CRC REVIVALS

Lightning Injuries

Electrical, Medical, and Legal Aspects

Edited by

Christopher Joh Andrews, Mary Ann Cooper, Mat Darveniza, David Mackerras

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Lightning Injuries:
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FOREWORD

While I greatly appreciate the opportunity of writing a foreword to *Lightning Injuries: Electrical, Medical, and Legal Aspects,* I should point out that my knowledge of lightning phenomena is associated with the physical rather than the medical side of the subject. Further, this knowledge was largely gained from the 1950s to the 1970s. A study of lightning fatalities in Australia toward the end of this period was relevant to the preparation of an Australian Manual on Lightning Protection, which included a section on personal safety during times of lightning activity. It is appropriate that this topic is fully dealt with in the present volume.

It is also fitting to remind readers that it is just 200 years since Benjamin Franklin died, and to recall his invention of the lightning rod and the innumerable lives it saved. Remarkably, his concept has probably undergone fewer subsequent changes than any other technical innovation of his period.

The editors are to be congratulated on attracting an exceptionally wide range of specialist contributors, thus providing a compendium of the latest information on the medical aspects of lightning injury — an area with many ramifications and uncertainties. The latter include the lack of means of estimating the strength of a lightning flash to ground as it affects a human being. In contrast, it is technically feasible, with special instrumentation, to obtain data on the magnitude of the current in a lightning flash to an inanimate object.

To achieve such a comprehensive coverage as the book provides, Dr. Andrews has clearly drawn on his experience both as an electrical engineer and as a medical practitioner. The outcome is that a balance has been struck between reporting the behavior of lightning as perceived by scientists and engineers and an analysis of its effect on the human body. In the latter connection, I am reminded of a statement by Dalziel in 1961 that, in spite of extensive research, the mechanism of death by lightning remains "entirely speculative". In 1976, Golde and Lee concluded that "while our knowledge of the physiological effects of lightning is not complete, the mechanisms by which it may cause death are fairly well understood...". Now, 15 years later, the most recent progress is well presented in this volume.

Emeritus Professor S. A. Prentice

PREFACE

This book sprang from a germ of an idea in early 1987 — an idea which was, in fact, initially quite different from the final form and content this published volume has grown to embody.

I had just been reemployed in the Academic Department of Electrical Engineering at the University of Queensland after an absence of several years. During that time, I had studied and practiced medicine, and in order to make use of both disciplines in which I had trained, was developing an interest in electromedicine. In a circuitous way, too long to relate here, my interest in lightning injuries was stirred and the fascination with these injuries began to grow.

At the same time, things at the University were changing. New building was occurring, and this entailed first the demolition of an old building inhabited by the Department since World War II. Much archival material was stored in the building and it was fascination itself to sift through it prior to the demolition. My former colleague, David Mackerras, had accumulated much material in his usual thorough way, but for me the material originating with Professor Sidney Prentice held particular interest.

While Professor Prentice taught me in the early 1970s, many others have great cause for gratitude to him. Many Queensland lightning researchers (all?) owe their beginnings and early training to him. It therefore gives me a great deal of satisfaction that he has agreed to write the foreword to this volume.

But Prentice's interests were not only in the physical aspects of lightning. He was among the first to publish a comprehensive examination of death and injury statistics. Remembering this, and my burgeoning interest in the medical aspects of lightning studies, I sought him out in his retirement. I spent an enjoyable morning sitting with him on his home veranda in Brisbane on a sunny tropical day being shown pieces of an amazing collection of accumulated material (from inevitable brown boxes!). Subsequently, it was Prentice who encouraged me to venture onto the international stage in my chosen area of interest, by presenting me with a brochure describing the 1988 Oklahoma Conference on Lightning and Static Electricity organized by Dr. Don McGorman. He also offered a curt, "You should go. And you should present" — both of which I did, with some trepidation and only because of his initiative.

Against this background, then, grew the original idea. Surely someone should bring together the wealth of material accumulated by Prentice and the Queensland group — a sort of collected works. But from there, the idea became bigger than its creator, and drove itself in a different direction.

