Australian Meteorological and Oceanographic Journal 64 (2014) 103–108

Climatology of lightning activity in Australia: spatial and seasonal variability

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(Manuscript received received February 2014; revised June 2014)

A climatology of lightning ground flash density is examined for the Australian region based on 18 years of data. The dataset and methodology used are consistent with that of a previous study based on eight years of data. Lightning flash densities are obtained from two satellite instruments—the Lightning Imaging Sensor and the Optical Transient Detector. A climatological map of lightning ground flash density is produced, covering the Australian region, representing the most comprehensive map of its type to date. For the first time, we present (i) maps detailing the seasonal variability of the lightning ground flash densities and (ii) examinations for the maritime regions surrounding the Australian continent as well as for land regions. A notable feature of the climatology is that a maximum in lightning activity during the cooler months occurs over the ocean to the east of the continent. The period of data available for this study is over twice as long as for the previous study, thereby allowing a significant update to the climatology. Results of this study are intended for use in relation to hazards associated with lightning occurrence and applications such as lightning safety standards.

Introduction

Lightning is a dangerous meteorological phenomenon that causes a number of fatalities in Australia each year, as well as significant economic losses. Records dating from 1824–2003 indicate that at least 774 persons in Australia have been killed by lightning strikes, with about three-fifths of these fatalities being work-related (Coates et al. 1993; Blong 2005). Lightning occurrence in Australia is also responsible for considerable damage to infrastructure in built-up regions, such as power lines, as well as a significant proportion of the total area burnt by fires each year (Dowdy and Mills 2012). Consequently, the best available climatology of lightning activity is an important resource for organisations such as government bodies, industry, insurance agencies and emergency services.

Early studies have examined the lightning climatology of Australia, generally based on records obtained by ground-based lightning flash counters (LFCs) (Mackerras and Darveniza 1994; Mackerras et al. 1998; Kuleshov and Jayaratne 2004). In Australia, a network of about 40 LFCs is operated by the Bureau of Meteorology and electric power companies—named the CIGRE-500 (Comité Internationale des Grands Réseaux Electriques, that is, International Committee on Large Electric Systems) as described by Anderson et al. (1979). While ground-based LFCs such as the CIGRE-500 sensors can provide good coverage over time for individual locations, they lack the wide spatial coverage provided by ground-based lightning location systems (LLS) and satellite-based instruments. LLS instruments produce information about lightning strokes occurring within the geographic bounds of a network of sensors (Betz et al. 2009; Pinto et al. 2007, 2013). For example, the National Lightning Detection Network (NLDN) produces reliable observations of lightning occurrence throughout the whole of continental United States (Cummins et al. 1998; Orvile and Huffines 2001). In Australia, a LLS operated by a commercial provider Global Position and Tracking System Pty. Ltd. Australia (GPATS) also covers the whole Australian continent. In addition to providing broad spatial coverage, the GPATS data also provide high temporal resolution, making them useful for applications such as examining individual case studies of lightning activity. However, due to changes over time in GPATS detection efficiency for various different locations throughout the Australian region, such as in

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relation to increasing numbers of sensors being installed in recent years and upgrades to data processing methods, satellite data are preferable to GPATS data for the broad-scale climatological examinations presented here (Kuleshov et al. 2011).

A climatological study of the spatial distribution of lightning activity over the Australian continent was conducted by Kuleshov et al. (2006) based on eight years of satellite data obtained from two NASA satellite sensors: the Lightning Imaging Sensor (LIS) and Optical Transient Detector (OTD), (Christian et al. 2003; Boccippio et al. 2002). The lightning ground flash density map derived by this study is currently included in the Australian / New Zealand Lightning Protection Standard AS/NZS-1768:2007 (Standards Australia 2007). The time period of available satellite-based lightning data is now over twice as long as was available for that previous study, providing the potential for a significantly improved climatological examination to be undertaken. In addition to reducing the influence of interannual variability on the features of the climatologies presented here, the longer period of available data allows greater confidence for examining smaller portions of the data (such as seasonal climatologies) and regions of relatively low flash densities (such as in some of the maritime regions surrounding the Australian continent).

