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Lightning fatalities in Singapore

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Summary

A study of the statistics of lightning deaths and the correlation with social and environmental circumstances was conducted for the island Republic of Singapore. While data were available as far back as 1922, the lack of recorded details of the circumstances of death resulted in a smaller data base for analysis.

Data were analysed for significant patterns or changes in lightning fatalities per million population, sex composition, age, monthly variation, diurnal variation, location, recreation/work ratio, elevation, severity of lightning incident, type of bodily injury, ratio of deaths to injured in an incident, and lightning fatality risk in Singapore.

The results of the analyses were compared with those of studies undertaken in temperate countries. As a result of the study, personal safety rules relevant to the Singapore environment have been proposed.

1. Introduction

Several detailed studies have been made on the statistics of lightning fatalities. In particular, Zegel (1967) surveyed lightning deaths in the USA from 1959 to 1965 and Prentice (1972) conducted a 25 year study (1945–69) on fatalities in Australia. Other countries with statistical studies include Republic of South Africa, German Federal Republic, Austria, Hungary and United Kingdom.

With its high thunderstorm frequency, the island Republic of Singapore seemed a good choice for a study of lightning deaths in an equatorial location. Data sources were (a) Meteorological Services Singapore, (b) Coroner's Courts, (c) Report on Registration of Birth and Deaths, (d) Department of Pathology, Ministry of Health, (e) daily English and Chinese newspapers. Individual deaths due to lightning could be traced back as far as 1922, but details of cases were only available from 1956 onwards. However, even from 1956, not all relevant data in each case were available. This lack of data showed up in the various forms of analysis attempted.

2. Thunderstorm and lightning frequency and distribution

Singapore experiences an average of 181 thunder days and 229 lightning days per annum (1961–78 average). These numbers may vary quite substantially from year to year (Fig. 1). The annual number of thunder days has varied from 150 to over 200, and that for lightning days from 150 to close to 300.

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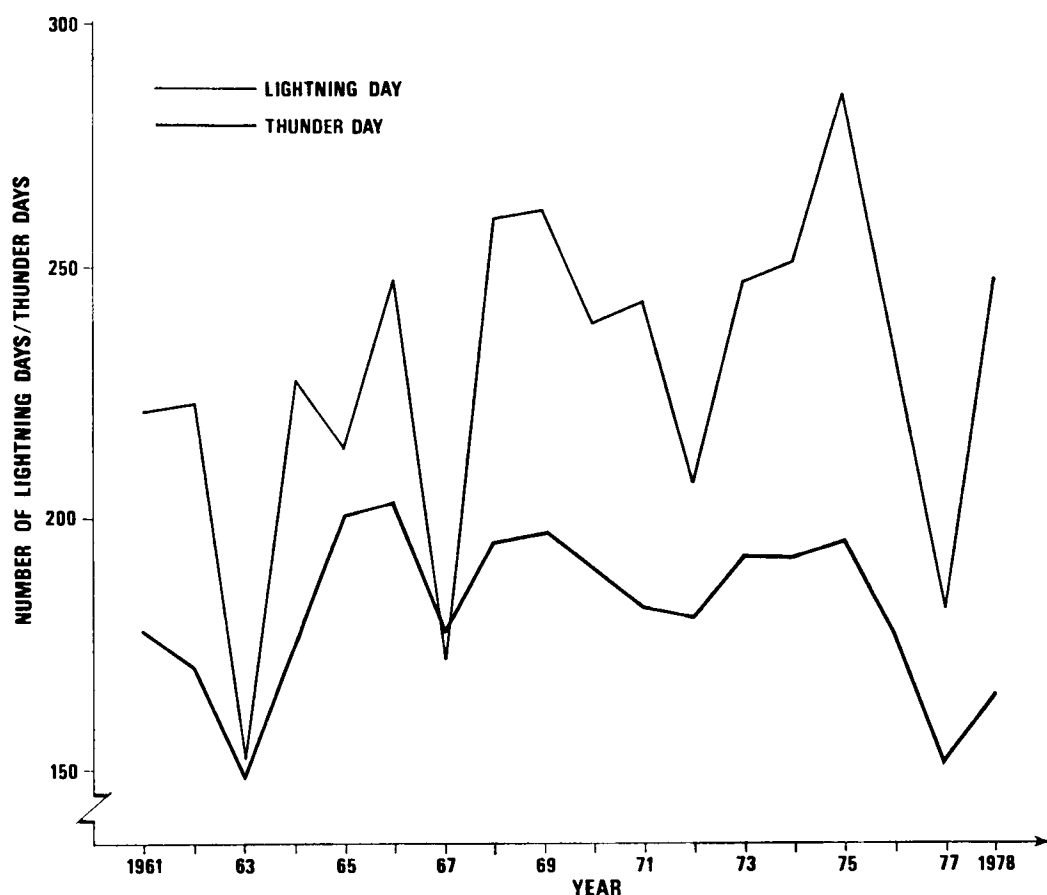


Figure 1. Variation of annual lightning days and thunder days in Singapore, 1961–78.

The seasonal distribution of the number of thunder days and thunderstorms is bimodal (Fig. 2). Two peak periods in April and November with about 20 thunderstorm days/month are separated by minima of 5 and 15 in January and July.

As might be expected, most of the thunderstorms occur in the late afternoon (Fig. 3).

3. Lightning fatalities/million

Lightning fatalities/million population were calculated for the period 1922–79 and are plotted in Fig. 4. Data for the year 1938 were not available. A unitary filter of order 4 (0.125, 0.250, 0.250, 0.125) was also plotted (Craddock, 1968).

The graph shows a gradual decrease in lightning deaths/million over the 58 year period. This can be more readily concluded when the means for the periods 1922–1941, 1942–1960 and 1961–1979 are calculated. The mean number of deaths/million for these periods is 2.6, 1.8 and 1.7 respectively. These values show that, in recent years, the number of lightning fatalities has remained constant at about 1.7/million.

Other countries such as USA, Australia and the U.K. (Zegel 1967, Prentice 1972) show a similar

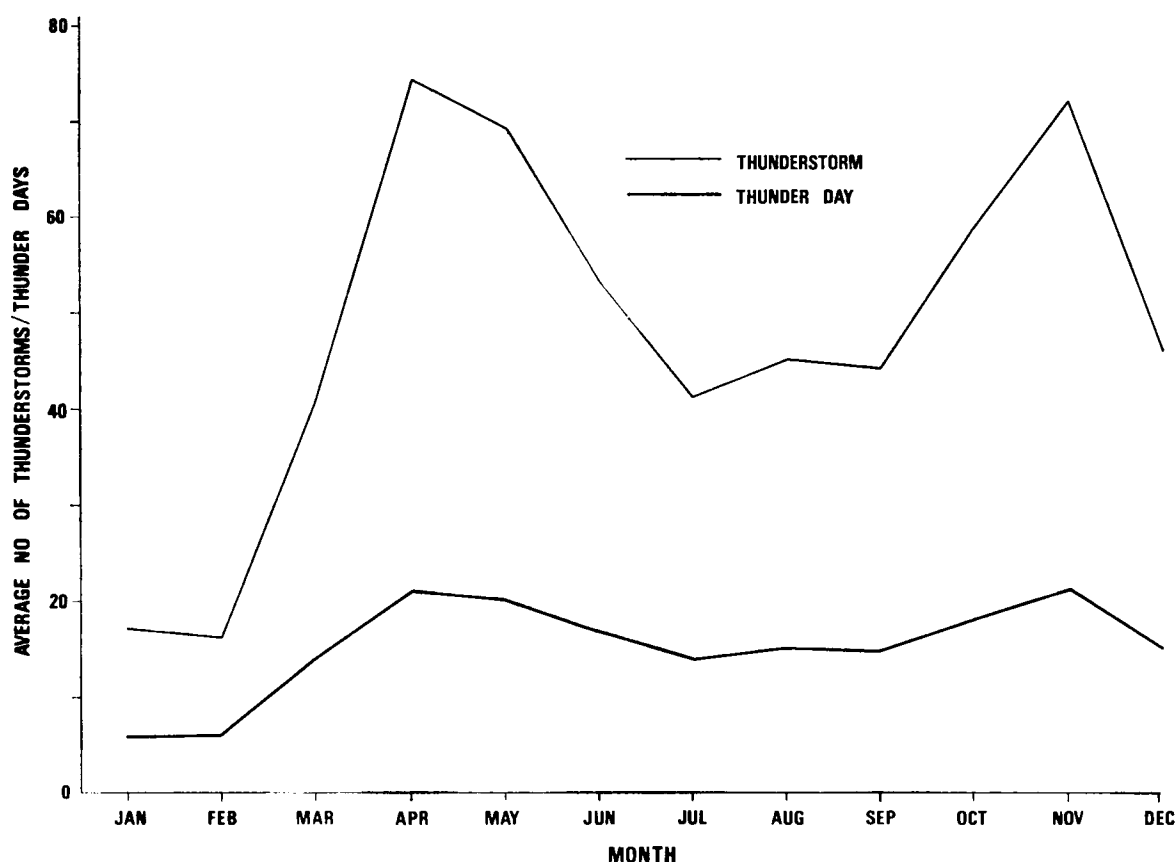


Figure 2. Average number of thunderstorms and thunder days per month in Singapore, 1961-78.

declining death rate, owing to better public education and increasing urbanization. Values of death rates for other countries and a comparison with Singapore are given in Table I.

The table shows that Singapore has the highest death rate of those countries examined. This may be attributable to the year-round high thunderstorm frequency.

Table I. Comparison of death rate/million for various countries

Country	Period	Death rate/million per annum
United Kingdom	1951-60	0.2
Australia	1950-60	0.4
United States of America	1959-65	0.6
German Federal Republic	1952-60	0.8
Austria	1964-68	1.3
Republic of South Africa	1963-69	1.5
Republic of Singapore	1961-79	1.7

4. Sex composition

For the years 1956 to 1979, there were 80 deaths, of which 66 were male and 14 female. The male/

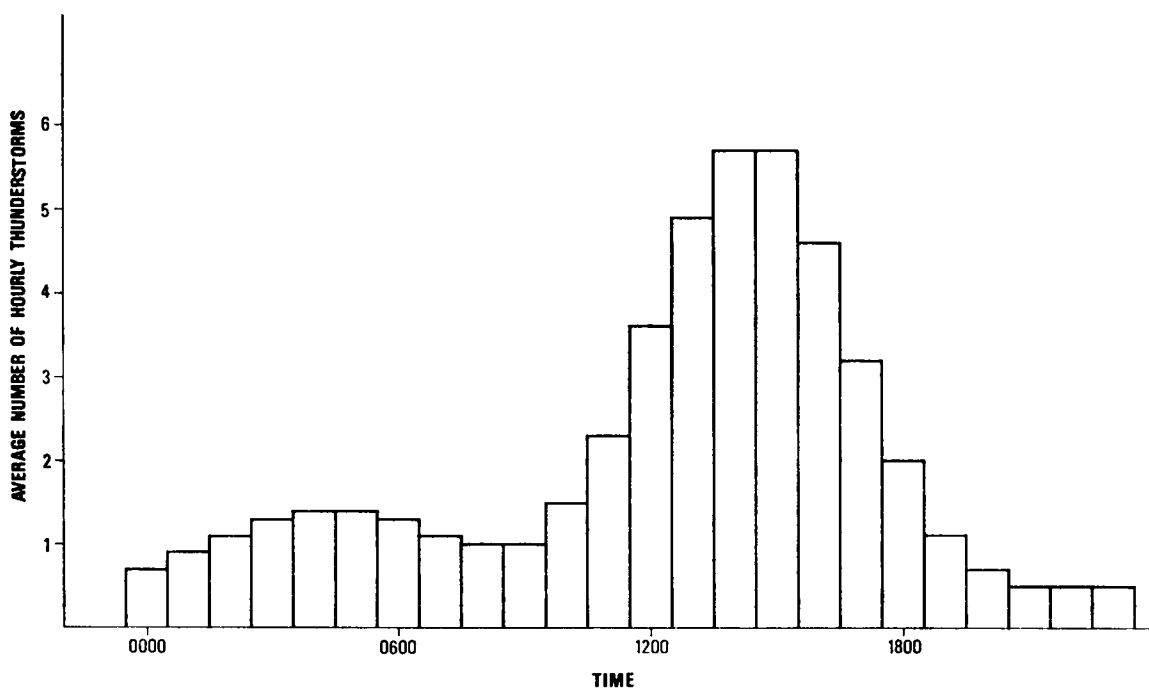


Figure 3. Diurnal distribution of hourly thunderstorms in Singapore (local time).