I became very aware of the uniqueness of lightning injury, and the fact that this was not widely appreciated. Mary Ann Cooper was to play a significant role later in reinforcing this conception. The extant literature was patchy and ill synthesized. Misunderstandings abounded, and speculation was often wild. The most recent review of any comprehensiveness and quality was that of Mary Ann (her chapter in *Management of Wilderness and Environmental Emergencies* edited by Paul Auerbach et al.). The only book I had seen on the topic was Spencer's delightful but largely historic work from the 1930s. Here was a gap desperately needing to be filled. And so the idea progressed. Obvious among the Queensland group to contribute to the work were Mat Darveniza and David Mackerras. Their work needs no introduction and it has been my pleasure and good fortune to work with them — not only on this project. It was also a delight when Mary Ann (who no doubt several years ago wondered who on earth this brash young Australian pestering her with mail really was) joined the team, complementing the technical aspects of the work with her wide medical experience, perhaps the widest currently in the world. And so the editorial group was formed. I then set about harassing a group of experts, worldwide, asking them to contribute sections to the work from the perspective of their own special areas. The quality of the work has been immeasurably enhanced by their contributions, representing those of fine and noted scientists and clinicians in their fields.

I record my thanks to my long-suffering co-editors, and also to the patience of the many contributors over the last 2 years. They can be justly proud of the result. It is also a great pleasure to acknowledge the sympathetic and skillful guidance of Janice Morey and her staff at CRC.

What has been attempted here? The problem with research such as ours is that it spans two quite separate disciplines, different in content and language, and also in fundamental approach —the detailed analysis and modeling of the physical scientist contrasted with the often empirical approach, but also urgent need to treat an immediate problem of the clinical scientist. To find a common language in order to appreciate the respective approaches and contributions is only the first part of the problem. Without input from both sides of the fence, the understanding of and rational basis for therapy for lightning injury is diminished. Mary Ann has reinforced my own thinking along these lines and has been a welcome conscience for technocrats who might otherwise have "gone wild" in trying to communicate their perspective of the topic.

So in this volume we are attempting to bridge a gap. How successful we are remains to be seen, and feedback on this matter will be welcomed. The physical basis of lightning phenomena has been set out with a view to assisting the clinician in understanding the "hard" science underlying the problem. The symptomatology is set out, and an attempt has been made to synthesize the underlying pathophysiology of the injuries. In a sense, the writers of these latter sections have had the most difficult job. Little real pathophysiology is known with certainty, and speculation is rife. The contributors have had the difficult task of presenting what is known, synthesizing competing theories of what is speculative and adding their own critical appraisal, and then pointing to areas for fruitful research regarding what is not known. Treatment has been recommended based on current experience. Technologists will, it is hoped, benefit from the clinical sections, just as the clinicians will from the physical. Legal aspects are assuming greater importance, especially with regard to injuries thought to be transmitted via agencies under control of public utilities, and a chapter explores this matter. Telephone-mediated injury is a special interest of three of the editors and provides an archetype of the latter injury mechanism, and is thus included as an appendix.

The task has been a difficult and challenging one, and it is hoped that we have succeeded.

C. J. Andrews
Brisbane, Australia
December, 1990

EDITORS

Dr. Christopher John Andrews (Chris) was born in Tamworth, New South Wales, Australia, and was educated in Wagga Wagga, NSW, and Brisbane, Queensland. He attended Brisbane State High School and the University of Queensland.

In 1973, he graduated B.E. with first class honors in electrical engineering, and in 1976 was awarded the Master of Engineering Science degree by research, and the postgraduate Diploma of Computer Science. For 2 years he was employed as Senior Tutor in Computer Science, teaching at all levels and pursuing research interests in digital design and microprocessor interfacing.

In 1977, he returned to undergraduate study and was awarded the degrees M.B., B.S., with honors in 1982. He practiced medicine for 2 years full time, and then returned to the University of Queensland where he was employed as a research fellow and lecturer in electrical engineering. During this time, he developed a research interest in lightning and lightning injuries, first examining injuries to patients receiving a shock via the public telephone system. Wider aspects of lightning injury were subsequently added to the research program. Due to his interests in this area, he has become known as an international expert in medical aspects of lightning injury. He has published in the field, and also presented at international symposia in the area. He has also received international invitations to lecture on the subject. He has just submitted his Ph.D. thesis on lightning injuries.