Here we present an updated climatology of lightning ground flash density throughout the Australian region. The climatology is based on OTD and LIS satellite data for a period of 18 years from 1995 to 2012 and the application of the method used by Kuleshov et al. (2006). The average lightning activity over this period can be expected to provide a good representation of the underlying climatology, rather than being characterised by short-term temporal variability associated with phenomena such as El Niño–Southern Oscillation (ENSO), given that this time period includes at least five of each of the three main phases of the ENSO (i.e. the El Niño, Neutral and La Niña—as defined using the classification system of the National Oceanic and Atmospheric Administration (NOAA)). Temporal variability of lightning activity is investigated through examining the lightning climatology individually for the warmer and cooler months of the year. The spatial variability of the climatology is also examined, including for both land and maritime locations throughout the Australian region. An example of extreme maritime lightning activity during the cool season is presented, for which GPATS data are used due to the requirements for this case of large spatial coverage and high temporal resolution.

Instruments, data and methodology

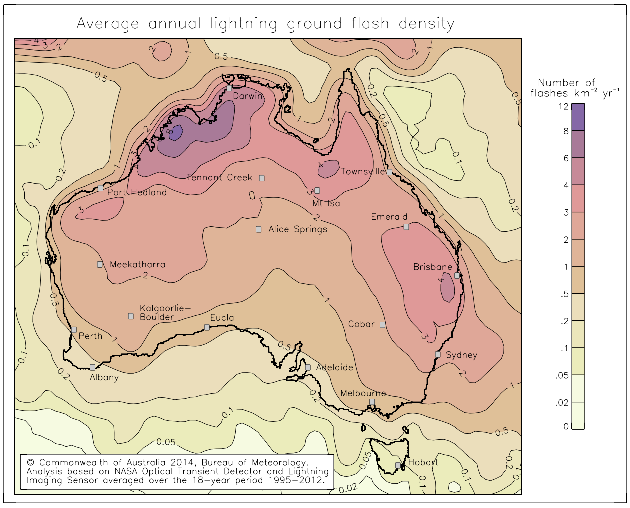
A variety of different observational datasets of lightning activity are available for the Australian region. The datasets vary significantly in terms of their spatial and temporal resolution, coverage, precision and length of records. Consequently, the most suitable dataset to use for a particular purpose is dependent on the specific application required.

Satellite data are used for the climatological investigations presented here. Lightning flash densities are obtained from the high resolution monthly climatology (product name 'LISOTD_HRMC') as described by Cecil et al. (2012). The flash densities are based on satellite data during the time period from 1995 to 2012, obtained from two NASA satellite sensors: the Lightning Imaging Sensor (LIS) and Optical Transient Detector (OTD, Boccippio et al. 2002; Christian et al. 2003). The LISOTD_HRMC product represents the result of merging the LIS and OTD data, including corrections for flash detection efficiency applied individually to each sensor. The OTD was launched into low earth orbit in April 1995 on the OV-1 satellite (formerly MicroLab-1), with this mission ending in March 2000 such that the total period of available data covers about five years. Data from the OTD sensor provides complete coverage throughout Australia. The LIS on the Tropical Rainfall Measuring Mission (TRMM) satellite was launched in December 1997 (Simpson et al. 1988) and is currently operational, providing a dataset that is updated regularly with each subsequent year that TRMM remains operational. Due to its orbit, the LIS sensor provides coverage only within the region from about 38°S to 38°N. Consequently, the LIS and OTD sensors both provide coverage for the Australian continent, while only the OTD sensor provides coverage throughout Tasmania as it is located further south of the field of view of LIS.