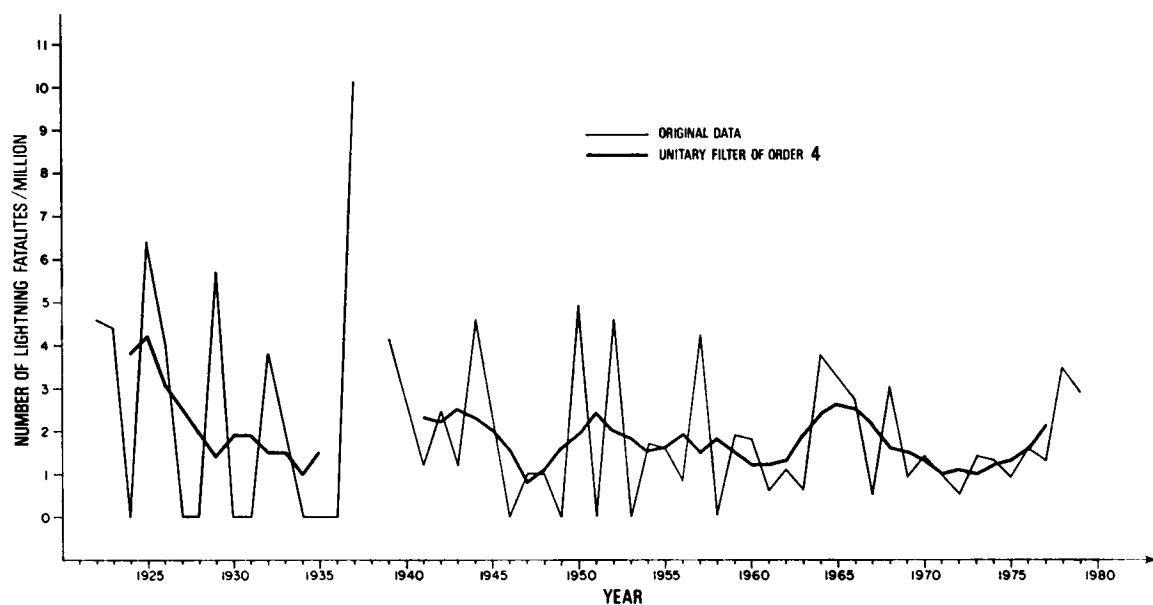


Figure 4. Annual variation of the number of lightning fatalities per million population.

female ratio is 4.7. Females only accounted for 17½% of the total fatalities, though the female sex composition for the whole population in 1967 was 48%.

The disproportionate number of female deaths can be attributed to the nature of work, with most outdoor activities being performed by males.

Similar high male/female ratios have been recorded in Australia (4.5) and USA (death and injury, 3.0–5.7).

5. Age

Table II gives the distribution of deaths caused by lightning accidents by age group for the 24 years of record. The greatest number of deaths occur in the age groups of 10–19 and 20–29. A comparison with the age distribution of Singapore's population for 1967 shows that about 58% of the deaths occur in these age groups, representing 38% of the population.

Young people are prone to lightning accidents because of their ignorance of dangers involved when lightning is nearby. The age group of 20–29 would also include those able-bodied workers who could be working in the open and who probably did not exercise the necessary precautions.

Comparison with other countries shows similar statistics. In the USA, 22% of those killed by lightning were under 18, whilst in Australia, 23% were between 10 and 19 and 30% between 20 and 29.

Table II. *Distribution of lightning deaths by age composition for 1956–79.*

Age group Years	Number of fatalities	Percentage of total number of deaths	Percentage of age group of total population for 1967
0–9	7	8.7	29.5
10–19	25	31.3	24.5
20–29	21	26.3	13.9
30–39	12	15.0	11.8
40–49	13	16.3	8.6
50–59	1	1.3	6.7
60–69	1	1.3	3.6
70+	0	0	1.4
Totals	80	100	100

6. Monthly variation of lightning deaths

Fig. 5 shows the distribution of the number of lightning fatalities by month for the period 1956–79. The maximum number of deaths due to lightning occurs in the month of November. This is 20 times more than the minimum which occurs in July. The second highest monthly death toll occurs in April.

The peak monthly periods of death correlate well with the peak monthly periods of thunderstorm activity (Fig. 2).

7. Diurnal variation of lightning deaths

Only 47 cases out of 80 had times of death recorded. The diurnal variation of these times of deaths is shown in Fig. 6.

A maximum is observed at around 1500–1600 hours local time. No deaths are recorded after 1830 hours and before 0500 hours. About 65% of deaths occur between 1330 and 1630 hours.

A comparison with the diurnal variation of thunderstorm (Fig. 3) shows good correlation of peak hours.

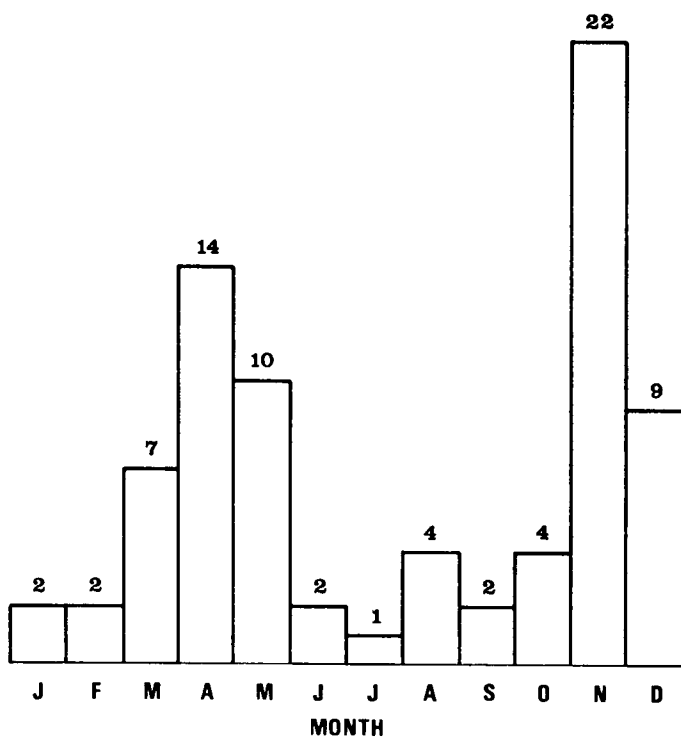


Figure 5. Number of lightning deaths per month for 1956-79.

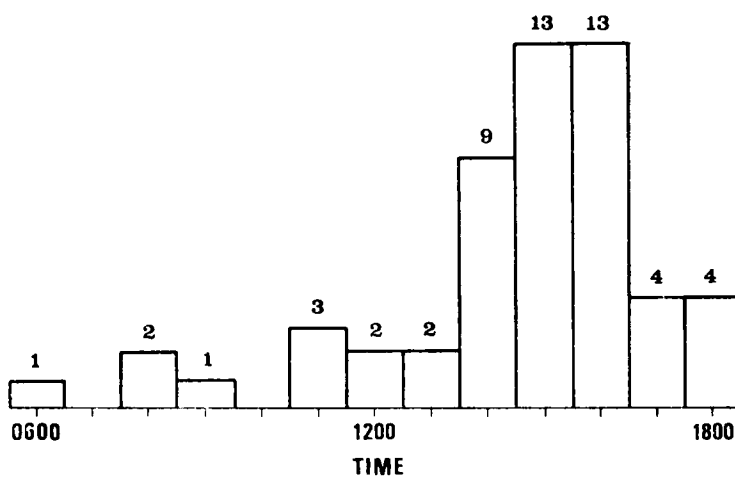


Figure 6. Number of lightning deaths by time of day.

Comparison of times of death with other countries shows good agreement. Table III gives the percentage of deaths in different time periods for USA, Australia and Singapore.

Table III. Percentages of deaths in different time periods for different countries

Country	Time of day			
	1200-1800	1800-0000	0000-0600	0600-1200
USA	70	20	1	10
Australia	85	4		11
Singapore	80	7	0	13

8. Location of lightning fatalities

Data were categorized into two broad groups—sheltered and open areas. From a study of the records, sheltered areas were found to be either (a) wooden huts and sheds, typically with a galvanized iron roof (or, in earlier times, an attap* roof) or (b) trees. No deaths were recorded when sheltering in substantial, protected buildings. Open areas comprised (a) small, open or partly covered, wooden boats, (b) sea or beach areas, (c) rooftops, (d) golf courses, (e) football fields, (f) animal-feeding areas, (g) other, including hilltops and slopes.

Table IV shows the fatalities classified into the different categories.

Table IV. Location of lightning deaths.

Location		Number of fatalities	Percentage of total
Sheltered	Hut, Shed	13	24
	Tree	5	9
	Boat	7	13
	Sea or beach	8	15
Open	Rooftop	3	6
	Golf course	1	2
	Football field	3	6
	Feeding animals	2	4
	Other	12	22
Total		54	

Thirty-three per cent of those killed were sheltering while 67% were killed in the open. The highest number of fatalities (13) were those sheltering in huts or sheds. These are low unprotected shelters, usually sited close to trees or in open areas. A significant number of fatalities (8) occurred on beaches or in shallow water and a comparable number (7) occurred while travelling on boats.

Other countries show similar statistics. Australia (Prentice 1972) recorded 63% of deaths in exposed areas and 32% in sheltered areas. The USA (Zegel, 1967) recorded 11% of deaths under trees (Singapore, 9%) and 8% in open water (Singapore, 13%).

A location map of all lightning fatalities with a recorded location is given in Fig. 7. The total number of data points is 72. The map shows that urban built-up areas with high population densities are much safer than rural, open areas.

9. Recreation/Work ratio

A study was carried out on the activity undertaken by a person while struck and killed by lightning.

* Attap (also spelt atap) = the nipa palm, the leaves of which are used for thatching.