In parallel with the university position, he also pursued part-time medical practice in intensive care medicine, returning full time to this practice in 1989. Currently, he continues the intensive care aspect of his practice and is in private medical practice otherwise. As part of this practice, he regularly is called on to assess and treat lightning-injured patients.

Chris is a senior member of IEEE and IREE, and a member of the Australian Computer Society (ACS).

He is married, with two sons aged five and two. Outside interests include the board of the children's kindergarten, photography, amateur radio, personal computing, fine music, and amateur theater.

Mary Ann Cooper, a native of Indiana, graduated magna cum laude from Michigan State University with a B.S. in biochemistry, and went on to receive her M.D. from the same university in 1974. She was ranked in the top 1% of her undergraduate class and was a member of Phi Beta Kappa. Since completing her years of education, she has garnered a number of awards, two of them for outstanding service in the area of emergency medicine. She has also been written up in *Who's Who of American Women.*

Dr. Cooper has directed, worked in, and trained others for a wide array of emergency medical services. She has been director of paramedics programs in Omaha, Nebraska, Louisville, Kentucky, and Hartford, Connecticut, and has taught emergency medicine at the University of Louisville and the University of Connecticut. She is currently an Associate Professor and Residency Research Director in the Program in Emergency Medicine at the University of Illinois in Chicago.

Through her extensive public service and professional involvements, Dr. Cooper has gained experience in many aspects of medical practice, including neonatal and pediatric intensive care, disaster preparedness, trauma care in the field and in the emergency room, and treatment of burns and electrical injuries.

She has written numerous articles on a variety of medical emergency topics, most notably on the care of lightning injuries, and has authored three books on related subjects. Dr. Cooper is an acknowledged authority on lightning injuries, and has appeared on local and national television and at dozens of lectures and conferences to discuss both the treatment of these injuries in particular and critical care in general.

Recently she has added a new responsibility to the many she already juggles: the care and treatment of her new baby.

Mat Darveniza, born in 1932 at Innisfail, Australia, is a graduate of the Universities of Queensland (B.E., 1953; D. Eng., 1980) London (Ph.D., 1959), and Chalmers University (Hon. D.Sc. Eng., 1990). He has worked in the electricity supply and manufacturing industries and at universities in Australia, U.S., Germany, Argentina, England, and Sweden.

Since joining the University of Queensland in 1959, his research and consulting interests have included lightning protection, high voltage and insulation engineering, and engineering education. He has over one hundred scientific and engineering publications, including a book entitled *The Electrical Properties of Wood and Line Design.* He is a regular contributor to international conferences and continuing education courses, often as the guest lecturer.

Professor Darveniza has a Personal Chair and between 1983 and 1987 was Head of the Department of Electrical Engineering. He is a Director of UniQuest Pty Ltd. and of NATA (National Association of Testing Authorities), Australia.

Professor Darveniza is a Fellow of IEEE, the IEAust, and the Australian Academy of Technological Sciences and Engineering.

He is married with three children. His recreations include music, squash/tennis, and surfing/windsurfing.

David Mackerras was born in 1926 in Sydney, Australia, and is a graduate of the University of Sydney (B.Sc., 1950; Dip. Ed., 1952) and of Queensland (B.E. Honors, 1960; Ph.D., 1971). He has worked in the NSW Department of Education, in the electricity supply industry, and in the Electrical Engineering Department, University of Queensland (1961 to 1988).

Since joining the University of Queensland, his research interests have included a study of the occurrence and characteristics of lightning in southeast Queensland, lightning effects in telecommunication systems, and the analysis and display of speech characteristics for therapeutic and diagnostic purposes.

He has authored about 60 scientific and engineering publications and reports, mainly related to the above topics. He has carried out several major consultations relating to lightning damage prevention and protection from electromagnetic hazards for Telecom Australia, the Department of Defense, and other organizations.

Since retiring from the Electrical Engineering Department in December 1988, he has continued to serve on the Committee on Lightning Protection of the Standards Association of Australia, is continuing consulting work on lightning protection, and is continuing a joint project with Mat Darveniza on the worldwide survey of the cloud-flash-to-ground-flash ratio using CGR3 instruments.