The spatial resolution of the dataset is 0.5 degrees in both latitude and longitude, although prior to being released for public use the data were smoothed with a 2.5°×2.5° boxcar moving average (representing an effective spatial resolution of about 250 km for Australia). In this study we apply a subsequent spatial smoothing to maps produced from the LIS and OTD high resolution monthly climatology data, consisting of three grid points in both latitude and longitude (based on the 0.5 degree grid resolution), as it is noted by Cecil et al. (2012) that arid regions and oceans (as is characteristic of a significant proportion of the Australian region) tend to be noisy due to insufficient sampling relating to relatively low flash rates. Cecil et al. (2012) also note that the high resolution versions of the satellite lightning data products show good agreement with the low resolution versions (e.g. the 'LRADC' product described by Cecil et al. (2012) which has a coarser smoothing applied), with the level of agreement being within about 1–10 per cent, with the exception of the high latitudes where only OTD data are available (in which case the agreement is about 30 per cent or better).

To examine lightning activity for a single day with complete coverage throughout Australia, as is required for one case examined in this study, LLS data are obtained from GPATS. The GPATS data are based on the time of arrival of the lightning discharge at a network of three or more radio receivers (e.g. Cummins and Murphy 2009) and represent individual lightning strokes, noting that individual lightning flashes (e.g. as measured by the satellite sensors)

Fig. 1. Map of average annual lightning ground flash density, N_g (flashes km^{-2} yr^{-1}).



may consist of multiple strokes. In southeast Australia, Dowdy and Mills (2009) report that the number of strokes per lightning flash (i.e. the 'multiplicity') closely follows an inverse power law relationship, with an average value of 1.5 strokes per lightning flash. It was demonstrated that the LFC registrations are generally more accurate than the LLS data for the Australian continent for ranges less than 30 km (Kuleshov et al. 2010). However, in preference to the other datasets available for this region, the GPATS data are used here to provide an example of lightning occurrence on a single day due to their finer temporal resolution as compared to the satellite data and their broader spatial coverage as compared to the CIGRE-500 LFC data.

Results

Annual climatology

The satellite lightning flash data consist of total lightning flashes, N_t, comprising the sum of the cloud flashes, N_c, (i.e. intra-cloud or from one part of the cloud to another part of the cloud) and the ground flashes, N_g, (i.e. from the cloud to the ground). Average annual flash densities, N_t, are shown in Table 1, for 19 different locations throughout Australia, highlighting the considerable degree of variation that occurs in the lightning climate throughout the Australian region. In particular, a strong relationship is apparent between flash density and latitude for these locations, with higher (lower) flash densities generally occurring at the more equatorward (poleward) locations.

The ratio, Z, of cloud flashes, N_c, to ground flashes, N_g, was discussed by Kuleshov et al. (2006) in relation to the total lightning flash data obtained from LIS and OTD satellite sensors and the CIGRE-500 sensors, finding that although some variation can occur in the specific value of Z (e.g., depending on the specific location and time period), a value of Z = 2 provides a useful measure of this ratio throughout

Table 1. Annual average lightning flash densities, N_t, during the period 1995–2012, from the LIS and OTD satellite sensors.

Location	*Latitude (°S)*	*Longitude (°E)*	N_t *(km^{-2} yr^{-1})*
Darwin Airport	12.3	131.0	13.4
Townsville	19.1	146.5	4.7
Tennant Creek	19.6	134.2	6.7
Port Hedland	20.4	118.6	4.8
Mt Isa	20.6	139.5	10.0
Meekatharra	26.6	118.5	5.9
Geraldton	28.8	114.7	2.7
Coffs Harbour	30.3	153.1	9.9
Moora	30.6	116.0	2.8
Kalgoorlie – Boulder	30.8	121.5	4.3
Cobar	31.5	145.8	5.6
Eucla	31.7	128.9	2.2
Perth Airport	31.9	116.0	1.9
Ceduna	32.1	133.7	1.2
Port Augusta	32.5	137.8	1.9
Albany	34.9	117.8	1.3
Whitlands	36.9	146.3	3.3
Ballarat	37.5	143.8	2.4
Melbourne Airport	37.7	144.8	2.3

Australia. The same method is used here for broad-scale climatological application in the Australian region.