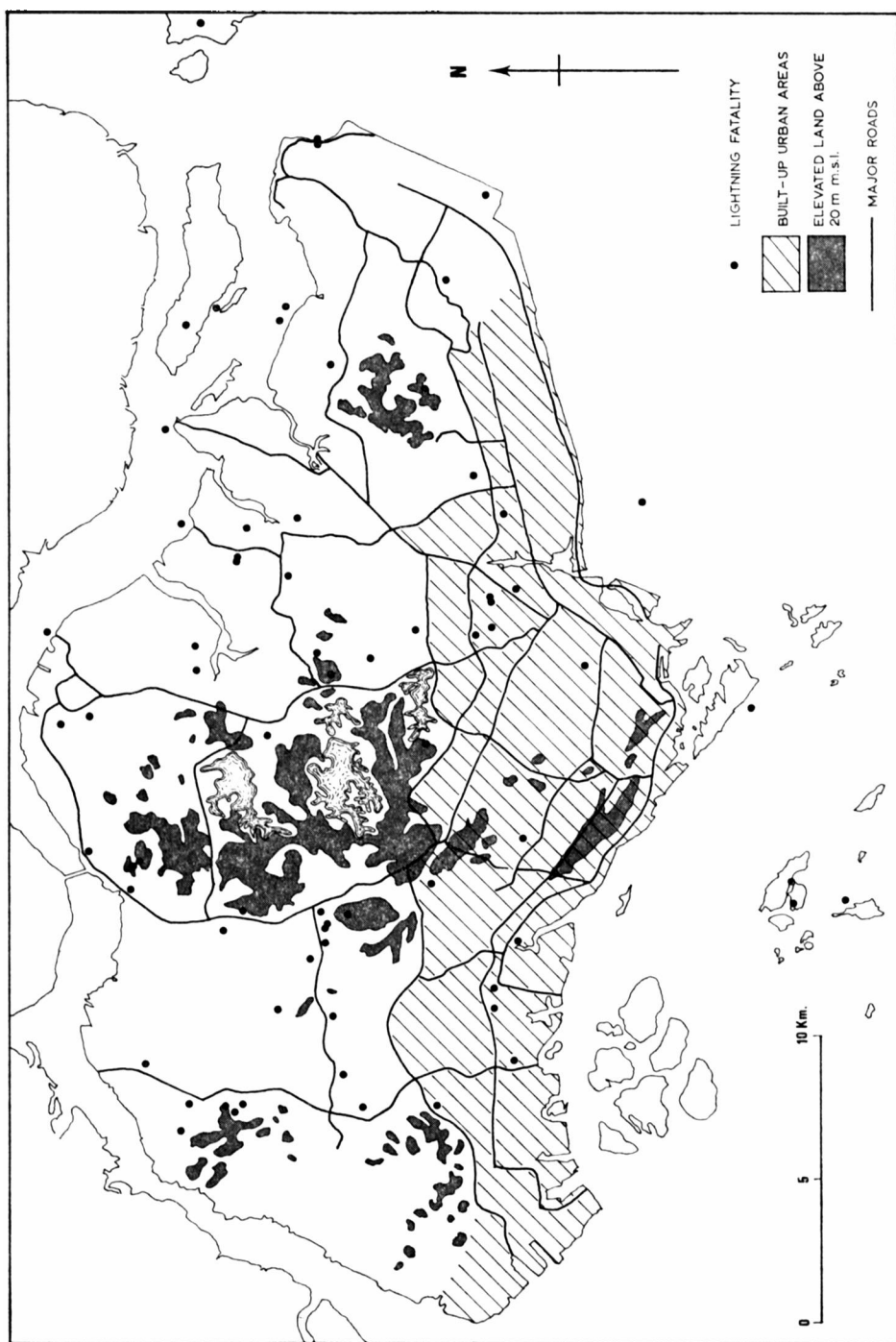


Figure 7. Location map of lightning fatalities in Singapore, 1956-79.

Activities were classified into the three categories of 'Work', 'Recreation' and 'Indefinite'. A working definition of each category is given below:

(1) Work category: Any person who is exposed to lightning injury risk by being compelled to remain outdoors, and shelter under trees or in huts by nature of his work. Besides workers, this category also includes workers running for shelters, people travelling to work, etc.

(2) Recreation category: Any person who is exposed to lightning injury risk by his own volition.

(3) Indefinite category: Any person whose circumstances of death are unknown.

Data were further subdivided as to whether the person killed was on foot, on bicycle or in a boat. Analysis was first carried out for exposed locations and then for sheltered locations. The results are presented in Tables V and VI.

Table V. Activity undertaken while in exposed location.

	Work	Recreation	Indefinite	Total
On foot	14	12	2	28
On bicycle	0	0	1	1
On boat	4	2	1	7
Totals	18	14	4	36

Table VI. Activity undertaken while in sheltered location.

	Type of location							
	Trees				Huts/sheds			
	Work	Recreation	Indefinite	Total	Work	Recreation	Indefinite	Total
On foot	0	2	2	4	10	1	2	13
On bicycle	0	0	1	1	0	0	0	0
On boat	0	0	0	0	0	0	0	0
Totals	0	2	3	5	10	1	2	13

The tables show that the majority of people killed were on foot (45 or 83.4% of total deaths), 28 (51.8%) were in exposed locations and 17 (31.6%) were in sheltered locations. Two (3.7% of total) were killed while travelling on bicycle while 7 (12.9% of total) deaths were recorded while travelling in a boat. The number killed in the work category was 28 and the number killed in the Recreation category 17, giving a Recreation/Work ratio of 0.61.

To determine whether there were any changes in Recreation/Work ratio patterns over the years, the study period was divided into two eight-year periods, 1965-72 and 1972-79, and the Recreation/Work ratios calculated (Table VII).

Table VII. Recreation/Work ratios for 1965-72 and 1972-79.

Period	No.	Work	No.	Recreation	No.	Indefinite	Total	Recreation/Work ratio
		Percentage of total		Percentage of total		Percentage of total		
1965-72	16	64	7	28	2	8	25	0.44
1972-79	14	44	11	34	7	22	32	0.79

The Table shows a notable change in recent times to higher Recreation/Work ratios (0.79) from earlier years (0.44).

Comparison with Australia shows that 34% (Singapore 51.8%) were killed while on foot in the open, 31% (Singapore 31.6%) while sheltering and on foot, while 22% (Singapore 16.6%) were killed while on

horseback or in an open vehicle. In terms of Recreation/Work ratios, Australia in recent times (1957–69) had a ratio of 1.0 compared to only 0.43 for the period 1945–57 (average over entire period was 0.60). Such trends towards higher Recreation/Work death ratios in recent years have also been noted in the USA.

10. Elevation of site of fatality

A topographic map was used to determine the elevation of the site of fatalities. A graph of the number of deaths against elevation was plotted (Fig. 8). Most of the deaths occur in low-lying areas with very few fatalities at higher elevations. The reason can be deduced from Fig. 7. The areas with elevations exceeding 20 m above m.s.l. are either catchment or reservoir areas which are sparsely populated.

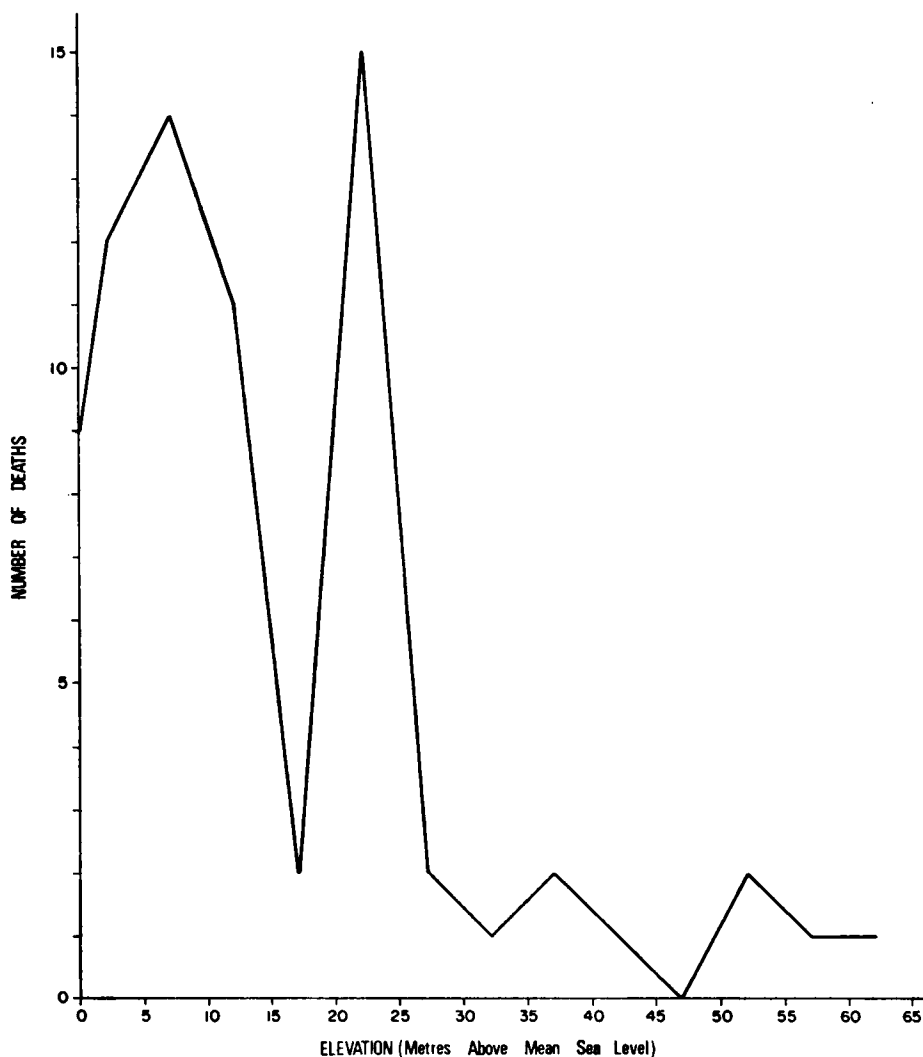


Figure 8. Relationship between lightning fatalities and elevation.

11. Severity of lightning accident

Of 54 fatalities investigated, 46 incidents resulted in single deaths (85% of total deaths) and 4 incidents resulted in 2 deaths (15% of total deaths). Of these 4 incidents, one occurred on a boat, one inside a hut, one on a beach and the last on a football field. If the criterion for most severe incident is taken as the most number of deaths followed by the most number of injured, then the most severe lightning incident occurred when a group of school-children, having a picnic on the beach, were struck, resulting in 2 deaths and 5 injured.

Compared with the USA, Singapore experiences about the same percentage of double deaths as the USA (15%), but the USA has 15% of fatalities occurring with 3 deaths or more and a smaller number (70%) of single deaths. The literature also reports a number of instances in other countries with multiple deaths. Singapore, in the 24 year period of study, has been fortunate in not having such severe incidents.

12. Type of bodily injuries

Only 39 cases had postmortems available for study. Injuries were classified and their relative frequency calculated. The results are given in Table VIII.

Table VIII. *Frequency of types of injury associated with lightning death.*

Location of injury	Number	Percentage of total
Head, face, neck	29	74
Chest	4	10
Abdomen	3	8
No external injuries	3	8

From the table, it can be noted that a direct strike, with current passing through vital organs (brain or heart) accounted for 84% of deaths. So far as has been documented in recent years in Singapore, only one person has been known to have survived a direct strike to the head. This investigation will be documented in a separate paper.

13. Ratio of injured to dead

It is not known how many people receive minor injuries or shocks due to lightning and either recover at home or are treated medically and discharged. The information that is available is the number of people injured and treated at hospital as a result of association with a lightning incident resulting in death. The total number of injured associated with 54 lightning fatalities has been ascertained to be 54, distributed in the following manner (Table IX). The ratio of injuries to death for Singapore is therefore 1.0.

Table IX. *Number of injured associated with a lightning fatality*

Number of persons injured in an accident	Number of incidents resulting in deaths	Total number injured	Comments
0	28	0	
1	12	12	
2	3	6	
3	2	6	
4	1	4	Timber loading, open area, low-lying.
5	1	5	Schoolchildren, picnic on beach.
7	3	21	Two incidents involving groups of people on hilltop. One incident involving a wooden boat.
Totals	50	54	

As far as other countries are concerned, evidence presented by Golde (1976) for Austria and Hungary showed a ratio of 2 injuries for every fatality.

The Singapore ratio is lower than for other countries, perhaps because there are fewer group activities, especially recreational ones, where large groups of people may be affected by a single lightning flash.

14. Lightning fatality risk in Singapore

The average number of deaths per annum in Singapore over the last 24 years is 3.3.