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CONTENTS

Chapter 1

LIGHTNING — THE MYTHOLOGY PERSISTS

M. A. Cooper and C. J. Andrews

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Lightning has played a prominent part in almost all ancient religions and has a great deal of mystery and mythology surrounding it to this day, both because it is difficult to study and because it is so wondrous and awe inspiring when it occurs

I. RELIGION

Even the earliest peoples saw lightning as a powerful force. Lightning could not only destroy, but could also protect and warm a person by providing a source for fire before people learned to start and propagate fire at will.

Some primitive peoples characterized lightning as an animal or bird, including the American Indian, the Bantu of South Africa, and the Aborigine of western Australia. Witch doctors and magic men from various cultures were believed to have power to allay storms and to call on the gods to deliver water to their people or destruction to their enemies. They often used charms and potions made of wood, stones, or plants that were connected to lightning in their belief systems to cause harm, bring about favorable outcomes, or cure disease.

Lightning appears prominently in the Buddhist, Druidic, and ancient Egyptian religions. It was used by Jove, Jupiter, and Thor to express their power and often their anger in the ancient Greek, Roman, and Norse religions, respectively. Priests used storms and lightning as omens to interpret the wishes of the gods and control matters of state. Even in Judaic and Christian writings, it was seen as a sign of a superior being's presence, being noted several times in the Old Testament. In the middle ages, church bells were rung to break up thunderstorms and avert lightning. Churches were felt to be protected by God and were sometimes used for munitions storage, with spectacular explosions on more than one occasion. Uman[1] draws attention to the fact that the fifth day of the week must have been particularly important. The Anglo-Saxon Thursday is derived from the Norse Thor's day and has equivalence in the Danish Thorsday, the German Donnerstag (thunder day), and the Italian Giovedi (Jove's Day).

The Second International Conference on Lightning and Static Electricity (Oklahoma, 1988) chose the mystical thunderbird as its emblem. A modern automobile also uses the name of Thunderbird, so one can see that the feeling of power from lightning is still important to our culture.

Such is the penetration of these beliefs that the reports of the strike to York Minster, where the cathedral was struck the day before the enthronement of one of England's most controversial bishops, even today betray a superstitious belief in omens and warnings from the Deity.

II. SCIENCE

Aristotle, Socrates, and Pliny all made observations about lightning. Herodotus and, more recently, da Vinci also described lightning phenomena, but without defining it further. It remained for Benjamin Franklin, the "Father of Electricity", to determine that lightning was a form of electricity and to do many simple but elegant experiments that helped to define some of the basic properties of lightning and electricity. Franklin's "invention" of the lightning rod, which to this day remains almost unmodified, may have been the first practical application derived from the study of electricity.

More recently, it has been postulated that lightning may have had a part in the formation of life as we know it on earth. Urey and Miller suggest that lightning catalyzed the original linking of water, hydrogen, and nitrogen (in the form of ammonia and methane) into amino and nucleic acids, the building blocks of organic life, and carried out experiments that seem to support their hypothesis.

Medical knowledge regarding the pathophysiology of lightning injury was unformed until Critchley's pioneering work in 1932, although Jex-Blake began some early work in 1913. This theme is elaborated elsewhere in the volume.

III. MODERN MYTHOLOGY

Despite all that we know about lightning, there are still many myths that surround it. Probably the most common belief is that injuries from lightning are rare and, when they occur, are invariably fatal. While the incidence of lightning injuries varies by the part of the world and the topography of the land, they are quite common in many areas. Between 150 and 200 deaths from lightning are reported each year in the U.S., with a much larger number of nonfatal injuries occurring.

In their reviews of the medical literature, Cooper[2] and Andrews et al.[3] have shown that lightning injuries are fatal in only 20 to 30% of the cases, depending on how the data are analyzed. Given that usually only the most serious or "special-interest" cases are reported in the literature, extrapolation of these reports suggests that there are probably a minimum of 600 to 1200 injuries per year in the U.S. that often are of only minor degree. In a 2-week period in the summer of 1989, 21 persons in the Chicago area were involved in four different incidents, with only one death occurring. Lightning injuries are much more common in areas where there are large bodies of water (such as the Great Lakes, the Ohio, Mississippi, and Hudson river valleys, along the Atlantic coast, and in the Florida swamplands) than in desert areas or along the Pacific coast, although the western plains of the U.S. can provide wonderful lightning displays as well. Mountainous areas tend to have a greater number of lightning strikes and injured persons than flatlands.

