral and Mackerras (1992, 1993), and Mackerras and Darveniza (1992, 1994). The CGR3 counter has separate registers for NGF, PGF, and CF. The effective ranges are estimated as 12 km for CF, 14 km for NGF, and 16 km for PGF. CGR3 counters were installed in eleven countries and used to derive and compare the characteristics of lightning activity around the world (Mackerras and Darveniza 1994; Mackerras et al. 1998). In Australia, these counters were installed in Brisbane and Darwin.

The CGR4 instruments (Mackerras et al. 2009) use the same (or similar) type of aerial for detecting electric field changes caused by lightning as the CGR3 LFCs; the main difference between the two instruments is that the CGR4 LFC uses a microprocessor to implement the flash discrimination procedures, the counting of flashes and the display of registrations. The CGR4 LFCs (first design) are estimated to have an effective range of 14 km for NGF and PGF and 12 km for CF (Mackerras et al. 2009). In an upgraded design (from February 2007), the CGR4 LFCs are estimated to have an effective range of 11.3 km for NGF, PGF and CF. As part of a pilot study by the Australian Bureau of Meteorology (ABM), the CGR4 LFCs are operated in Brisbane, Darwin and Melbourne.

The GPATS lightning location network

The ABM and GPATS Pty Ltd have had a cooperative agreement in place since 1998 whereby lightning data are provided to the ABM in exchange for hosting GPATS’ sensors at its field offices. The GPATS system operates on the principle of accurately measuring the time of arrival of the electric field component of lightning impulses at each sensor, by using GPS-synchronised local clocks to timestamp observations to sub-100 ns accuracy. These measurements are transferred over the ABM’s communications network to a central processing system at GPATS, where they are correlated and combined to produce estimates for the location (latitude and longitude), time (to milliseconds), peak current (kA), type (cloud-ground or cloud-cloud) and polarity of each stroke. The sensors have the ability to discriminate individual strokes in a CG flash comprising multiple strokes.

The original agreement between the ABM and GPATS specified that the detection efficiency of the network was to be at least 50 per cent throughout Australia, except for in the vicinity of capital cities and major population centres where it should be at least 70 per cent. No limits were specified for location accuracy, however, numerous comparisons undertaken within the ABM between GPATS data, satellite imagery, and radar reflectivity plots has confirmed that lightning strokes show a good correlation with thunderstorm systems. (Starting in 2008 with the release of an updated data format, GPATS began providing the parameters of an error ellipse for each stroke comprising major and minor axis lengths and major axis bearing. Major axis length values for strokes in the Brisbane area where the CGR4 instrument is located for this comparison are consistently in the range of 250 to 750 m.)

Data sets

Based on registrations obtained by the CGR4 LFC, a data set for Brisbane (2005–08) has been prepared. This data set consists of daily total registrations of NGF, PGF, CF and TF (i.e. GF + CF). To account for different effective radiiues of
lightning flashes, flash densities for NGF, N\textsubscript{pg}, varied from about 43 to 77 per cent (Table 1). For the specific types of year (km–2 yr–1).

The lightning flash densities are denoted as \( N_g \), \( N_p \), \( N_c \) and \( N_t \) for NGF, PGF, GF, CF and TF, respectively, and expressed as a number of flashes per square kilometre per year (km\textsuperscript{2} yr\textsuperscript{-1}).

For 2005, 2007 and 2008, respectively) while the CGR4 LFC detection for CGR4 LFCs during the period of study, flash density for specific types of flashes was derived from the counter registrations. The lightning flash density, defined as the number of flashes of a specific type occurring on or over unit area in unit time, is commonly used to describe lightning activity. The lightning flash densities are denoted as \( N_g \), \( N_p \), \( N_c \) and \( N_t \) for NGF, PGF, GF, CF and TF, respectively, and expressed as a number of flashes per square kilometre per year (km\textsuperscript{2} yr\textsuperscript{-1}).

The GPATS data set for 2005–08 from the ABM Observations and Engineering Branch was also used in this study to derive daily records for NGF and PGF. Strokes were grouped into flashes using an algorithm to compare their spatial and temporal separation, with maximum values of 5km and 1s, respectively, and used to determine if consecutive strokes were to be included in the same flash.