The number of lightning strokes to earth per annum may be deduced from a number of studies. Stanford Research Institute has estimated the number of ground strokes per km² per thunderstorm day per annum for different latitudes (Pierce *et al.* 1962). For Singapore, the upper limit is about 0.06. The number of lightning strokes to earth is therefore $0.06 \times 600 \text{ km}^2 \times 200 \text{ thunderstorm days} = 7200/\text{annum}$.

Another study by Müller-Hillebrand (1965), corrected for latitude, gives the number of ground strokes per 100 km² per 10 thunderstorm days as about 100 for Singapore. The total number of strokes is $100 \times 6 \times 20 = 12\,000/\text{annum}$.

From these two studies, an estimated value of the number of strokes can be taken as 10 000/annum. This implies that 1 in 3000 ground strokes in Singapore results in a fatality.

15. Personal safety in Singapore

Taking into account the nature and location of lightning fatalities in Singapore, a simple set of rules for personal safety may be drawn up.

(a) *Time of commencement of precautionary measures.* The major personal protective measure taken by the layman against the vagaries of the thunderstorm is to avoid getting wet. However, a downpour may drench but will not kill a healthy person as may a lightning flash. Since lightning activity in an area does not necessarily correlate with the heaviest rainfall in that area (very often, lightning occurs when rain is not falling and it may still continue when the rain has ceased), precautions against being struck by lightning should be taken independently of the fear of getting wet. A good procedure in a lightning storm is to count the interval between a lightning flash and the accompanying thunder. An interval of three seconds implies that lightning is about one kilometre away. It is suggested that precaution be taken when the time interval is 20 seconds and shorter, whether the storm is approaching or receding.

(b) *Target audience.* The age group to be educated on lightning hazards is mainly the 10–29 year old group who comprise 58% of all deaths. Thus, schoolchildren appear to be the target audience. In view of increasing recreation/work death ratios in recent years, emphasis must be placed on hazards due to recreation.

(c) *Precautionary measures*

(i) Seek shelter in a substantial well-grounded building or within a metal-bodied vehicle (e.g. a motor vehicle). Urban, built-up areas are safe. If one is forced to seek shelter in an unprotected wooden shed or building, keep away from metal objects, metal pipes, electrical wiring and wooden beams or walls that are wet. Crouch on the floor, with feet together and away from all extended objects.

(ii) Do not stay out in an open area, such as beaches, the sea, rooftops, tops and slopes of hills, recreation fields, etc. Do not carry tall metal objects such as metal umbrellas or golf clubs. If caught on open ground, crouch down in the lowest point or depression in the area with feet together.

(iii) Avoid standing close to the trunk of tall isolated trees or touching or standing close to tall metal structures, wire fences or pipes.

Conclusions

1. Lightning fatalities occur at a rate of 1·7/million. This is the highest rate reported in the literature to date and may be attributable to the high year-round thunderstorm frequency.
2. The male/female death ratio is 4·7, which is about the same as for other countries.
3. Fifty-eight per cent of the fatalities occur in the 10–29 year age group. This is a finding similar to that of other countries.
4. The distribution of lightning fatalities through the year correlates well with the distribution of thunderstorms. Peaks occur in November and April, with minima in July and January–February.
5. The diurnal distribution of lightning fatalities correlates well with the diurnal distribution of thunderstorms. A maximum is observed between 1500–1600 hours local time. About 65% of deaths occur between 1330 hours and 1630 hours.
6. Of all the deaths investigated, 33% were killed in open areas and 67% in sheltered areas. Other countries report similar results.
7. The recreation/work death ratio averages 0·60, with a value of 0·44 in earlier times and 0·79 in modern times. The prevalence of recreation deaths in recent times is similar to that in other countries and may be attributed to rising affluence and increasing leisure periods.
8. Most of the deaths occur in low-lying areas. Higher-elevation areas in Singapore are sparsely populated.
9. Eighty-five per cent of deaths are single events and 15% are double deaths. The most severe incident occurred at a picnic when two were killed and five injured.
10. Direct strikes with current passing through brain or heart account for 84% of deaths.
11. The ratio of dead to injured is 1·0 in Singapore. Other countries report ratios of about 2·0. This may be due to fewer group activities, especially recreational ones, in Singapore.
12. Lightning death rate in Singapore is 3·3/year. From the estimated number of lightning strokes in Singapore, it can be calculated that about 1 in 3000 ground strokes in Singapore results in a fatality.
13. Personal safety should be emphasized to schoolchildren, especially those recreating.

Acknowledgements

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The problems of anemometer exposure in urban areas—a wind-tunnel study

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Summary

The problem of defining a mean wind speed which reflects the general characteristics of the surrounding terrain is examined for the particular case of the area around Sheffield University. This problem has arisen in connection with the data analysis procedures for a full-scale wind force measurement project where a reference wind speed is required for data presentation. Wind-speed data are available on the site from three separate buildings. Data from one of these anemometers are supplied to the Meteorological Office. Initial attempts to establish a single vertical relationship between the outputs of these three anemometers were not successful, and a wind-tunnel study of the wind structure over the area was therefore undertaken. This study enabled the response of each of the three anemometers to be examined for dependence on wind direction and roof location.

The results of this project imply that considerable uncertainty is associated with any mean wind-speed definition whose reference height is comparable with the size of the objects which compose the surrounding terrain. It follows from this that representative mean wind speeds for urban areas can only be defined for heights considerably in excess of 10 metres.

1. Introduction

This paper presents some of the results of an investigation into the relationship between the wind velocity measured at three points on the site of a full-scale wind-loading test. These investigations were initiated in order to assist with the data analysis program associated with the wind-loading experiment. The building concerned, the 20 storey Arts Tower at Sheffield University, has been the subject of an extensive program of research whose aim has been to determine the dynamic wind loads which act on the structure. The method of determination of these dynamic wind loads is fully described by Jeary, Lee and Sparks (1979).

It is important that during the measurement of the wind loads simultaneous records of the wind speed and direction are made, in order to determine the levels of load which are associated with various combinations of wind speed and direction and, for a given wind direction, how the dynamic load and the wind speed are related to each other. Ideally it would be preferable to be able to relate the dynamic wind-force data to a wind velocity measured at a height of 10 m above open, level ground which properly reflected the general characteristics of the terrain in the vicinity of the test site. Such a definition of the reference wind speed would then conform to the definition of the basic wind speed for a particular geographical location as defined in the BSI Code of Practice for wind loading (1972) and might facilitate a straightforward application of the project's results.

2. Sources of wind data

The wind-speed recordings, used as a reference for calculating building response to given levels of wind activity have, in the past, been obtained from two sources. The principal source, i.e. the wind speed which is recorded together with building acceleration levels, thus providing the basic data for modal force analysis, has been obtained from a Casella cup anemometer mounted on a 6 m mast located on the roof of the Arts Tower (see Plate I). The height of this anemometer is 84 m above street level. The positioning of the anemometer is well within the 'building-induced' interference to the wind flow, the magnitude of this interference being strongly directional. This necessitates the inclusion of an incident wind-direction correction factor for the wind speed during data analysis. The correction used



Plate I. University Arts Building (right) and Geography Building (left). The anemometer heads are encircled. (See facing page.)



Plate II. Weston Park Museum viewed from the University Arts Tower. The anemometer head is encircled. (See facing page.)

in the past was determined by a wind-tunnel investigation of the variation of mean wind speed with direction, measurements having been made on a 1 : 400 scale model of the isolated building, with no modelling of other buildings on the surrounding site. One of the aims of the present investigation is to attempt to identify and measure any significant site-induced wind-speed variations which should be included in the correction factor.

Wind-direction data are obtained from recordings available from the Weston Park Museum (Plate II), which had, until December 1979, a Dines pressure-tube anemograph mounted on a 10 m mast on the roof, at a total height of 22 m above street level. This instrument has since been replaced by a Munro cup anemometer, which started its operation in February 1980. It is worth noting here that although the Weston Park anemometer station has been superseded by that situated on the University's Geography Building (Plate I), as the official source of Meteorological Office data for Sheffield, it nevertheless possesses long-term recordings for the area which may prove a useful data source.

The instrument situated on the Geography Building is a Munro three-cup anemometer on a 6 m mast and is 31 m above street level. The relative horizontal dispositions of the three instruments are shown in Fig. 1.

Investigations into the relationship between the wind velocity measured at the three anemometers on the site (Arts Tower, Geography Building and Weston Park Museum) of the full-scale test have therefore, been initiated in an attempt to characterize any major peculiarities of the site in so far as they may affect the full-scale wind-loading tests and to provide a means of normalizing the force data with respect to a reproducible characteristic wind-velocity parameter. The general aims of this investigation are then:

(a) To determine the variation in mean wind speed with incident wind direction measured by the Arts Tower anemometer and, by comparing this with the undisturbed free wind speed at that height, attempt to separate 'building-induced' variations and 'site-induced' variations. The undisturbed free wind speed at a point is the wind that would blow at that point if the surrounding terrain were open and level. By 'open terrain' is meant an area no part of which is nearer to an obstruction than ten times the height of the obstruction; such obstructions can be either natural, for example trees, or artificial, for example buildings. In a wind tunnel the free wind is known fairly precisely; in the real world, whilst it has been found to be a useful concept for wind engineering design purposes, it is a concept difficult to quantify accurately in practice. The free wind as defined here is to be distinguished from the gradient wind just above the atmospheric boundary layer, a wind which is closely related to the large-scale pressure field.

(b) To compare this information with the mean wind speeds measured at the two other anemometer stations in an attempt to identify the major flow characteristics of the site, and to define a law of variation with height of the mean wind speed.

A series of investigations to satisfy these aims has been carried out using wind-tunnel techniques in which both the local terrain and the characteristics of the atmospheric boundary layer have been modelled.

3. The wind tunnel and models

(a) *The wind tunnel.* The experiments were carried out in the Sheffield University 1.2 m × 1.2 m Boundary Layer Wind Tunnel. The simulation of the dominant characteristics of the natural wind flow over the suburban/urban area was achieved by the inclusion of flow-mixing devices and roughness sheets in the forward part of the working section. Both the wind tunnel and the method of atmospheric boundary layer simulation are fully described by Lee (1977). The majority of the tests were performed at a scale of 1 : 1000, in order to include the maximum site area on the wind-tunnel turntable. However,