Another myth could be called the "crispy critter" myth: the idea that when lightning strikes a victim they are burned to a crisp, vaporized, or reduced to a tiny pile of dust. Whenever one lectures on lightning, as the audience warms to the question-and-answer period, someone will invariably ask with a slightly embarrassed expression whether lightning is responsible for the stories told about persons walking down the street who burst into flames without apparent cause. Fortunately, the idea of vaporization and spontaneous combustion is the figment of several science fiction writers' and sensationalists' imaginations and has no basis in fact.

However, many quite reasonable and intelligent people believe that anyone hit by lightning will be severely burned, perhaps beyond recognition and repair, because of lightning's tremendous energy and violence. Fortunately, lightning seldom causes deep burns, but usually results in very superficial damage to the skin and soft tissues, although it may play havoc with the cardiac and neurological systems as it interferes severely with the body's natural electrical circuits. While burns from lightning can occasionally mimic the burns seen with high-voltage electrical injuries, this is quite rare, probably because of the brief time course involved in a strike.

Mystery and fantasy still surround lightning. One of the sensationalist rumor sheets sold at the checkout line in many grocery and drug stores in the U.S. recently reported the story "Lightning Turns Man into Woman". One might understand how lightning could result in emasculation and a necessary switch to the female sex if a part of the "crispy critter" myth were operational, but it is difficult to understand how lightning could turn a woman anatomically, physiologically, or genetically into a man.

Many persons who might otherwise have survived their lightning injuries have died because bystanders believed that the victim was "electrified" by the strike and could electrocute the rescuers if they attempted to aid the victim. While lightning energy can spread through the surface of the ground and backflash through pipes, wires, and other metal objects, this happens in a few hundredths of a second and the lightning energy does quickly dissipate and will not harm anyone who would touch the victim.

However, a victim who has been hit by lightning may be in an area that continues to be dangerous during a thunderstorm, since lightning can and often does strike the same place twice (despite the popular belief to the contrary). It is only logical that if conditions favor a lightning strike occurring once, lightning may strike again under the same conditions. For instance, tall buildings are struck many times each year, and sometimes in a single thunderstorm, which is one reason that properly designed lightning protection systems are so important. Thus, it is prudent not to subject a rescuer to excess risk in this manner, and removal of a victim from a risk area in accord with the usual practice of first aid is wise, but not for the reason of residual electrification!

A notion that continues to occur in the medical literature is that lightning causes a state of "suspended animation", so that a lightning victim can recover from a prolonged cardiac or respiratory arrest without any brain damage. The initial report on which this belief is based cited a pediatric case that did not have a documented prolonged arrest. In addition, the original report claimed that the child recovered from the arrest (the management of which included open chest cardiac massage) with an IQ higher than that tested prior to the injury, which is difficult to accept. There have been other anecdotal reports similar to this, but there exists no experimental evidence for believing that a lightning victim who receives prolonged cardiopulmonary resuscitation will be protected from hypoxic brain damage or will have their mental abilities improved by the lightning stroke. The preponderance of evidence is quite contrary to this and in agreement with the current literature on cardiac arrest.

Some people believe that the victim will be spared cardiac damage if the lightning travels over the right side of the body (thus "avoiding" the heart, which is thought to be on the "left" side of the body). Lightning energy may "flash over" the exterior of the victim's body, markedly decreasing the cardiac insult. Alternatively, lightning energy may penetrate the body. Electrical energy treats the soft tissues of the body like a continuous medium, although it does have a tendency to travel through the areas of the body that offer the least resistance, especially the blood vessels. These pathways lead readily to the heart. Even if the energy did flow over only one side of the body, a cursory study of human anatomy shows the heart to be situated in the center of the chest, extending into both sides with only a slight preponderance into the left chest, so that it would be affected regardless of the "side" struck.

Other myths concern the degree of protection a person has if they are inside a building. Unfortunately, there are multiple reports of persons being injured by flow of current through plumbing, telephones, electrical appliances, or other conduits, although they are within a building. Small open-sided sheds, tents, and soft-top automobiles all offer substantial risk to the person caught in a violent thunderstorm.

