Prof. Dr. K. Berger
Zurich

Cigré St.C.33, WG 01 (1970)

Summary about

a) Duration of Flashes

b) Stroke Intervals

c) No-current Intervals

Sources: Malan D. J., Review GEOFISICA PURA e APPLICATA, Milano
Vol. 34, pp. 224-230 (1956)

Kitagawa N., Brook M, and E. J. Workman,
Journal of Geophysical Research,
Vol. 65, No. 5, May 1960

Oszillograms } Downward Strokes 1963...1969
San Salvatore } Upward Strokes 1967...1969

Definitions:

1. Lightning flash (short "flash") is a lightning discharge in its totality, consisting of one or several lightning strokes (Schonland)

2. Lightning stroke (short"stroke") is a partial discharge or component discharge (Schonland), initiated by a leader stroke

3. Leader stroke (short "leader") is the faint and low current progressing discharge which opens the lightning channel (Schonland)

4. Lightning channel is the conductive path of the lightning current

5. Return stroke is the bright , high current discharge which happens when a downward leader contacts the earth (Schonland)

6. Downward stroke is a stroke whose leader progresses from a cloud towards earth

7. Upward stroke is a stroke whose leader begins at the earth or earthed conductors and progresses towards the cloud

8. Discrete stroke (Kitagawa and all) or impulse stroke is a stroke whose current has the characteristics of an impulse current, i.e. a very high current with short duration

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9. Continuing stroke is a lightning discharge with a current of low amplitude but with rather long duration (tenths of a second)

10. Hybrid stroke (Kitagawa and al) is a stroke which contains both Discrete and Continuing strokes

11. Single stroke flash, short"single flash" is a flash with only 1 stroke

12. Multiple stroke flash, short "Multiple flash" is a flash with 2 or more strokes

13. Duration of a flash is the duration of the whole lightning discharge

14. Duration of a stroke is the duration of a single stroke, i.e. leader plus return stroke generally or first leader of an upward stroke

15. Stroke interval (Kitagawa) is the time between the beginning of two successive strokes

16. No-current interval is the time duration of the current-pause between two successive strokes; the current is measured at the earth

17. Non-luminosity interval (Kitagawa) is the time duration of the luminosity-pause between two successive strokes

18. M-Component (Malan - Schonland) is a sudden enhancement of the continuing luminosity which occasionally follows a stroke in the channel; corresponding to superimposed impulse currents on a long-duration continuing current (San Salvatore)

19. K-Component or K-change (Kitagawa and al) is a small rapid electric field change which occurs in the intervals between and after the strokes of a multiple stroke flash who corresponds to impulse currents which appear on current zero (San Salvatore)

20. C-Change is a slow field change which occurs during the interval of luminosity of the lightning channel

21. J-Change is a slow field change which occurs during non luminosity of the lightning channel.

Results

All results are given in tables of frequencies of occurrence.

Time was too short to draw probability-curves. Discussion of results will be given at the Stuttgart-meeting. Communication about other sources are welcome.

List of Tables 1...12

T a b l e 1

Total Duration of Flashes

Pos.	Duration ms	MALAN Fig. 2 530 (?) Discharges p %	Kitagawa, 36 Discrete flashes p %	Brook & Workman 36 Hybrid flashes p %	Brook & Workman Mean value 72 flashes p %	San Salvatore 57 Downward flashes p %	San Salvatore 250 upward flashes p %	San Salvatore Mean value 307 flashes p %
0						0	0	0
1	0...50	11,5	0	0	0			
2	0...100	23,5	6	0	3	44	27	30
3	0...150	36	16,5	0	8	53	43	45
4	0...200	50	22	0	11	63	59	60
5	0...250	62	28	0	14			
6	0...300	74	37	6	21	82	78	79
7	0...350	81,5	47,5	11	29			
8	0...400	86	53	16,5	35	86	91	90
9	0...450	89	55	28,5	41,5			
10	0...500	92	67	42	54,5	93	96	95
11	0...550	93,5	72	50	61			
12	0...600	95,5	81	53	67	95	98	98
13	0...800	98	92	78	85	98	99	99
14	0...1000	98	95	80	92	100	100	100
15	0...1200	98	97,5	95	97,5			
16	0...1400	98	98	97,5	99			
17	0...1600	98	99	97,5	99			
18	0...1800	100	100	100	100			