Figure 1 shows a map of average annual lightning ground flash density, N_g (flashes km^{-2} yr^{-1}), throughout the Australian region, based on the average annual total flash densities obtained from the satellite data, and the ratio Z = 2 of cloud flashes to ground flashes consistent with the method of Kuleshov et al. (2006). The large-scale features of the climatology are broadly similar to previously developed lightning climatologies, including the highest values occurring in the northwest of the continent (N_g > 8 flashes km^{-2} yr^{-1}), with the lowest values occurring in the south and southwest regions of the continent as well as in Tasmania (N_g < 0.5 flashes km^{-2} yr^{-1}). Some small differences are notable in comparison to previous climatologies, such as somewhat higher values in central and eastern Australia than seen in the ground flash climatology based on eight years of satellite data presented by Kuleshov et al. (2006).

The longer period of data used here, in comparison to previous studies, provides a higher degree of confidence that the features apparent in the map of lightning ground flash density (Fig. 1) are a good representation of the climatology, with a reduced influence from short-term interannual variations and variability associated with phenomena such as ENSO and other large-scale modes of atmospheric and oceanic variability.

Fig. 2. Map of average seasonal lightning ground flash density, N_g (flashes km^{-2} season^{-1}) during (upper panel) the Austral warm season (from November to April), and (lower panel) the Austral cool season (from May to October).

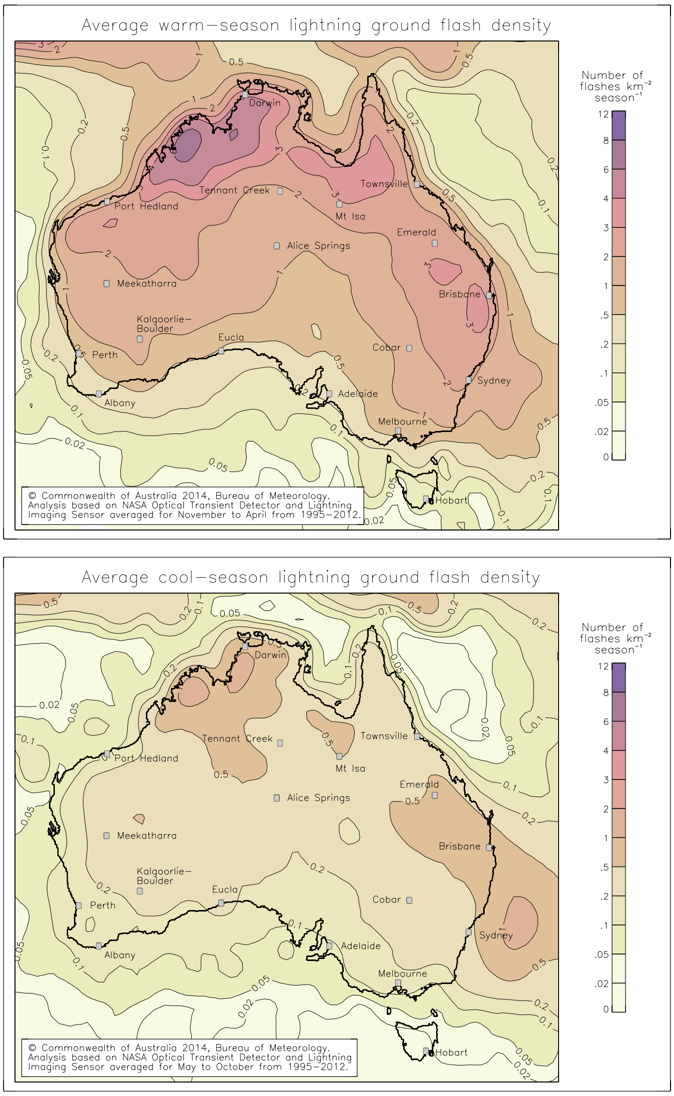
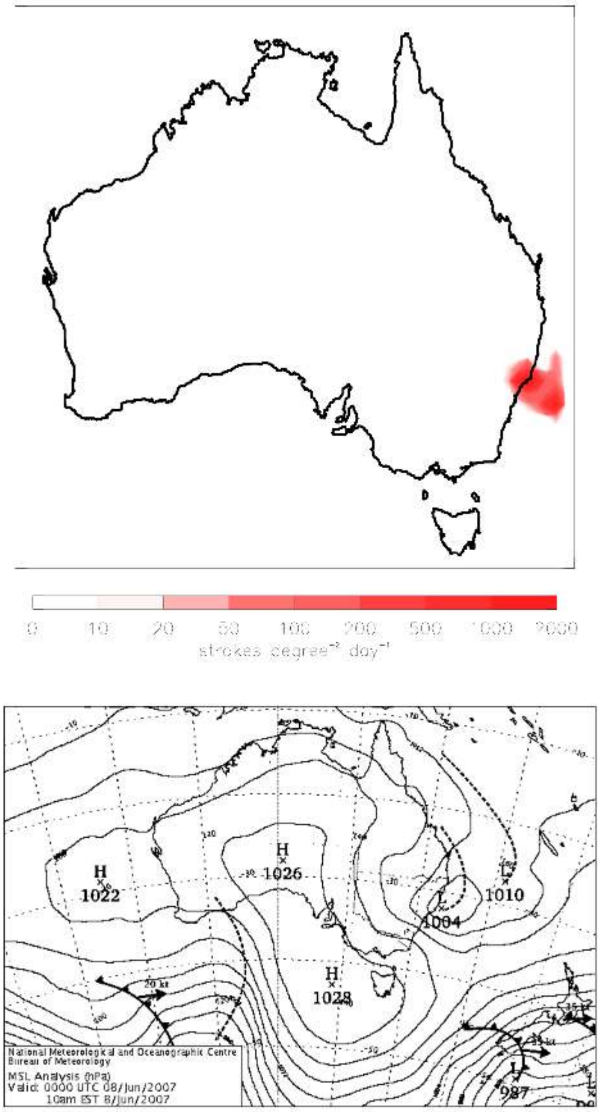