Many people believe that rubber, in the form of tires or shoe soles, is a good insulator against lightning. Since lightning can traverse a mile or more of air, which is a much better insulator than rubber, an inch or less of rubber (or more likely a petroleum by-product) cannot be counted on to protect a person. The recommendation that persons take off the raincoat they are wearing and place it on the ground to insulate themselves in a storm is even more ludicrous.

Lightning, as a spectacular natural phenomenon, has had a large mythology generated about it. Many "modern myths" have hampered not only effective resuscitation of lightning victims, but also research in this area.

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Chapter 2

PHYSICS OF LIGHTNING

Martin A. Uman

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I. INTRODUCTION

In this chapter, we examine those aspects of lightning important to an understanding of lightning injury and death. We first discuss the characteristics of lightning and then consider briefly the mechanisms by which that lightning causes damage, injury, and death. A more detailed discussion of the electrical aspects of lightning events is found in Chapter 3.

II. HOW MUCH LIGHTNING IS THERE?

Brooks,[1] in 1925, on the basis of worldwide weather station data on the occurrence of thunder, estimated that the global lightning flash rate, both cloud and ground discharges, was about 100/s. Modern measurements made with satellites[2-4] are in reasonably good agreement with this early estimate. A global flash rate of 100/s represents a global flash density, the number of lightning flashes per unit area per unit time, of about 6 per square kilometer per year (km^{-2} yr^{-1}), which would appear reasonable considering the data on flash density over land to be presented next and the fact that there is less lightning over the oceans than over the land.

Prentice[5] has summarized much of the published and unpublished data on average lightning flash density. For example, southeast Queensland, Australia has a total (cloud and ground discharges) flash density of 5 km^{-2} yr^{-1}, of which 1.2 km^{-2} yr^{-1} are ground flashes; Norway, Sweden, and Finland have measured ground flash densities between 0.2 and 3 km^{-2} yr^{-1}, depending on location; and South Africa has ground flash densities from below 0.1 to about 12 km^{-2} yr^{-1}, depending on location. Flash density maps and the statistics noted above are given by Prentice and Mackerras[6] and Mackerras[7] for Australia, by Muller-Hillebrand[8] for Scandinavia, and by Anderson[9] and Anderson and Eriksson[10] for South Africa.

Piepgrass et al.[11] measured the total (cloud and ground discharges) flash density at the Kennedy Space Center in Florida during the months of June and July, 1974 through 1980. Total flash densities ranged from 3.7 km^{-2} mo^{-1} in 1977 to 21.9 km^{-2} mo^{-1} in 1975. The mean of 6 years was 12 km^{-2} mo^{-1}, with a standard deviation of 8 km^{-2} mo^{-1}. From the ratio of cloud flashes to ground flashes reported by Livingston and Krider,[12] Piepgrass et al.[11] estimate a mean ground flash density of 4.6 km^{-2} mo^{-1}, with a standard deviation of 3.1 km^{-2} mo^{-1}.

Maier et al.[13] mapped geographic variations of flash density in south Florida. Their results show that, due to local meteorological effects that occur along the Florida coastline, flash density may vary by an order of magnitude over distances from the coastline inland 20 to 30 km. Most of the lightning occurs inland due to the effect of the sea breeze in producing storms there, and relatively little occurs along the coastline. Darveniza and Uman,[14] in the Tampa Bay area of Florida, found that the ground flash density, averaged over 2 years, determined from seven CIGRE 10-kHz flash counters was between 7 and 17 flashes km^{-2} yr^{-1}, depending on the assumptions made about the effective range and counter response to cloud flashes. A CIGRE 500-Hz counter, based on the extrapolation of 4 months of summer measurement and with an effective range and cloud flash response determined in Australia, gave a yearly ground flash density of 9.5. A two-station magnetic direction finding system operated only during the summer months gave an extrapolated yearly ground flash density of 12.9 ± 5.2 km^{-2} yr^{-1}.