The subset of GPATS data used for this study was centred on the location of the CGR4 LFC in Brisbane, and included strokes within the effective NGF and PGF detection radius of the CGR sensors of 15 km. This value was used to convert number of GPATS events to a flash density in Table 3.

### Results

Records of lightning activity measured in Brisbane by a CGR4 LFC in 2005–08 are presented in Tables 1 and 2. For these four years, significant variation in lightning activity was recorded, with flash densities of TF, \( N_t \), varying from around 2 to 6 km\textsuperscript{2} yr\textsuperscript{-1}, and percentage of GF varying from about 43 to 77 per cent (Table 1). For the specific types of lightning flashes, flash densities for NGF, \( N_g \), varied from around 1.3 to 3.7 km\textsuperscript{2} yr\textsuperscript{-1} and for PGF, \( N_p \), from 0.06 to 0.12 km\textsuperscript{2} yr\textsuperscript{-1} (Table 2). However, little variation was found in the percentages of NGF and PGF: for NGF it was between 95 and 98 per cent and for PGF it was between 2 and 5 per cent (Table 2).

Long-term measurements using CGR3 instruments provided additional information concerning lightning occurrence that was used in this study as a check on the validity of results derived from short-term CGR4 data. In Brisbane, for the nine years July 1995 to June 2004 (for reporting purposes the years are from July to June, covering complete thunderstorm seasons), the mean ratio of positive to negative ground flashes was 0.04 (Kuleshov et al. 2006).

For Darwin, using CGR3 instruments, it was reported that the mean ratio of positive to negative ground flashes was 0.02, for a three-year period between 1987 and 1991 (Mackerras and Darveniza 1994). For the period August 2003 to June 2004, a CGR4 instrument has been in use at Darwin Airport and the proportion of positive ground flashes was 0.04.

On examining GPATS LLS data for 2005–2008 (Table 3), it was found that GPATS’ detection of cloud flashes was somewhat lower than expected—cloud flashes constituted a small proportion of total flashes (0.4, 3.8 and 1.6 per cent for 2005, 2007 and 2008, respectively) while the CGR4 LFC data indicated 57.4, 36.8 and 23 per cent for those years, respectively (Table 1). This resulted in significantly lower values of \( N_p \) as derived from GPATS LLS data (0.0028, 0.0594 and 0.0156 km\textsuperscript{2} yr\textsuperscript{-1}, respectively (Table 3)) compared with \( N_g \) values as derived from the CGR4 data (3.44, 0.8 and 1.17 km\textsuperscript{2} yr\textsuperscript{-1}, respectively (Table 1)). For 2006, GPATS-derived \( N_p = 0.31 \) km\textsuperscript{2} yr\textsuperscript{-1} (21 per cent of total flashes) was still lower compared with \( N_g = 1.79 \) km\textsuperscript{2} yr\textsuperscript{-1} (49 per cent of total flashes) obtained from the CGR4 data.

Comparing detection of ground flashes, it was found from the CGR4 LFC data that GF constituted 43 to 77 per cent of TF (Table 1). As a result of under-detecting CF by the GPATS LLS, derived proportion of GF in the GPATS data was higher, ranging from 79 to 99 per cent of TF for those four years. The \( N_g \) values as derived from GPATS LLS data (0.72, 1.15 and 0.96 km\textsuperscript{2} yr\textsuperscript{-1} for 2005, 2006 and 2008, respectively) were lower than \( N_g \) values as derived from CGR4 LFC data (2.55, 1.85 and 3.76 km\textsuperscript{2} yr\textsuperscript{-1}, respectively) with the exception of 2007 when the \( N_g \) values were comparable (1.37 km\textsuperscript{2} yr\textsuperscript{-1} for the CGR4 LFC and 1.49 km\textsuperscript{2} yr\textsuperscript{-1} for the GPATS LLS).

The ratio of NGF to GF estimated from GPATS LLS data was significantly lower than that for the CGR4 for 2005 and

### Table 1. A comparison of flash densities (km\textsuperscript{-2} yr\textsuperscript{-1}) of GF, CF, TF and the percentage of GF and CF recorded by a CGR4 LFC in Brisbane in 2005–2008.