Fig. 3. The 'Pasha Bulker' East Coast Low event: lightning activity (lightning strokes degree^{-2} day^{-1}) from 0000 to 2400 UTC on 8 June 2007 (upper panel). The mean sea level pressure field is also shown, valid for 0000 UTC on 8 June 2007 (lower panel).



Seasonal climatologies

Figure 2 shows climatologies for the southern hemisphere warm season (November to April) and cool season (May to October) of the average seasonal lightning ground flash density (flashes km^{-2} yr^{-1}). The patterns of spatial variability during the warm and cool seasons are broadly similar to the case for the annual climatology (Fig. 1), with local maxima in the northwest and east and minima in the south and southwest of the continent and Tasmania. The majority of the lightning activity occurs during the warm season. This is the case for most locations throughout Australia and the surrounding maritime region. There is also a clear prevalence for lightning to occur over land rather than ocean during both the warm and cool seasons.

A notable feature of the cool season climatology occurs in the maritime region off the southeast coast of Australia, where a local maximum in lightning activity occurs. The lightning flash densities over this part of the ocean are stronger than at any other land location throughout Australia during the cool season, with the exception of the far northwest of Australia where the lightning flash densities are similar in magnitude to this maritime region. In contrast to other locations throughout the Australian region, the flash densities in this region during the cool season (Fig 2(b)) are similar in magnitude to the case for the warm season (Fig. 2(a)).

A potential explanation for the high prevalence of cool season lightning in this maritime region is that it relates to a local maximum in the occurrence of extratropical cyclones during the cool season in this region (as shown in Fig. 4 of Dowdy et al. 2013a). As an example of lightning occurrence associated with an extratropical cyclone in this region, Fig. 3 shows a map of the total number of lightning strokes recorded throughout Australia by the GPATS lightning sensors on 8 June 2007, as well as the map of mean sea level pressure on this day (produced by the Bureau of Meteorology) showing the location of the extratropical cyclone. This was one of the most intense extratropical cyclones in this region (known as East Coast Lows) to have occurred in recent history, and is commonly referred to as the Pasha Bulker East Coast Low in reference to the name of the bulk coal carrier ship that was grounded during this storm (Mills et al. 2010; Dowdy et al. 2013b). Intense lightning activity occurs in the vicinity of the low pressure system. There was over 4000 lightning strokes on this day in the east coast region, with the highest intensity of the lightning activity recorded at any single location (based on a one degree grid in both latitude and longitude) being over 1000 strokes degree^{-2} day^{-1}. However, it is noted that a more detailed systematic examination is required to accurately determine the reasons for this feature of the cool season lightning climatology, as in addition to East Coast Lows there are various other phenomena that could potentially be related to the local maximum in cool season lightning activity in this region, including the occurrence of cold fronts, as well as the warm East Australian Current as a possible source of latent heat fluxes into the cool wintertime boundary layer.