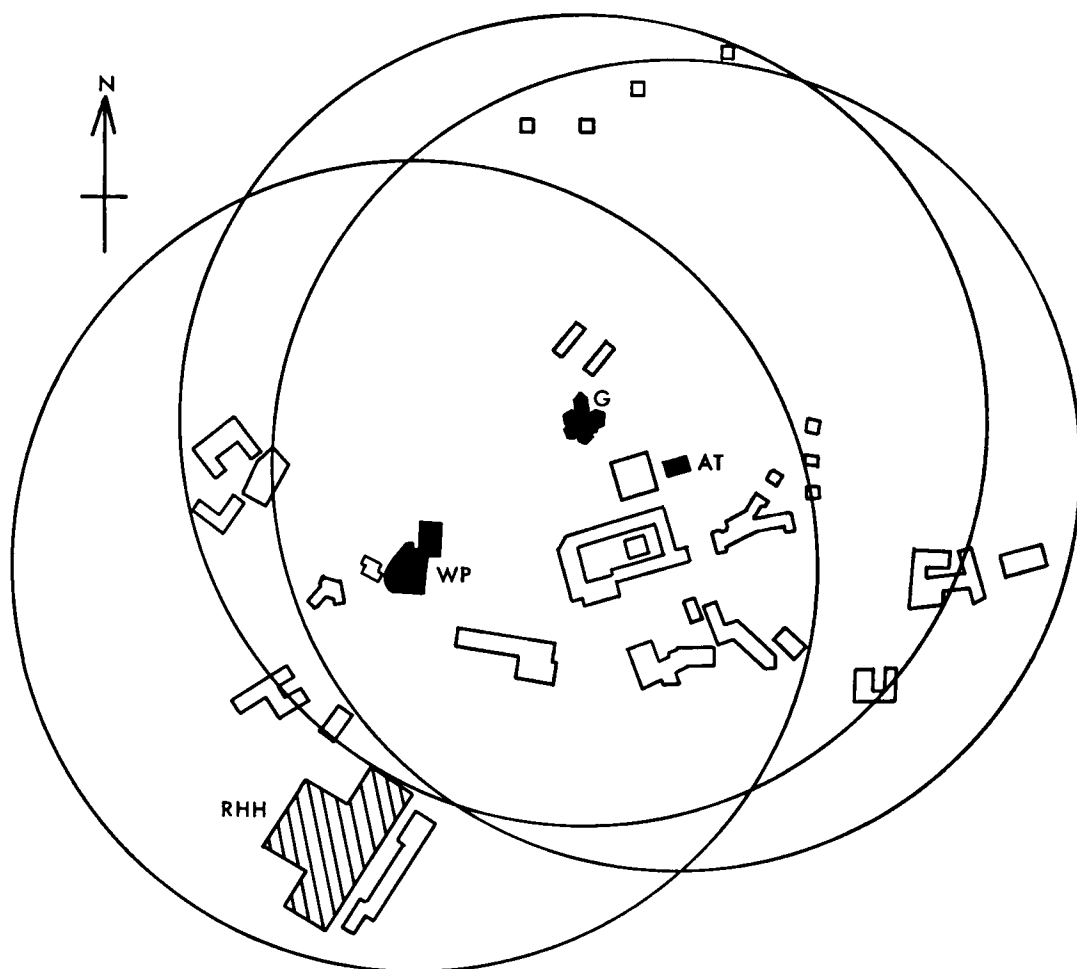


Figure 1. The wind-tunnel site model. AT = Arts Tower; G = Geography Building, RHH = Royal Hallamshire Hospital; WP = Weston Park Museum.

in order to examine the influence of roof detail and anemometer location on the measured wind speed, some tests were performed with larger models, at a scale of 1 : 350.

The modelled anemometer speed measurements were made with a miniature NPL type pitot-static tube connected to a Betz manometer. These measurements were all checked using a linearized Disa hot-wire anemometer fitted with a straight wire probe. The wind-tunnel reference speed was monitored by a further NPL type pitot-static tube connected to a Betz manometer and located at the modelled gradient height, 900 mm above floor level.

(b) *The models.* A linear modelling scale of 1 : 1000 was used for the majority of the tests in order to accommodate the extent of the relevant site on the 1.1 m diameter wind-tunnel turntable. This scale enabled all major buildings within a radius of 550 m of any of the anemometer stations to be modelled.

Fig. 1 shows a plan of the major buildings on the site, modelled as level ground. All other buildings, usually less than about 15 m in height, were modelled as simple scaled blocks and, for the sake of clarity, are not shown here. The site model was not contoured.

The desirability of presenting each of the three anemometer stations, in the absence of any surrounding modelled buildings, with nominally identical wind patterns (i.e. so that the effect of tunnel variables was minimized) dictated the use of a sectional model layout. This was constructed in such a way that each of the measuring stations in turn could be positioned in the centre of the turntable and still be surrounded with an accurate representational model of all major buildings within a scaled radius of 550 m. The model sections are indicated by the circles in Fig. 1. The lettering on Fig. 1 indicates the buildings as follows: AT (Arts Tower), WP (Weston Park Museum), G (University Geography Building) and RHH (Royal Hallamshire Hospital). This last building referred to, the Royal Hallamshire Hospital, is a major site feature whose height is comparable to that of the Arts Tower. The RHH building was only modelled on the turntable for the model section centred on the Weston Park Museum anemometer, since for the other two sections it lay outside their 550 m radii. For these two sections of the model the RHH building was positioned in the wind-tunnel working section at the appropriate distance and orientation upstream of the turntable rotation.

Whilst the authors are aware of the difficulties of using wind-tunnel models to represent the real world, some justification for presuming that the model results can be applied to full scale do exist. A comparative full-scale and wind-tunnel model survey of the environmental wind conditions around the base of the Arts Tower has been carried out (Lee and Hussain 1979) and good agreement between both sets of results was obtained. Additionally the full-scale dynamic wind-loading project results have been compared with those obtained by corresponding wind-tunnel models (Evans and Lee 1981) and again good agreement has been achieved.

4. Results of wind-tunnel measurements

(a) *The Arts Tower anemometer—speed measurements.* In Fig. 2 a number of sets of data are presented which depict the variation of wind speed with direction, for different test conditions, all measured using the 1 : 1000 site model. The wind speeds U_A , are all shown non-dimensionalized by U_O , which is defined as follows: U_O is the value of the mean wind speed at the height of the anemometer, determined from the characteristics of the simulated atmospheric boundary layer incident flow and represents a mean speed unaffected by any particular building geometry or site detail modelled on the turntable. It should be noted that the anemometer is not centrally located above the building's roof and so a degree of asymmetry will arise from this source, amongst others which may be due to the site.

Referring first to the measurements taken with the anemometer in its normal position, a number of characteristics of this graph are worth noting:

(1) The peaks of the graph appear to correspond to the wind flow being incident on the building corners. In this case the angular separation between the peaks calculated from the distances of the anemometer position from the building corners predicts angular separations of approximately 55°, 120°, 75°, and 110°. These values compare favourably with the experimentally observed values of 55°, 110°, 80°, and 115°, the differences being well within the limit of expected experimental error.

(2) Minima in the graph correspond to the wind flow being incident normally on to the building faces. The difference between the true compass direction shown in Fig. 2 and the direction of the nominally north face of the building is 20°, with the building 'north' facing 340°.

(3) The minimum at about 350° is of particular significance to the wind-loading program since wind force is proportional to the square of wind speed. This direction corresponds to the wind being incident normally on to the northerly broad face of the building and also corresponds with a frequent wind direction. With the wind in this direction the speed measured by the anemometer on the Arts Tower would indicate only approximately 50% of the undisturbed, free wind speed at that height.

When the Arts Tower building was removed from the 1 : 1000 site model and the test was repeated it

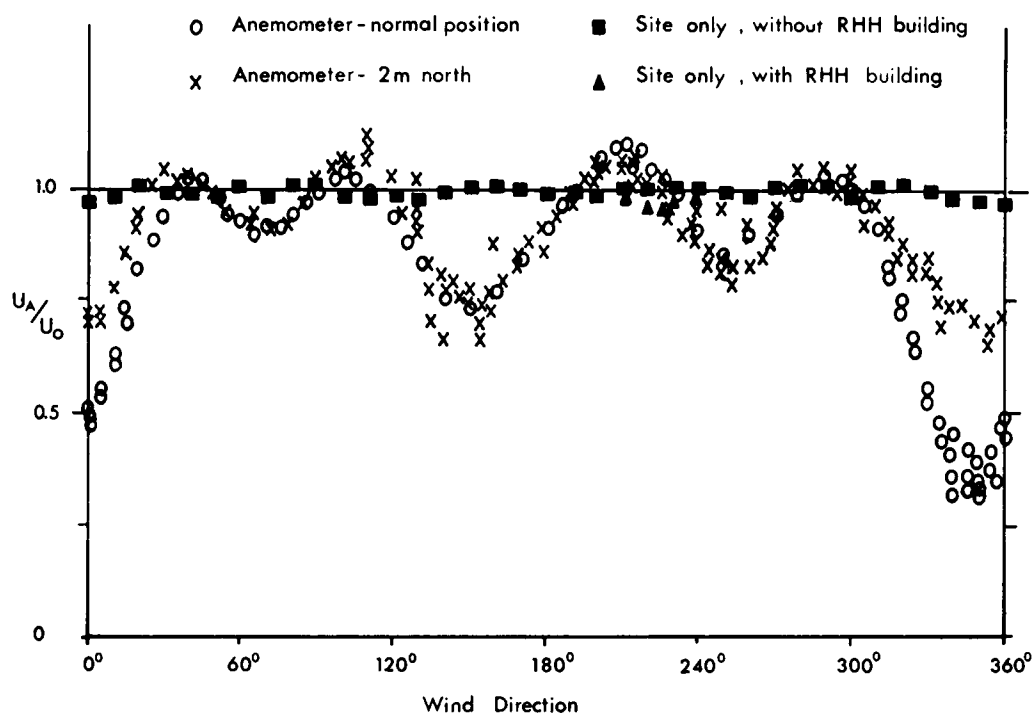


Figure 2. Variation of mean wind speed with wind direction for the Arts Tower anemometer, from wind-tunnel tests with a 1:1000 scale model.

was found that the measured wind speed at the anemometer height remained approximately constant with wind direction. An examination of this set of data in Fig. 2 shows that the inclusion of the RHH building, located 600 m away from the Arts Tower on a bearing of 225°, in the working section produces only a barely discernible effect. Thus, a comparison of the variation of mean wind speed with incident direction made at the modelled location of the Arts Tower anemometer, both with and without the Arts Tower model in position, indicates this variability to be almost entirely building-dependent. Very little contribution to the mean wind variation is considered to be generated by the surrounding site.

Clearly small errors in the positioning of measuring devices at a modelling scale of 1:1000 are likely to introduce significant errors in the magnitudes of measured speeds in regions of high wind shear such as exists near the roof of the Arts Tower. In order to illustrate this, the anemometer position was moved 2 mm north (on the model scale) and the variation of mean wind speed with direction re-examined. Fig. 2 also shows the effect of this movement of the anemometer position on the measured wind speed and may be compared with the original position data. The measurement shows that whilst the general shape of the curve remains similar, the magnitude of the minimum at 350° changes dramatically. This would seem to indicate that whilst the general properties of the graph may be confidently accepted, the actual magnitudes of all the peaks and troughs require more careful examination.

Further tests have been conducted on a model of the Arts Tower at a scale of 1:350, the larger model enabling a more accurate anemometer positioning to be maintained. These tests at the larger scale have

not been performed in the presence of a site model, following the conclusions reached from Fig. 2. The initial 1 : 350 Arts Tower model had a flat roof, unlike the actual building whose roof surface is a complex group of small shapes housing lift-motor rooms, water tanks, flue housings, etc.

The influence of small changes in anemometer height, or mast height, is shown in Fig. 3, where the directionally dependent speed variations are shown for mast heights of 4 m, 6 m and 8 m full scale. The very large speed differences at 170° and 350° caused by reducing the 6 m mast height to 4 m imply that very small errors in vertical positioning on the 1 : 1000 model tests could be responsible for large errors in their results.