<table>
<thead>
<tr>
<th>Year</th>
<th>( N_g )</th>
<th>( N_p )</th>
<th>( N_t )</th>
<th>GF per cent</th>
<th>CF per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>2.55</td>
<td>0.34</td>
<td>2.92</td>
<td>42.6</td>
<td>57.4</td>
</tr>
<tr>
<td>2006</td>
<td>1.85</td>
<td>0.17</td>
<td>2.05</td>
<td>50.8</td>
<td>49.2</td>
</tr>
<tr>
<td>2007</td>
<td>1.37</td>
<td>0.08</td>
<td>2.16</td>
<td>63.2</td>
<td>36.8</td>
</tr>
<tr>
<td>2008</td>
<td>3.76</td>
<td>1.17</td>
<td>4.89</td>
<td>77</td>
<td>23</td>
</tr>
</tbody>
</table>

### Table 2. A comparison of flash densities (km\textsuperscript{2} yr\textsuperscript{-1}) of NGF, PGF, GF and a percentage of NGF and PGF recorded by a CGR4 LFC in Brisbane in 2005–2008.

<table>
<thead>
<tr>
<th>Year</th>
<th>( N_g )</th>
<th>( N_p )</th>
<th>( N_c )</th>
<th>( N_t )</th>
<th>GF per cent</th>
<th>PGF per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>2.4263</td>
<td>0.1234</td>
<td>2.55</td>
<td>95.16</td>
<td>4.84</td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>1.7848</td>
<td>0.0633</td>
<td>1.85</td>
<td>96.57</td>
<td>3.43</td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>1.3038</td>
<td>0.0623</td>
<td>1.37</td>
<td>95.44</td>
<td>4.56</td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>3.6769</td>
<td>0.0872</td>
<td>3.76</td>
<td>97.68</td>
<td>2.32</td>
<td></td>
</tr>
</tbody>
</table>

### Table 3. A comparison of flash densities (km\textsuperscript{2} yr\textsuperscript{-1}) of NGF, PGF, GF, CF and a percentage of NGF and PGF derived from GPATS stroke data for Brisbane in 2005–2008.

<table>
<thead>
<tr>
<th>Year</th>
<th>( N_g )</th>
<th>( N_p )</th>
<th>( N_c )</th>
<th>( N_t )</th>
<th>NGF per cent</th>
<th>PGF per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>0.4584</td>
<td>0.2631</td>
<td>0.7215</td>
<td>0.0028</td>
<td>63.54</td>
<td>36.47</td>
</tr>
<tr>
<td>2006</td>
<td>0.5857</td>
<td>0.5687</td>
<td>1.1544</td>
<td>0.3056</td>
<td>50.74</td>
<td>49.26</td>
</tr>
<tr>
<td>2007</td>
<td>1.4784</td>
<td>0.0212</td>
<td>1.4996</td>
<td>0.0594</td>
<td>98.59</td>
<td>1.41</td>
</tr>
<tr>
<td>2008</td>
<td>0.9521</td>
<td>0.0141</td>
<td>0.9662</td>
<td>0.0156</td>
<td>98.54</td>
<td>1.46</td>
</tr>
</tbody>
</table>
2006 at 63.5 per cent and 50.7 per cent respectively, compared to 95.2 per cent and 96.6 per cent for the CGR4. On the other hand, the GPATS-derived ratio of PGF to GF was 36.5 per cent and 49.3 per cent for 2005 and 2006, respectively, compared to 4.8 per cent and 3.4 per cent for the CGR4.

The results for 2007 and 2008 indicate that a change in processing of raw GPATS sensor data, which was implemented in January 2007, moved the above ratios significantly closer to that observed by the CGR4. The ratio of NGF to GF as derived from GPATS data for 2005 and 2006 was 98.6 per cent and 98.5 per cent respectively, compared to 95.4 per cent and 97.7 per cent for the CGR4. The GPATS-derived ratio of PGF to GF was 1.4 per cent and 1.5 per cent for 2007 and 2008 respectively, compared to 4.6 per cent and 2.3 per cent for the CGR4.