Discussion and conclusions

A comprehensive climatology of lightning ground flash density in the Australian region was presented. Maps of average annual lightning ground flash density were produced, based on the data from the LIS and OTD satellite sensors, following the method of Kuleshov et al. (2006). Climatological maps of lightning ground flash density were presented for the first time with a focus on the Australian region for the Austral warm (November to April) and cool (May to October) seasons, as well as examining features of the lightning ground flash climatology with a specific focus on the Australian region over both land and ocean.

The highest amount of lightning activity generally occurs in the northern parts of Australia, with lower values in the more southern parts of the Australian continent. For example, in Fig. 1 the contour line representing N_g = 2 flashes km^{-2} yr^{-1} runs across the continent from near the central west coast to the southeast coast. The highest lightning ground flash densities occur in the northwestern part of the Australian continent, with N_g values of up to 9 km^{-2} yr^{-1} (corresponding to N_t = 27 km^{-2} yr^{-1}), with this being the region of peak thunderstorm occurrence in Australia (> 50 thunder days recorded per year, Kuleshov et al. 2002). For comparison, the planet's location with the maximum lightning flash density, Kamembe in Rwanda, has N_t = 83 km^{-2} yr^{-1} and 221 thunder days recorded on average per year (Christian et al. 2003), which is considerably higher (i.e. of the order of about three times higher) than the peak lightning flash density in Australia. Analysis of the seasonal climatologies (Fig. 2) clearly indicates that most locations have higher lightning activity over land than over ocean regions and that lighting is predominantly a warm season phenomena in the Australian region, broadly consistent with previous studies of seasonal and temporal variations in lighting activity globally and in the Australian region (Christian et al. 2003; Kuleshov 2004; Blakeslee et al. 2012; Kuleshov 2012).

A notable exception to the general patterns of spatial and temporal variability of the climatology is an area of high lightning activity that occurs during the cool season in a maritime region off the east coast of Australia. The average lightning ground flash densities during the cool and warm seasons are similar in magnitude to each other, in contrast to any other location throughout the Australian region. The winter lightning flash densities in this maritime region are higher than at any other location throughout the Australian region during the cool season, with the exception of the far northwest of Australia where the lightning flash densities are similar in magnitude to this maritime region. There are a range of potential reasons for this anomalously high cool season maritime lightning activity, including the frequent occurrence of intense extratropical cyclones in this region (Dowdy et al. 2013a), as well as the occurrence of cold fronts and the warm East Australian Current, noting that further examinations are required to systematically determine the physical reasons for this feature of the lightning climatology. There are no previously published results examining the potential relationship between extratropical cyclone occurrence and lightning activity in the Australian region, with very few results presented for other regions of the world (e.g. Market et al. 2006, Pessi and Businger 2009).

The resultant climatological maps of ground flash density presented here for the Australian region are the most comprehensive to date to have been developed for this region, with the study period from 1995 to 2012 being over twice as long as available for previous studies. The use of a longer period of data, as compared with previous studies, provides a considerably improved degree of confidence in the climatology, with a reduced influence of features associated with short-term temporal variability and large-scale modes of variability such as ENSO. It also allows improved confidence for examining smaller portions of the lightning climatology (such as for the warm and cool seasons individually) and for examining regions of very low lightning activity (such as some of the maritime regions near the Australian continent). Thus, we recommend with confidence the climatological maps presented here for inclusion in such applications as a current revision of the Australian / New Zealand standard 'Lightning Protection', as well as being suitable for use in a range of different applications such as for use by insurance agencies and electrical power generators and distributors, as well as by emergency management authorities such as in relation to wildfires ignited by lightning.