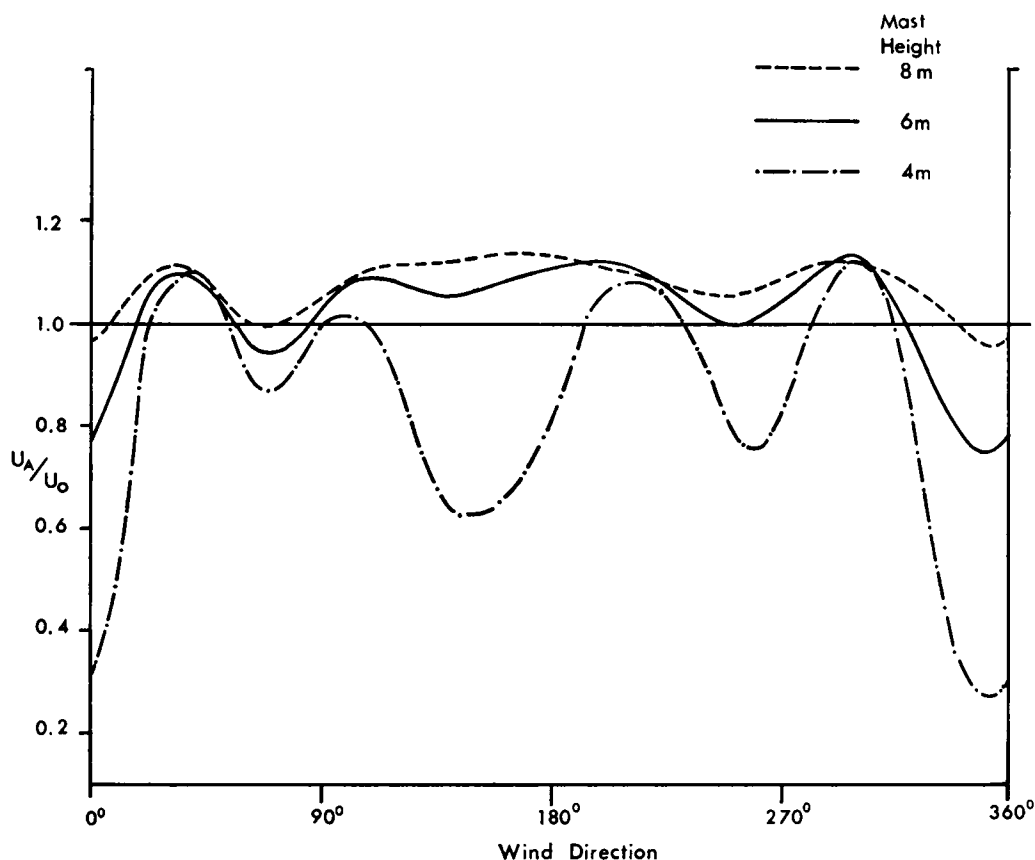


Figure 3. Influence of mast height on the variation of wind speed with direction, from wind-tunnel tests with a 1 : 350 scale model of the Arts Tower.

The last test with the 1 : 350 model was to inspect the influence of the actual roof structure as opposed to the flat-roof model used so far. The results of this test are shown in Fig. 4 where the true roof structure model and the flat-roof model are compared. With the exception of the minimum at 70° the two models produce very similar results.

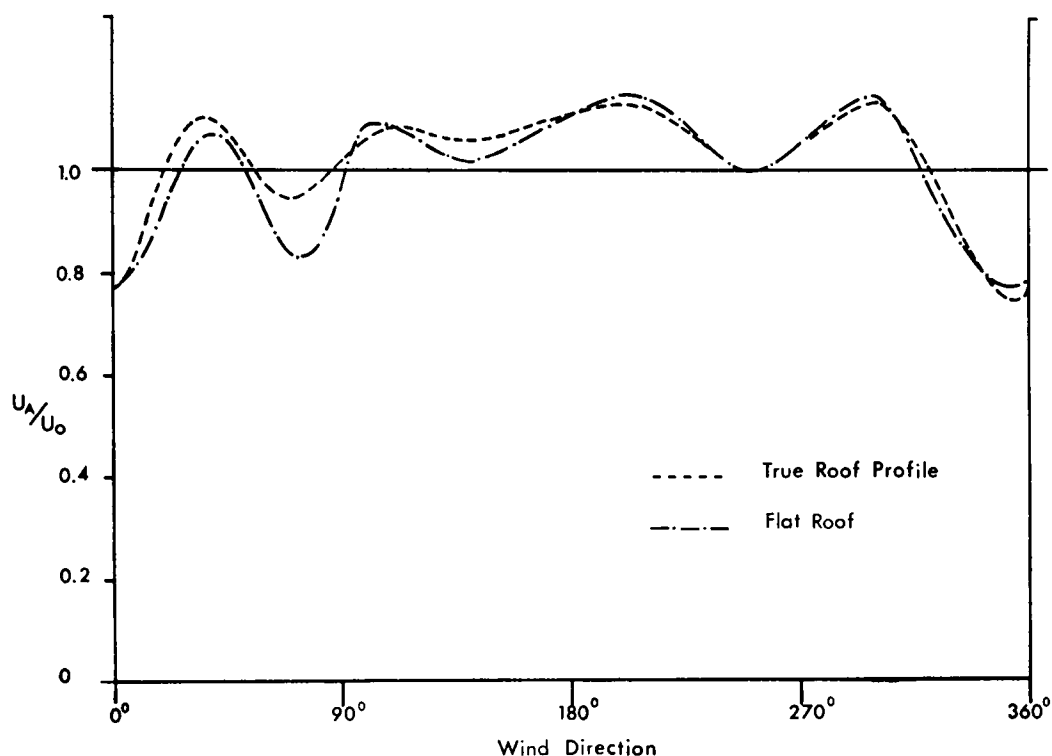


Figure 4. Influence of modelled roof shape on the variation of wind speed with direction. Arts Tower model, 1 : 350 scale.

This final data set, i.e. of the 1 : 350 true-roof-structure model, is recommended as the basis for the directionally dependent wind speed correction factor to be applied in the analysis of the full-scale experimental data. The application of a set of correction factors, based on these data, will convert the measured wind speed at 84 m above street level to an equivalent undisturbed free wind speed at a height of 84 m which reflects the general terrain characteristics of the area.

(b) *The Arts Tower anemometer—direction measurement.* Some preliminary tests have been conducted on a 1 : 1000 model of the Arts Tower in order to estimate the accuracy of the full-scale wind direction vane. In these tests a small vane, approximately 3 mm square, was mounted on a jewel watch bearing on the model roof and the direction of the vane relative to the tunnel axis, and hence wind direction, was monitored for different building orientations. It was found that for some directions, notably those for which a roof corner lay upstream of the vane position, large angular differences existed between the vane indication and the tunnel axis. The tentative conclusion drawn from these preliminary tests is that the full-scale vane indication is unlikely to be a reliable source of information and that it is not possible at present to produce a vane measurement correction factor.

(c) *The University Geography Building anemometer.* The University Geography Building anemometer is a Munro three-cup anemometer mounted on a 6 m mast attached to the 25 m roof and is thus 31 m above street level. The output data from this instrument are supplied to the Meteorological Office as a source of wind data for the Sheffield area.

Tests, carried out using the 1 : 1000 site model, have been conducted in a manner similar to those described in the preceding sections. The variations of measured wind speed with wind direction are shown in Fig. 5, where the speed, U_G , is shown non-dimensionalized by the average undisturbed free wind speed at that height for all wind directions, U_0 . In order to distinguish between wind speed variations due to the proximity of the building itself and, separately, those due to the characteristics of the site, the 1 : 1000 model of the Geography Building was removed from the site model and the measurements were repeated. From the two sets of results shown together in Fig. 5 it can clearly be seen that all the major features of wind speeds measured above the building are due to the site features alone and not to the proximity of the building itself. This conclusion is the reverse of that found in the case of the Arts Tower anemometer.

Figure 5 shows a number of interesting features:

- (1) The minimum at 120° corresponds to the Geography Building being downstream of the Arts Tower. This proximity effect is dramatically visualized in Plate I.
- (2) A small, but measurable, reduction in the indicated wind speed may be attributable to the presence of the RHH building, situated 600 m away on a bearing of 210° .
- (3) The minimum seen at 170° occurs when the building is downstream of the fairly high-density University complex which is nominally 30 m high and 100 m away from the Geography Building (see Fig. 1).
- (4) The trace maximum at 270° corresponds to the wind incident across Weston Park, just west of the site.

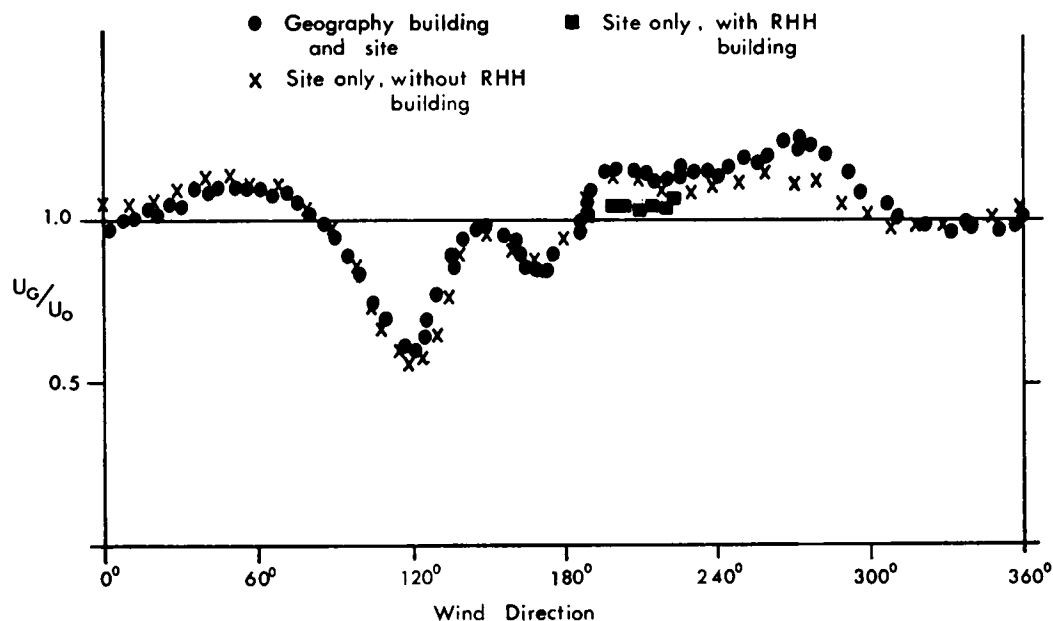


Figure 5. Variation of mean wind speed with wind direction for the Geography Building anemometer, as deduced by rotating a 1 : 1000 scale model of the building and surrounding site in the wind tunnel.

In order to check the main conclusion of the comparison shown in Fig. 5, i.e. that the directionally dependent speed variation of the Geography Building anemometer is dependent on the site rather than on the building, a further test at 1 : 350 scale was performed. This test utilized a larger-scale model of the building without the site features being present. The results, shown in Fig. 6, demonstrate the validity of the earlier finding. However, Fig. 6 should not be interpreted as indicating that the site for this anemometer is acceptable, in that it provides a good estimate of what the wind would be if the building were not there, since this is shown not to be true by Fig. 5. What Fig. 6 does indicate is simply that the ratio of the anemometer mast height to building height, for a building of that particular shape, is sufficiently large for the anemometer to be clear of flow effects above the building's roof.

(d) *The Weston Park Museum anemometer.* The Museum viewed from the Arts Tower is seen in Plate II, where the anemometer head, 10 m above the 12 m high building roof, is shown circled. The tests carried out on the 1 : 1000 model of the Weston Park Museum anemometer complete with its surrounding site, including the RHH building, were performed as described in the preceding sections. Fig. 7 shows the variation of mean wind speed, U_w , with direction. Two large minima are easily identified on bearings of approximately 80° and 180° . The first of these appears when the high-density University complex is upstream, whilst the second minimum, slightly more extreme than the first, is associated with the RHH building 300 m away (see Fig. 1).