T a b l e 2

Reproduction of extreme values of total duration of flashes and stroke intervals, by D. C. Malan, Geofisica Pura e Applicata, Milano, Vol. 34, pp. 224 - 230 (1956)

Reproduction of author Malans' Table 2 "Total duration of flashes"

	Total Duration in msec		
	0...200	200...400	400...1000
Percentage of all flashes having those durations	50 %	35 %	15 %
Percentage of each group having 5 or more strokes	5 %	50 %	90 %
Average interval between strokes in msec	40	50	80

Reproduction of author Malans' Table 3 "Long stroke intervals"

1 Type	2 Number of strokes	3 Intervals between successive strokes msec	4 Total duration msec	5 Sum of intervals not underlined in Col. 3 msec	6 Percentage occurrence
A	7	67- 28- 51- 75- 48- 180	449	269	
	6	46- 184- 58- 72- 150	510	176	
	9	22- 24- 40- 36- 225- 130- 58- 100	635	180	
	10	22- 29- 18- 29- 140- 140- 190- 53- 450			

Table 3

Frequency of long Stroke Intervals of 4 flashes

(Author's Table 3, Type A, Malan)

Pos.	Stroke intervals ms	Number of intervals	Stroke intervals ms	Number of stroke intervals	
				n	p %
1	0...20	1	0...20	1	3,6
2	21...40	8	0...40	9	32
3	41...60	6	0...60	15	53
4	61...80	3	0...80	18	64
5	81...100	1	0...100	19	68
6	101...120	0	0...120	19	68
7	121...140	3	0...140	22	78
8	141...160	1	0...160	23	82
9	161...180	1	0...180	24	86
10	181...200	2	0...200	26	93
11	201...220	0	0...220	26	93
12	221...240	1	0...240	27	96
13	241...450	1	0...450	28	100
		28			

Table 4

Analysis of 36 Discrete Multiple Flashes by N.Kitagawa, M.Brook & E.J.Workman
Journal of Geophysical Research, Vol. 67, No. 2, Feb. 1962

Reproduction of the author's Table 3
"Analysis of 36 Discrete Multiple Flashes"

1 Flash No.	2 Number of Channels per Flash	3 Number of Strokes per Flash	4 Total Duration of Flash msec	5 Stroke Interval,* msec Min.	6 Stroke Interval,* msec Max.	7 Channel Interval,† msec
3	2	2	111			110
4	1	3	151	24	(3.5) 107	
8	3	4	241	(2.4) 91		61, 68
13	2	8	496	31	(6.6) 65	185
16	2	7	421	40	(3.0) 104	134
18	1	8	257	16	55	
19	4	12	1699	53	(24.0)271	86, 345, 90
23	2	21	1145	12	(8.4) 108	112
24	1	2	291	16		
25	1	3	53	12	29	
27	1	6	133	(2.0) 9	70	
28a	1	6	228	22	62‡	
29	1	17	471	12	67	
34	3	13	559	5	128§	67, 128
35	2	2	991			78
36	1	22	641	14	(2.0) 77	
41	1	15	595	8	(11.3)185	
43	1	14	623	9	(2.4) 83	
45	2	2	122			104
47	2	6	648	66	91	242
48	3	13	548	13	71	58
51b	4	6	489	18	(1.2) 70	85, 60, 104
59	1	3	130	24	(29.5) 85	
60	3	6	331	(1.5 36	(1.0) 76	52, 51
61	2	6	324	23	99	70
64	2	2	185			129
65b	1	11	356	14	31	
66	1	2	53	33		
69	2	4	310	(4.2) 51	(1.0) 73‡	170
70	1	2	261	(1.0) 71		
73	1	11	611	38	(4.0) 117	
76	2	2	308			74
77	2	2	392			56
79	2	2	498			90
83	2	2	599			69
84	1	12	501	13	(6.6) 67	
Average	1	7	438	24	92	105