Acknowledgments

Dedicated to the memory of Dr David Mackerras (1926–2014), a leading Australian lightning scientist.

This work was supported by the Australian Climate Change Science Programme. The authors would like to thank Harald Richter and Paul Hettrick from the Bureau of Meteorology for providing comments on earlier drafts of this paper and 'Lightning Protection' Committee of Standards Australia/Standards New Zealand for providing comments on earlier drafts of the manuscript.

References

Anderson, R. B., H. R. van Niekerk, S. A. Prentice and D. Mackerras. 1979. Improved Lightning Flash Counter, *Electra, 66,* 85–98.

Betz, H. D., U. Schumann and P. Laroche (Eds). 2009. Lightning: Principles, Instruments and Applications, *Springer Science + Business Media B.V.*, 641 p.

Blakeslee, R. J., D. M. Mach, M. G. Bateman and J. C. Bailey. 2012. Seasonal variations in the lightning diurnal cycle and implications for the global electric circuit, *Atmos. Res.*, doi: 10.1016/j.atmosres.2012.09.023.

Blong, R. 2005. Natural hazards risk assessment - an Australian perspective, *Issues in Risk Science 4*, Benfield Hazard Research Centre, London, 28 p.

Boccippio, D. J., W. J. Koshak and R. J. Blakeslee. 2002. Performance Assessment of the Optical Transient Detector and Lightning Imaging Sensor. Part I: Predicted Diurnal Variability, *J. Atmos. Oceanic Technol., 19,* 1318–32.

Cecil, D. J. and coauthors. 2012. Gridded lightning climatology from TRMM-LIS and OTD: Dataset description, *Atmos. Res.*, doi: 10.1016/j.atmosres.2012.06.028.

Christian, H. J., R. J. Blakeslee, D. J. Boccippio, W. L. Boeck, D. E. Buechler, K. T. Driscoll, S. J. Goodman, J. M. Hall, W. J. Koshak, D. M. Mach and M. F. Stewart. 2003. Global frequency and distribution of lightning as observed from space by the Optical Transient Detector, *J. Geophys. Res., 108(D1)*, 4005, doi: 10.1029/2002JD002347.

Coates, L., R. Blong and F. Siciliano. 1993. Lightning fatalities in Australia, 1824–1991, *Natural Hazards, 8*, 217–33.

Cummins, K. L., E. P. Krider and M. D. Malone. 1998. The U.S. National Lightning Detection Network and Applications of Cloud-to-Ground Lightning Data by Electric Power Utilities, *IEEE Trans. Electromagn. Compat., 40(4)*, 465–80.

Cummins, K. L. and M. J. Murphy. 2009. An overview of lightning locating systems: History, techniques and data uses, with an in-depth look at U.S. NLDN. *IEEE Trans. Electromagn. Compat., 51,* 499–518.

Dowdy, A. J. and Mills, G. A. 2009. Atmospheric states associated with the ignition of lightning-attributed fires in southeast Australia. Centre for Australian Weather and Climate Research, Australia, *CAWCR Technical Report No. 19* (available at www.cawcr.gov.au/publications/technicalreports/CTR_019.pdf).

Dowdy, A. J. and G. A. Mills. 2012. Atmospheric and fuel moisture characteristics associated with lightning-attributed fires, *J. Appl. Meteorol. Climatol., 51*, 2025–37, doi: 10.1175/JAMC-D-11-0219.1

Dowdy, A. J., G. A. Mills, B. Timbal and Y. Wang. 2013a. Changes in the risk of extratropical cyclones in eastern Australia, *J. Clim., 26,* 1403–17, doi: 10.1175/JCLI-D-12-00192.1.

Dowdy, A. J., G. A. Mills and B. Timbal. 2013b. Large-scale diagnostics of extratropical cyclogenesis in eastern Australia, *Int. J. Climatol., 10,* 231802327, doi: 10.1002/joc.3599.