Comparing CGR4 LFC and GPATS LLS data prior to 2007 on a daily basis, we found that for individual storms GPATS LLS typically underestimated a number of NGF and overestimated a number of PGF (example of data for Brisbane for December 2005 is given in Table 4). Also note the low detection efficiency of GPATS LLS to CF—only one intra-cloud flash was recorded for December 2005 compared to 483 records by a CGR4 LFC (Table 4).

Discussion

The significant difference in the proportion of NGF and PGF as recorded by the CGR4 LFC and GPATS LLS prior to 2007, and possible reasons for these discrepancies, are discussed in this section. Typically, most GF are negative, and in tropical and subtropical areas, the proportion of PGF is small (e.g. Uman 1987). However, PGF are reported to occur more frequently in winter thunderstorms in parts of Japan, Sweden and Norway (Takeuti et al. 1978; Brook et al. 1982). Nevertheless, results from LFCs demonstrate that PGF typically constitute two per cent to ten per cent of GF. Proportion of PGF at fourteen sites located in eleven countries covering latitudes from 60°N to 27°S recorded by CGR3 instruments has been reported by Mackerras and Darveniza (1994). At thirteen sites, percentage of PGF was in a range from two per cent to fifteen per cent. A higher percentage of PGF (28 per cent) was recorded in Kathmandu, Nepal (Mackerras and Darveniza 1994). These findings were discussed in detail in Baral and Mackerras (1993); possible reasons for the relatively high rate of occurrences of PGF were given as the site altitude, thundercloud charge heights, vertical wind shear and the mountainous nature of the terrain.

Recent results obtained by LLSs in different countries are in agreement with early results obtained by LFCs. We compared long-term lightning statistical data obtained by LLSs in Austria (ten years) (Schulz et al. 2005), Brazil (six years) (Pinto et al. 2006), Italy (seven years) (Bernardi et al. 2002), Spain (ten years) (Soriano et al. 2005), and the USA (five and ten years) (Zajac and Rutledge 2000; Orville and Huffines 2001). This comparison is presented in Table 5.

Based on results obtained by the LLSs, it was confirmed that PGF usually constitute a small proportion of all cloud-to-ground discharges, in the range of about five per cent to ten per cent in all countries where studies have been conducted apart from Austria where a higher value (seventeen per cent) was observed (Schulz et al. 2005). Comparing the monthly distribution of cloud-to-ground lightning flashes as observed by LLSs in different countries, it was suggested in Pinto et al. (2006) that the large difference of the values for Austria with respect to the other countries can be explained by the very short base line of the network in Austria compared to the others.

The detection efficiency of the LLS was reported as 80–90 per cent for GF with peak currents above 5 kA (Cummins et al. 1998). However, during the EULINOX experiment, signals detected by the LLS in Germany were compared with a VHF interferometer, and it was found that 32 per cent of LLS NGF were in fact CF and 61 per cent of LLS PGF were found to be CF (Thery, 2001).

In Australia, during the Down Under Doppler and Electricity Experiment (DUNDEE), which was conducted near Darwin during the wet seasons of November 1988 through February 1989, and November 1989 through February 1990, about 90 per cent of GF were reported as NGF (Petersen and Rutledge 1992). However, results obtained by the GPATS LLS in Australia are different from results in other countries. Conducting the BIBLE experiment near Darwin, the Northern Territory, in December 2000 it was noted that about 80 per cent of GF were reported by GPATS LLS as positive (Koike et al. 2007).