Explanation remarks see next page

Continuation of table 4 (remarks)

* The stroke interval is measured as the time between two successive return streamers. When a flash involves more than two stroke intervals, the shortest and longest durations among them are shown in columns 5 and 6, respectively. If the preceding stroke involves continuing luminosity of short duration (a short-continuing stroke), its duration is also shown in milliseconds by the number in parantheses.

† When a flash involves two or more channels, the time interval between two strokes taking different channels is designated as the channel interval (as distinguished from a usual stroke interval).

‡ During these intervals dart streamers which did not reach ground occurred 37 and 9 msec, respectively, before the following strokes.

§ The following stroke was preceded by a slow dart stepped leader which took 4.5 msec to reach ground.

The authors give not all particular numbers of "Stroke Intervals", but only the Min.-and Max. - number of each stroke interval occurrence. The frequency-evaluation is possible therefore only for these Min- and Max.-values.

Table 5

Analysis of 36 Discrete Multiple Flashes

by N.Kitagawa, M.Brook & E.J.Workman

Journal of Geophysical Research, Vol. 67, No. 2, Feb. 1962

Frequency of occurrence of "Stroke Intervals"

Pos.	Stroke Interval ms	Number of Intervals		Stroke Interval ms	Number of Stroke intervals			
		Min. Value	Max. Value		Min. Value		Max. Value	
		n_{min}	n_{max}		n	p %	n	p %
1	0...10	4	0	0...10	4	14	0	
2	11...20	10	0	0...20	14	48	0	
3	21...30	5	1	0...30	19	65	1	4
4	31...40	5	1	0...40	24	82,5	2	8
5	41...50	0	0	0...50	24	82,5	2	8
6	51...60	2	1	0...60	26	90	3	12
7	61...70	1	6	0...70	27	93	9	36
8	71...80	1	4	0...80	28	96	13	52
9	81...90	0	2	0...90	28	96	15	60
10	91...100	1	3	0...100	29	100	18	72
11	101...150	0	5	0...150	29	100	23	92
12	151...200	0	1	0...200	29	100	24	96
13	200...300	0	1	0...300	29	100	25	100
		29	25					

Table 6

Analysis of 36 Hybrid Flashes

by N.Kitagawa, M.Brook & E.J.Workman

Journal of Geophysical Research, Vol. 67, No. 2, Feb. 1962, p.641

(Columns 7 and 8)

Pos.	Stroke intervals ms	Number of stroke intervals	Number of non-luminosity intervals	Stroke intervals	Number of stroke intervals		Number of non-luminosity intervals	
					n	p %	n	p %
1	0...20	0	0	0...20	0	0	0	0
2	21...40	0	0	0...40	0	0	0	0
3	41...60	0	4	0...60	0	0	4	9,5
4	61...80	0	9	0...80	0	0	13	54
5	81...100	0	3	0...100	0	0	16	67
6	101...120	0	2	0...120	0	0	18	75
7	121...140	1	2	0...140	1	4	20	83
8	141...160	1	1	0...160	2	8	21	87,5
9	161...180	1	1	0...180	3	12,5	22	92
10	181...200	1	0	0...200	4	16,5	22	92
11	201...220	3	2	0...220	7	29	24	100
12	221...240	2	0	0...240	9	37	24	100
13	241...260	2	0	0...260	11	46	24	100
14	261...280	2		0...280	13	54	24	100
15	281...300	2	0	0...300	15	62,5	24	100
16	301...>300	9	0	0...>300	24	100	24	100
		24	24					