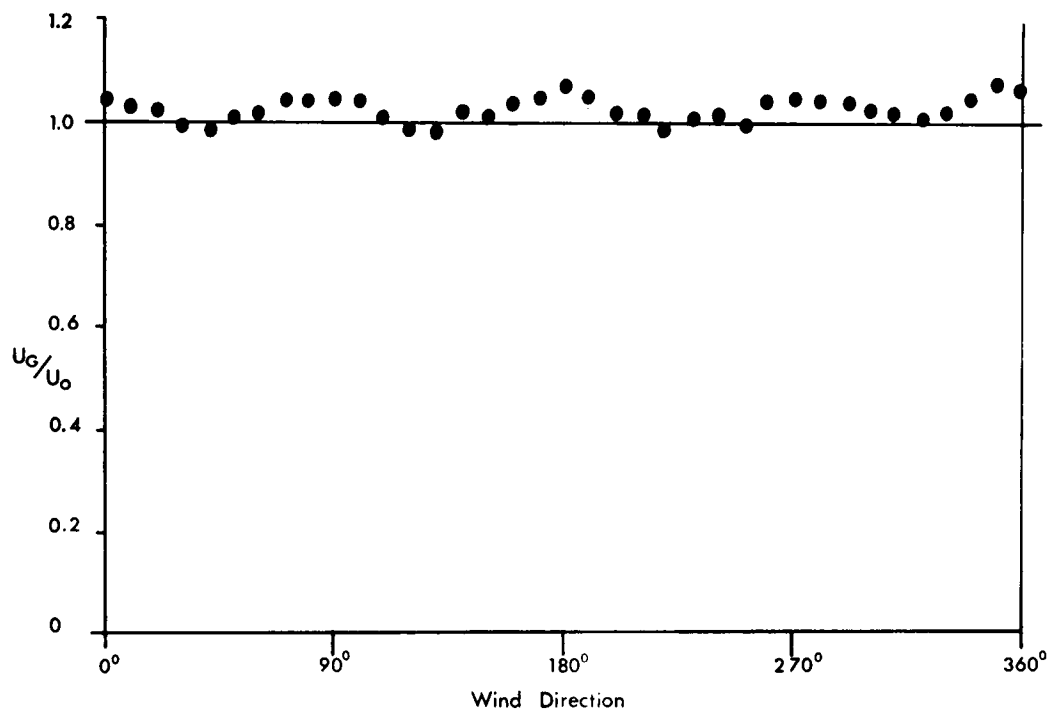


Figure 6. Variation of mean wind speed with wind direction for the Geography Building anemometer, as deduced by rotating a 1 : 350 model of the building without the surrounding site in the wind tunnel.

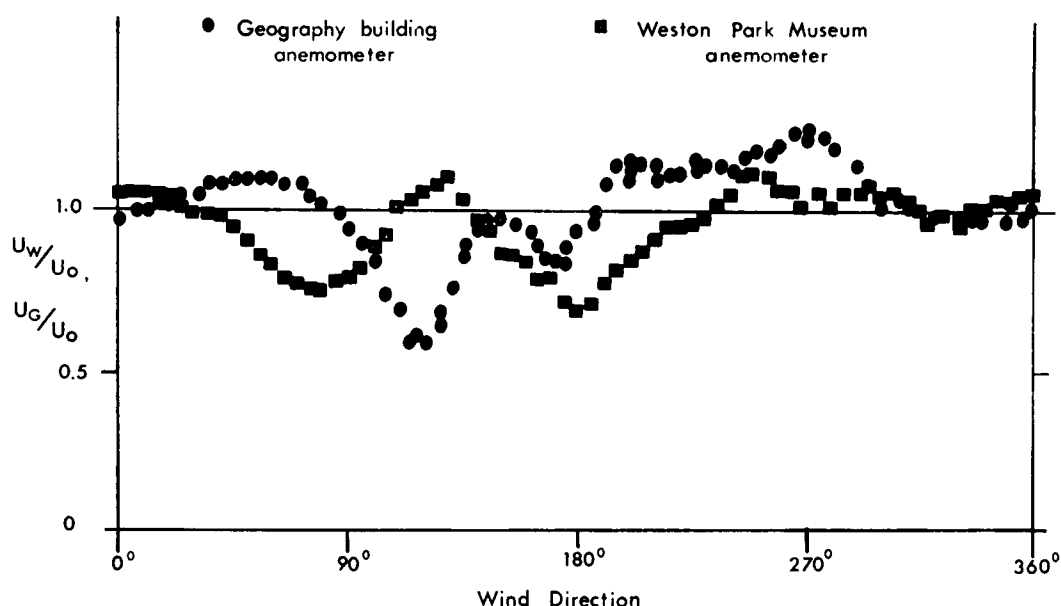


Figure 7. Variation of mean wind speed with wind direction for the Weston Park Museum anemometer compared with that for the Geography Building anemometer, from wind-tunnel tests with a 1 : 1000 scale model.

Although no separate test on a 1 : 350 model of the Museum has been carried out it seems most likely to the authors that the major features of Fig. 7 can be explained with reference to the site details and that the directionally dependent variations are unlikely to be building-dependent to any significant extent. This conclusion has been reached in view of the tests carried out on the Geography Building anemometer where the anemometer was shown to be sufficiently far above the building to escape its influence. In the case of the Weston Park Museum the ratio of anemometer mast height (10 m) to building height (12 m) is even greater than for the Geography Building. In view of this the authors did not consider that any useful purpose would be served by a 1 : 350 model test of the Weston Park Museum. It is, therefore, worth commenting on the statement by J. S. Hopkins (1979), 'The museum roof above which it [the Dines anemograph] is mounted has a 'zig-zag' profile and so can be expected to create more turbulence than a roof of conventional shape. This defect of exposure contributed to the Meteorological Office's decision to cease publication of the Weston Park anemograph data in the *Monthly Weather Report* with effect from January 1975 and to replace it with data from an electrical cup instrument mounted on a nearby university building [the Geography Building]'.

The conclusions drawn from Fig. 7 seem to suggest that Hopkins's unsupported estimate of the effect of the 'zig-zag' roof is a significant overestimate. An inspection of the Museum roof reveals the 'zig-zag' profile to consist of an irregular array of north-facing roof lights, light-wells, access stairways, store chambers, etc. having height variation of approximately 1 m above and below the façade roof level, which, since the anemograph mast is 10 m high, might be considered negligible, particularly in comparison with the new Meteorological Office data source which is only on a 6 m mast.

In general, the wisdom of the removal of the Meteorological Office data source from the Museum building to the Geography Building can be judged from Fig. 7 which compares the corresponding velocity variations. The overall directionally dependent speed variation of the new data source is seen

to be slightly larger than that of the old one. Incidentally it must not be forgotten that the construction of the RHH building took place during the decade prior to change of data source location and so Fig. 7 cannot be used as the single correction for all Weston Park Museum data prior to 1975.

5. A wind speed relationship with height

From the wind-tunnel tests the following relationships between the wind speeds measured by the three different anemometers have been evaluated:

$$U_A/U_G = 1.28, \sigma = 0.30$$

$$U_A/U_W = 1.39, \sigma = 0.25$$

$$U_G/U_W = 1.10, \sigma = 0.20$$

These ratios have been averaged for all wind directions and have the standard deviations, σ , as indicated.

It is required, then, to produce a relationship from the available information which will enable a directionally corrected 84 m wind speed from the Arts Tower to be reduced to a corresponding wind speed. The power-law equation is the most convenient form for establishing such a vertical wind-speed relationship, and states in its general form

$$V_H/V_{10} = (H/10)^\alpha.$$

For areas with sizeable obstructions in the terrain this equation can be amended to read

$$V_H/V_{10} = ((H-d)/10)^\alpha,$$

where

V_H is the wind speed at any height H in metres,

V_{10} is the 10 m wind speed

d is the zero-plane displacement, and

α is the power-law exponent.

The values of V_{10} obtained from this relationship are critically dependent on the value of d chosen to represent the adjacent terrain. The BSI Code of Practice for wind loading (1972) gives some guidance in making this choice, suggesting a value of average roof height of 10 m for terrain described as surfaces covered by numerous large obstructions, such as towns and their suburbs and the outskirts of large cities. Whilst such a description may be considered appropriate to the sites of the three anemometers, it would be useful to know of the effect of using values of d both greater and smaller than 10 m, since there is known to be a degree of uncertainty associated with the value given implicitly in the BSI Code of Practice. Using values of d of 7 m, 10 m and 15 m, the power-law equation has been used, together with the results of the wind-tunnel study, which gave three relationships between the speeds measured by the three anemometers, to yield a set of values of the power-law exponent α . These values varied from 0.116 to 0.212.

Applying the values of the power-law exponent given in the preceding paragraph to a real situation has the following results. If a mean wind speed measured by the Arts Tower anemometer has a value, corrected for wind direction, of say 50 kn, this may then be translated into a velocity at 10 m, thought to be representative of the site terrain, which varies between 32.4 kn and 40.1 kn, depending on the values chosen for α and d .

It is clear to the authors that this degree of possible error in the stipulated normalizing velocity renders the use of a nominal 10 m wind speed inappropriate for the purposes of the experiments being carried

out in this instance. In a wider context the authors would question the validity of any nominal 10 m wind speed which might be considered to be representative of the terrain characteristics in suburban or urban areas in which the average obstruction height is itself of the order of 10 m.

6. Conclusions and recommendations

(a) A standard height of 10 m is in use as a reference point for the definition of mean wind speeds by some compilers of climatic data bases, used in building design, though not necessarily by the Meteorological Office for this particular purpose. In the light of their findings the authors recommend that the use of such a reference height for the determination of mean wind speeds intended to be representative of a particular area should cease where that area includes terrain features whose average height is of the same order. Wind-tunnel experiments have demonstrated that mean wind speeds measured at low levels in urban areas can be significantly influenced by the immediate locality of the measuring point.

(b) It is recommended that all who use mean wind speed data from anemometers mounted on masts on buildings in urban areas should familiarize themselves with the probable influence of surrounding objects on the recorded wind speed. Consideration should be given by those who supply such data to the application of corrections which take account both of the directional characteristics of the wind and also of the height of the instrument, since it is the supplier who is responsible for the choice of site.

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The effects of inadequate sampling and of circulation pattern on real and apparent zonal mean temperature

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Summary

It is shown to what extent the restriction of meteorological observations to land is likely to cause overestimation of climatic variability of zonal mean temperature. The effect is particularly marked if circulation changes induce temperature changes having a low zonal wavenumber.

1. Introduction

During the past few decades it has become customary to express estimated changes of the temperature of the earth in terms of global, hemispheric or at least zonal averages. These parameters are the focus of frequent debate because they are among the most obvious indicators of changes in the earth's heat balance, for instance as a result of carbon dioxide, volcanic dust, or other man-made or natural influences. However, the supporting data have until very recently been mostly limited to land areas—and even to a small selection of these areas.

This paper includes examples of possible sampling errors of estimated climatic changes based on zonal mean temperature when the input data are for land only or for those limited land areas for which observations are available. The basic thesis is that reported changes of global, hemispheric or zonal mean surface air temperature may arise from three sources:

- (a) Real changes in the total heat content of the atmosphere plus ocean.
- (b) Redistribution of heat between atmosphere and ocean.
- (c) Systematic sampling error caused by preferential siting of land stations in the ridges or troughs of a low-wavenumber pattern of temperature changes.

It is clear that (b) and (c) above are linked, because low-wavenumber patterns of temperature change will systematically affect the air temperature over the oceans, and therefore alter the heat fluxes across the sea surface so as to tend to cancel the air temperature changes there. Therefore, the true zonal mean air temperature will change in the same sense as the mean change over land, but the observations, restricted to land, will overestimate this zonal mean change because the air temperature changes in oceanic regions, though reduced, will still be in the opposite sense. Observed variances of land and oceanic monthly mean surface air temperatures are used to quantify the damping effect of the ocean.

Monthly mean data are used throughout because they smooth the effects of individual atmospheric disturbances and are commonly employed in studies of climatic change.