<table>
<thead>
<tr>
<th>Day</th>
<th>NGF (CGR4)</th>
<th>PGF (CGR4)</th>
<th>CF (CGR4)</th>
<th>TF (CGR4)</th>
<th>NGF (GPATS)</th>
<th>PGF (GPATS)</th>
<th>CF (GPATS)</th>
<th>TF (GPATS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>8</td>
<td>172</td>
<td>21</td>
<td>2</td>
<td>4</td>
<td>109</td>
<td>1</td>
<td>283</td>
<td>26</td>
</tr>
<tr>
<td>13</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>46</td>
<td>0</td>
<td>47</td>
<td>0</td>
<td>44</td>
</tr>
<tr>
<td>16</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>4</td>
<td>47</td>
<td>0</td>
<td>48</td>
<td>5</td>
</tr>
<tr>
<td>17</td>
<td>118</td>
<td>27</td>
<td>2</td>
<td>70</td>
<td>92</td>
<td>0</td>
<td>212</td>
<td>97</td>
</tr>
<tr>
<td>25</td>
<td>110</td>
<td>35</td>
<td>3</td>
<td>29</td>
<td>189</td>
<td>0</td>
<td>302</td>
<td>64</td>
</tr>
</tbody>
</table>
Table 5  A comparison of median peak current values of NGF and PGF and a percentage of PGF recorded by lightning location networks in different countries.

<table>
<thead>
<tr>
<th>Country /Data source</th>
<th>Peak current of PGF, kA</th>
<th>Peak current of NGF, kA</th>
<th>Percentage of PGF, per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria (Schulz et al. 2005)</td>
<td>10 (for 2001)</td>
<td>10 (for 2001)</td>
<td>17.0</td>
</tr>
<tr>
<td>Brazil (Pinto et al. 2006)</td>
<td>29.5</td>
<td>26.5</td>
<td>8.5</td>
</tr>
<tr>
<td>Italy (Bernardi et al. 2002)</td>
<td>35.8</td>
<td>22.7</td>
<td>5.0</td>
</tr>
<tr>
<td>Spain (Soriano et al. 2005)</td>
<td>35.3</td>
<td>23.5</td>
<td>9.0</td>
</tr>
<tr>
<td>USA (Zajac and Rutledge, 2000)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| USA (Orville and Huffines, 2001) | 20 | 22 | 10 per cent¹  
(>20 per cent²) |

The high proportion of PGF (up to 50 per cent) recorded by the GPATS LLS in Australia prior to 2007 may be attributed to one or more possible factors, including: (i) changes in the processing of raw GPATS sensor data, implemented in January 2007; (ii) upgrades to sensor firmware; and (iii) the installation of more GPATS sensors. CF could be misclassified as PGF (Mackerras and Darveniza 1992), and sensors might detect the reflected sky wave component rather than the ground wave. The latter situation may come about due to large baseline distances between sensors in the GPATS network resulting in a highly attenuated ground wave signal going undetected by majority of sensors contributing to a solution. By comparison, the corresponding (one-hop) sky wave impulse would be relatively unattenuated and therefore detectable, but inverted in polarity due to its reflection from the ionosphere. As a result of this reversal, the impulse signature of what was originally an NGF may be interpreted as a PGF. A careful analysis of the three possible factors indicates that reduction in the excessive proportion of PGF is mostly explained by changes in processing GPATS sensor data.

Conclusions

A comparison with CGR4 LFC data for a location in Brisbane over the period 2005–2008 has shown that prior to January 2007 the GPATS LLS was reporting an excessive proportion of total GF as being PGF, with a correspondingly low proportion being reported as NGF. Over the same period the CGR4 LFC reported PGF and NGF ratios consistent with those obtained by other researchers both in Australia and elsewhere using a range of instrumentation, including the CGR4’s predecessor, the CGR3. After January 2007, the PGF and NGF ratios reported by the GPATS changed significantly to become more aligned with the CGR4 observations. Indeed, the ratio of PGF to total GF for 2007 and 2008 is somewhat lower than that derived from the CGR4 data and lightning cloud flash density values, \( N_\ell \), are lower by an order of magnitude than those estimated from the CGR4 measurements indicating that further investigation of later data may be required. This transition coincided with an upgrade to the GPATS’ stroke processing software. It is therefore concluded that the polarity of GPATS stroke data prior to January 2007 should be considered in light of the outcome of this study.

References

Improved Lightning Flash Counter. Electra, 66, 85–98.
GPATS website, www.gpats.com.au
Katron website, www.lightning.net.au

¹Over most of the contiguous United States.
²Over the north-central United States and along, and near, the Pacific coast.
³The annual percentage of positive lightning has increased from 3 per cent in 1989 to 9 per cent in 1998. Orville and Huffines (2001) attributed the increase to improved sensor detection capability.