Kuleshov, Y. 2004. Seasonal and latitudinal variations of lightning ground flash activity in Australia. *Aust. Meteorol. Mag. 53*, 197–204.

Kuleshov, Y., G. de Hoedt, W. Wright and A. Brewster. 2002. Thunderstorm distribution and frequency in Australia, *Aust. Meteorol. Mag. 51*, 145–54.

Kuleshov, Y. and E. R. Jayaratne. 2004. Estimates of lightning ground flash density in Australia and its relationship to thunder-days, *Aust. Meteorol. Mag. 53*, 189–96.

Kuleshov, Y., D. Mackerras and M. Darveniza. 2006. Spatial distribution and frequency of lightning activity and lightning flash density maps for Australia, *J. Geophys. Res., 111*, D19105, doi:10.1029/2005JD006982.

Kuleshov, Y., D. Mackerras and M. Darveniza. 2010. Spatial Distribution and Frequency of Thunderstorms and Lightning in Australia, Chapter 8, in Lightning: Principles, Instruments and Applications. H.D. Betz et al. (eds), *Springer Science + Business Media B.V.*, 189–209, doi 10.1007/978-1-4020-9079-0_8.

Kuleshov, Y., P. Hettrick, D. Mackerras, M., Darveniza and E. R. Jayaratne. 2011. Occurrences of positive and negative polarity cloud-to-ground lightning flashes: case study for Brisbane, Australia. *Aust. Met. Oceanogr. J., 61*, 107–12

Kuleshov, Y. 2012. Thunderstorm and lightning climatology, Chapter 4, in book *'Modern Climatology'*, Intech, ISBN: 979-953-307-337-7, 85–120pp.

Mackerras, D. and M. Darveniza. 1994. Latitudinal variation of lightning occurrence characteristics, *J. Geophys. Res., 99*, 10,813-21.

Mackerras, D., M. Darveniza, R. E. Orville, E. R. Williams and S. J. Goodman. 1998. Global lightning: Total, cloud and ground flash estimates, *J. Geophys. Res., 103*,19,791–809.

Market, P. S., A. M. Oravetz, D. Gaede, E. Bookbinder, A. R. Lupo, C. J. Melick, L. L. Smith, R. Thomas, R. Redburn, B. P. Pettegrew and A. E. Becker. 2006. Proximity soundings of thundersnow in the central United States, *J. Geophys. Res., 111*, D19208, doi:10.1029/2006JD007061.

Mills, G. A., R. Webb, N. E. Davidson, J. Kepert, A. Seed and D. Abbs. 2010. The Pasha Bulker east coast low of 8 June 2007, *CAWCR Technical Report 23*, 62pp.

Orville, R. E. and G. R. Huffines. 2001. Cloud-to-Ground Lightning in the United States: NLDN Results in the First Decade, 1989–98, *Mon. Weather Rev., 129,* 1179–93

Pessi, A. T., S. Businger. 2009. Relationships among Lightning, Precipitation and Hydrometeor Characteristics over the North Pacific Ocean. *J. Appl. Meteorol. Climatol., 48*, 833–48, doi: 10.1175/2008JAMC1817.1

Pinto Jr., O., I. R. C. A. Pinto and K. P. Naccarato. 2007. Maximum cloud-to-ground lightning flash densities observed by lightning location systems in the tropical region: A review, *J. Atmos. Res., 84*, 189–200.

Pinto Jr., O., K. P. Naccarato and I. R. C. A. Pinto. 2013. Thunderstorm incidence in southeastern Brazil estimated from different data sources, *Ann. Geophys., 31*, 1213-19, doi:10.5194/angeo-31-1213-2013.

Simpson, J., R. F. Adler and G. R. North. 1988. A proposed tropical rainfall measuring mission (TRMM) satellite, *Bull. Am. Meteorol. Soc., 69(3)*, 278–95.

Standards Australia. 2007. *Lightning Protection—Australian Standard/New Zealand Standard 1768:2007*, 199pp, Sydney, Australia and Standards Association of New Zealand, Wellington, New Zealand.