2. Procedure and results

At each point the temperature change over a period may be expressed as $T' = A \cos n(\phi - \phi_x)$ where n is zonal wavenumber, ϕ is longitude, ϕ_x is the longitude of maximum warming, and A is the amplitude of the field of changes, differing between land and ocean. Note that, because $A_{\text{land}} > A_{\text{ocean}}$, T' does not necessarily average zonally (or globally) to zero, even if it results entirely from internal circulation changes. When most of the warming is over land the true zonal mean $[T']_{\text{true}} > 0$ because the changes have greater magnitude over land. Similarly $[T']_{\text{true}} < 0$ for cooling over land. But it is intuitively obvious that when the warming is mainly over land, the value $[T']_{\text{land}}$ averaged over land only, commonly used as an estimate of $[T']_{\text{true}}$ especially for the earlier years of instrumental data, in fact exceeds $[T']_{\text{true}}$ because there is cooling over the oceans. Again the converse applies when the cooling is over land.

This note attempts to quantify the discrepancy between $[T']_{\text{true}}$ and $[T']_{\text{land}}$ using observed standard deviations of monthly mean air temperature over land and ocean.

Monthly mean upper-air data have recently been collected for nearly 50 stations in the northern hemisphere, mainly at middle or high latitudes. In the process of quality-control, statistics for generally 15 to 30 years ending at about 1978 have been computed, and these include standard deviations as well as normals of monthly data, for the surface and for levels aloft. Because of the application of this note to the earlier years of instrumental data, only the surface will be considered. It is found that the standard deviation of January monthly surface temperature is 1.1°C at OWS 'M' and OWS 'P' but about 3.2°C in interior Canada and at Verhojansk in Siberia. At Sable Island off south-east Canada it is 1.3°C and at Vancouver 1.7°C . Corresponding July values are 0.8°C at the weather ships, and 1.5 to 2.0°C far inland. Now the local standard deviation resulting from a sinusoidal curve of amplitude A of random phase is $A/2^{1/2}$; therefore values of $A_{\text{land}} = 4.5^\circ\text{C}$, $A_{\text{ocean}} = 1.5^\circ\text{C}$ will be considered, representing winter, and the computation of mean T' over land, over ocean, and over all longitudes will be made for 50°N for various ϕ_x , and $n = 1$ to 8 , assuming that A_{land} applies over all land and A_{ocean} over all ocean.

The results for $n = 1$ to 3 are shown in Tables I to III. For wavenumber 3 (Table III), possibly the most applicable to winter, it is seen that if the maximum warming is at 20°E the true zonal mean warming is 0.5°C but the mean warming over land is 1.1°C . When the maximum warming is at 80°E (cooling at 20°E) these values become -0.5°C and -1.1°C respectively. Thus measurement restricted to land has the potential to yield values of zonal mean climatic variation about double (actually $1.1/0.5 = 2.2$) the true values at 50°N in winter.

This factor of about two applies also to wavenumbers 1 and 2 (Tables I and II), but for wavenumbers ≥ 4 the total and land-only variations in T are small, possibly a situation applicable to summer. The ratio r of apparent to true standard deviation tends to

$$\sigma_{\text{land}} / \{(\sigma_{\text{land}}^2 \times p_{\text{land}}^2) + (\sigma_{\text{ocean}}^2 \times p_{\text{ocean}} \times p_{\text{land}})\}^{1/2},$$

ignoring spatial coherence, as wavenumber becomes large so that phase bias is eliminated: here σ is standard deviation and p is the proportion of total longitude, p_{land} being 0.68 and p_{ocean} 0.32 at 50°N . For $\sigma_{\text{land}} = 3\sigma_{\text{ocean}}$ (winter) we have $r = 1.44$; for $\sigma_{\text{land}} = 2\sigma_{\text{ocean}}$ (summer) we have $r = 1.39$. These limiting minima of the factor of overestimation of zonally meaned air temperature change if the cause is redistribution of heat between atmosphere and ocean. If $\sigma_{\text{land}} = \sigma_{\text{ocean}}$, $r = (p_{\text{land}})^{-1/2} = 1.21$.

For combinations of wavenumbers the ratio may be estimated by taking

$$r = (\sum A_n r_n^2 / \sum A_n)^{1/2},$$

where r_n is the ratio for wavenumber n .

At 60° – 70°N the proportion of ocean is smaller and the problem is reduced. Even at 50°N , inclusion of the Aleutians (which are not far north of 50°N) would ameliorate the situation but this would not benefit mean temperature estimates for periods before about 1900 because the stations were not yet founded. At 40°N the very wide Pacific without islands is a severe problem.

In the tropics, east–west variations in temperature will be far less marked than in a mid-latitude winter, although it is difficult to guarantee complete freedom from the problem.

3. Comments on existing northern hemisphere temperature series

(a) Budyko's (1969) series is based on maps of temperature anomalies compiled at the Main Geophysical Observatory in Leningrad. Only to the extent that the maps cover the ocean, with realistic interpolation where observations are lacking, will the bias caused by irregular sampling of thermal troughs and ridges have been avoided.

Table I. Estimates of actual and measured surface temperature change at 50 °N for data over land only, assuming that the real temperature change is a wavenumber 1 of amplitude 4.5 °C over land, 1.5 °C over ocean.

Phase of maximum warming (°East)	Mean temperature change (°C)			
	land	sea	all	land minus all
0	0.7	-0.5	0.3	0.4
30	0.9	-0.6	0.4	0.5
60	0.9	-0.6	0.4	0.5
90	0.6	-0.4	0.3	0.3
120	0.2	-0.1	0.1	0.1
150	-0.3	0.2	-0.1	-0.1
180	-0.7	0.5	-0.3	-0.4
210	-0.9	0.6	-0.4	-0.5
240	-0.9	0.6	-0.4	-0.5
270	-0.6	0.4	-0.3	-0.3
300	-0.2	0.1	-0.1	-0.1
330	0.3	-0.2	0.1	0.1

Table II. As Table I but for wavenumber 2.

Phase of maximum warming (°East)	Mean temperature change (°C)			
	land	sea	all	land minus all
0	-1.2	0.9	-0.6	-0.7
20	-0.8	0.6	-0.4	-0.4
40	0.0	-0.0	0.0	0.0
60	0.9	-0.6	0.4	0.5
80	1.3	-0.9	0.6	0.7
100	1.1	-0.8	0.5	0.6
120	0.4	-0.3	0.2	0.2
140	-0.5	0.3	-0.2	-0.3
160	-1.1	0.8	-0.5	-0.6

Table III. As Table I but for wavenumber 3.

Phase of maximum warming (°East)	Mean temperature change (°C)			
	land	sea	all	land minus all
0	0.6	-0.5	0.3	0.4
10	1.0	-0.7	0.5	0.6
20	1.1	-0.8	0.5	0.6
30	0.9	-0.7	0.4	0.5
40	0.5	-0.3	0.2	0.3
50	-0.1	0.1	-0.0	-0.1
60	-0.6	0.5	-0.3	-0.4
70	-1.0	0.7	-0.5	-0.6
80	-1.1	0.8	-0.5	-0.6
90	-0.9	0.7	-0.4	-0.5
100	-0.5	0.3	-0.2	-0.3
110	0.1	-0.1	0.0	0.1

(b) Willett's (1950) paper includes diagrams giving contours of 20 year surface temperature change, based only on land stations but with some spatial interpolations and extrapolations based on meteorological flow patterns, thus reducing the thermal sampling problem. However, his world trend graph weights all stations equally and takes no account of developments over the oceans, though his restricting the data to 1 station per 10° square reduces the over-emphasis on Europe and North America, so there may be serious sampling error.

(c) Mitchell's (1961) series, unlike Willett's, corrects for the northward decrease of the size of 10° squares. However, like Willett, he has not taken account of oceanic areas, so serious thermal sampling errors may have taken place.

(d) Köppen's (1914) series is also for land only, though he includes a limited study of Atlantic shipping routes.

(e) Angell and Korshover (1977, 1978) used radiosonde land stations, distributed as evenly as possible, and including an Aleutian station. They also used ship 'P' in the Pacific (50 °N, 145 °W). However, the oceanic coverage was still sparse. There were 12 stations altogether between 40 °N and 60 °N.

(f) Harley (1978) used grid-point data which avoid the sampling problem (or sweep it under the carpet, introducing other difficulties (Parker 1980)). Harley's paper includes a table comparing different authors' results. Unfortunately the different workers have used different sets of levels, e.g. surface only; surface–500 mb; surface–100 mb; mean sea level–75 mb; so exact comparison is impossible.

(g) Painting (1977) also used mean charts, whose reliability will suffer from the same shortcomings as grid-point data.

(h) The present computations may explain positive correlations between central England temperature (Manley 1974) and the average of the Mitchell and Budyko series used by Miles and Gildersleeves (1978). Wavenumber 3 (Table II) gives true mean warming (cooling), which is overestimated by the data network, when the maximum warming (cooling) is near Greenwich. The deduction of hemispheric trends from scattered early instrumental data may be impossible.

4. Final remarks

This note does not disprove the possibility of net hemispheric or global warming or cooling, but emphasizes that movement of mean trough and ridge positions can give the impression of changes of global mean temperature if the data are irregularly distributed, especially in mid-latitudes. Apparent changes may be superimposed on real ones. The position of the two sharpest winter-time thermal troughs near the east coasts of the northern hemisphere continents is such that slight longitudinal shifts could have a considerable effect on mean temperature over these land masses, even if the true zonal means were unchanged.

It has also been demonstrated that movements of mean trough and ridge positions will eventually result in changes of true mean temperature in the same sense as the apparent changes. Thus if the troughs are more over the ocean than usual, transfer of sensible and latent heat from ocean to atmosphere will be enhanced because of increased (ocean minus air) temperature difference, and the atmosphere will be warmed. At the same time the thermal sampling error will be more positive than usual (warmth being more over land than usual). Also, external factors being unchanged, the ocean will cool and the system (ocean + atmosphere) will have constant heat content. Other factors such as changes in albedo have not been considered.

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Notes and news

100 years ago

The following extracts are taken from *Symons's Monthly Meteorological Magazine*, July 1881, 16, 112 and August 1881, 16, 128.

REGULAR OBSERVATIONS UPON THE TOP OF BEN NEVIS

We have not space upon the present occasion to express fully our views respecting mountain stations, but we should be sorry for this number to go forth without chronicling the laborious undertaking commenced on June 1st by Mr. Clement Wragge, whose station on the Weaver Hills, in Staffordshire, we have already noticed.* Mr. Wragge having left Farley, opened communication with Mr. Buchan respecting the efforts of the Scottish Meteorological Society to establish an observatory at Ben Nevis, and the final result briefly is, that a complete set of instruments is fixed upon the top of Ben Nevis, the highest point in the British Isles, 4,406 feet above sea level. Mr. Wragge has gone into residence at Fort William, and has commenced the somewhat alarming task of rising between 4 and 5 a.m., and after making a low level observation, climbing to the summit in readiness for observations at 9, 9.30 and 10 a.m., *every day*. If this be not devotion to Meteorology, we should rather like to know to what that term should be applied.

OBSERVATIONS ON BEN NEVIS

To the Editor of the Meteorological Magazine

SIR.—In your last number it is stated that I ascend Ben Nevis *every day*. Kindly allow me to say that a trained assistant usually relieves me at the rate of twice a week. It is certainly hard and trying work, especially so in bad weather; but it must be remembered that, through the kindness of the Scottish Meteorological Society, I take a horse half-way, and this is a great relief to me.

Yours faithfully,
Clement L. Wragge, F.M.S.

Fort William, August 2nd, 1881

* *Meteorological Magazine* Vol. XV, p. 98 (August, 1880).

Correction

Meteorological Magazine, **110**, 1981, p. 17, line 10. After ‘. . . the ratios of’ insert ‘wet rainfall-day incidence for other thresholds to’.

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