Ground flash density has, until the recent development of sophisticated lightning location systems such as the magnetic direction finding networks used by Maier et al.[13] and by Darveniza and Uman,[14] not been considered a simple parameter to measure. The thunderday level, the number of days per month or year on which thunder is heard, is more easily measurable and hence has been recorded at most weather stations worldwide for many years. A world thunderday map is found in Figure 1, and a thunderday map of the U.S. is given in Figure 2. A considerable effort has been made to relate the thunderday level, for which there are considerable statistics, to the flash density, for which there is relatively little, since it is a knowledge of the

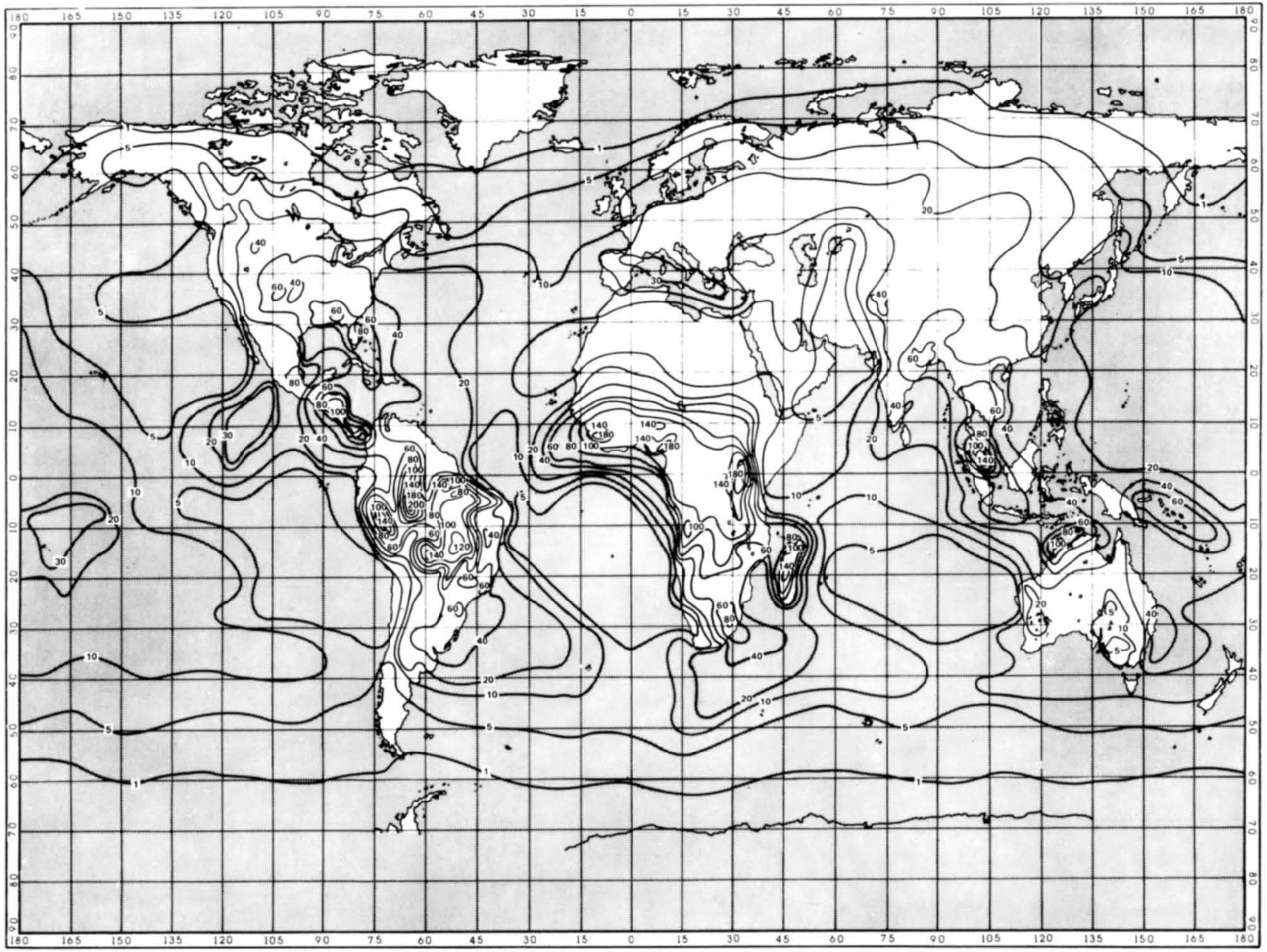

FIGURE 1. World Thunderday Map. Mean annual days with thunderstorms. (Adapted from *World Distribution of Thunderstorm Days, Part 2. Tables of Marine Data and World Maps,* World Meteorological Organization Publ. 21, Geneva, Switzerland, 1956.)

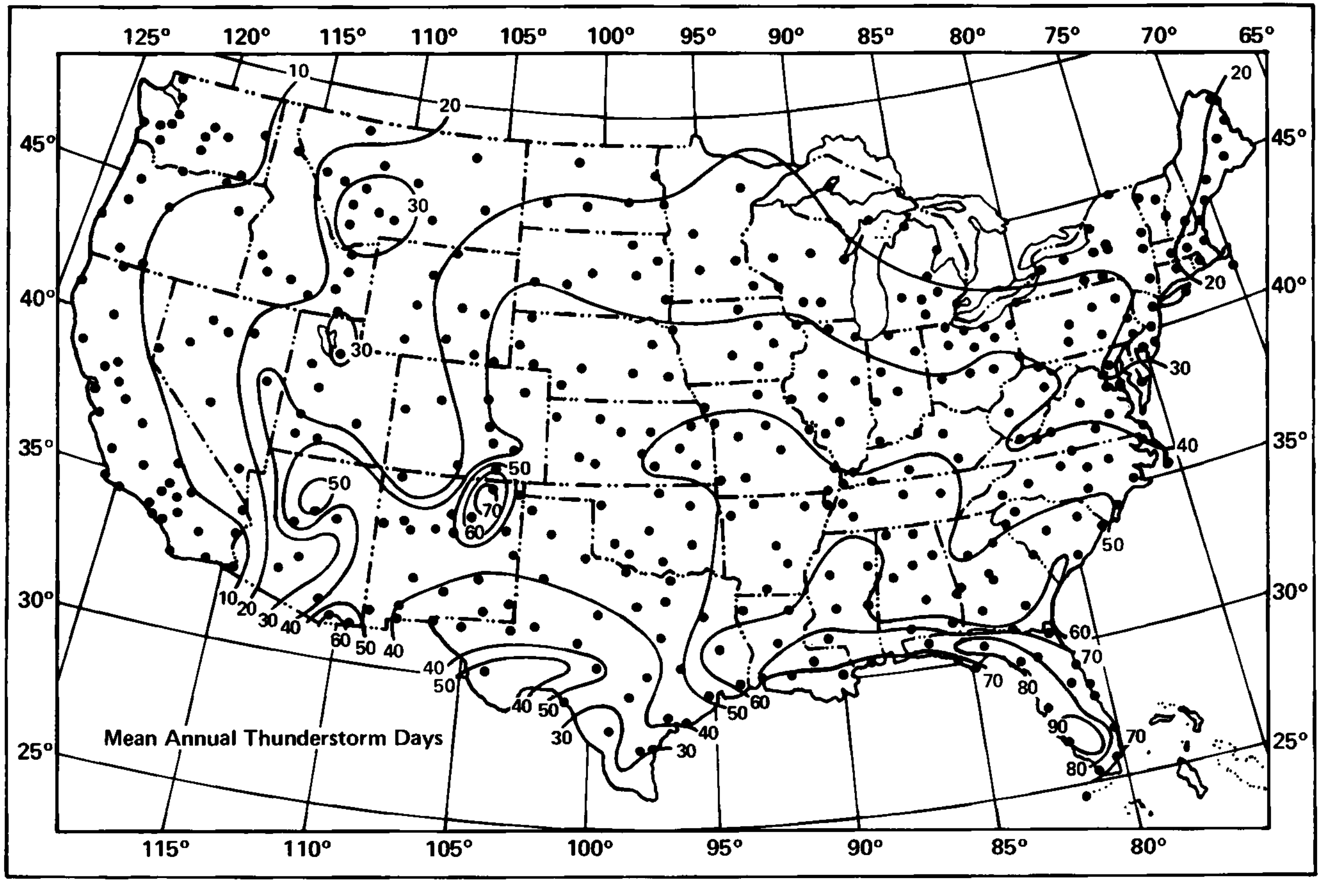

FIGURE 2. A thunderday map of the U.S. compiled from data from 450 air weather stations shown as dots. Most stations had 30-year records and all had at least 10-year records. (Adapted from MacGorman, D. R., Maier, M. W., and Rust, W. D., Lightning Strike Density for the Contiguous United States from Thunderstorm Duration Records, NUREG/CR-3759, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, Washington, D.C., May 1984.)