Table 7

Analysis of the Lightning Discharge of July 26, 1959, 8 h 00

by Workman, Brook & Kitagawa
Institute of Geophysical Research, Vol. 65, No. 5, May 1960

Pos.	Stroke intervals 1) ms	Number of intervals	Stroke intervals ms	Number of strokes with smaller stroke intervals		Number of strokes with larger stroke intervals	
				n	p_1%	n	p_2%
0			0	0	0	26	100
1	0...10	-	0...10	0	0	26	100
2	11...20	8	0...20	8	31	18	69
3	21...30	7	0...30	10	38,5	16	61,5
4	31...40	3	0...40	13	50	13	50
5	41...50	-	0...50	13	50	13	50
6	51...60	1	0...60	14	54	12	46
7	61...70	1	0...70	15	58	11	42
8	71...80	1	0...80	16	61,5	10	38,5
9	81...90	1	0...90	17	65	9	35
10	91...100	1	0...100	18	69	8	31
11	101...120	2	0...120	20	77	6	23
12	121...150	2	0...150	22	81	4	15,5
13	151...200	2	0...200	24	92	2	7,7
14	201...300	2	0...300	26	100	0	0

1) "Stroke interval" is given by the authors as:
"Time between 2 successive returns streamers" 1 flash with 26 distinct leader-return-strokes within 1,928 sec.

Table 8

Multiple downward strokes to San Salvatore 1963...69

17 flashes and oscillograms = 46 strokes

Pos.	Stroke interval ms	Number of stroke intervals	Stroke intervals ms	Occurrence of stroke intervals	
				n	p %
0	0	0	0	0	0
1	0...20	6	0...20	6	13
2	21...30	4	0...30	10	22
3	31...40	15	0...40	25	54
4	41...50	3	0...50	28	61
5	51...60	4	0...60	32	70
6	61...70	2	0...70	34	74
7	71...80	1	0...80	35	76
8	81...90	1	0...90	36	78
9	91...100	0	0...100	36	78
10	101...150	3	0...150	39	85
11	151...200	1	0...200	40	87
12	201...250	2	0...250	42	91,5
13	251...300	0	0...300	42	91,5
14	301...400	1	0...400	43	94
15	401...500	2	0...500	45	98
16	501...600	0	0...600	45	98
17	601...>600	1	0...>600	46	100
		46			

p = Probability of stroke intervals

T a b l e 9

Multiple downward strokes to San Salvatore, 1963...1969

17 flashes and oscillograms, 45 strokes

Pos.	No-current interval between strokes ms	Number of intervals	No-current interval between strokes ms	Number of strokes with smaller intervals		Number of strokes with greater intervals	
				n	p_1 %	n	p_2 %
0			0	0	0	45	100
1	0...20	7	0...20	7	16	38	84
2	21...40	19	0...40	26	58	19	42
3	41...60	6	0...60	32	71	13	29
4	61...80	4	0...80	36	80	9	20
5	81...100	1	0...100	37	82	8	18
6	101...120	1	0...120	38	84,5	7	13,5
7	121...150	1	0...150	39	87	6	13
8	151...200	2	0...200	41	91	4	9
9	201...630	4	0...630	45	100	0	0
		Σ 45					

p_1 = probability of smaller no-current-intervals

p_2 = probability of greater no-current-intervals

T a b l e 10

Multiple upward strokes from S. Salvatore 1967...69

46 flashes and oscillograms = 255 strokes

Pos.	Stroke Interval ms	Number of stroke intervals	Stroke intervals	Occurrence of stroke intervals	
				n	p %
0		0	0	0	0
1	0...20	104	0...20	104	50
2	21...30	32	0...30	136	65
3	31...40	10	0...40	146	70
4	41...50	6	0...50	152	73
5	51...60	3	0...60	155	74
6	61...70	2	0...70	157	75
7	71...80	4	0...80	161	77
8	81...90	3	0...90	164	78
9	91...100	0	0...100	164	78
10	101...150	4	0...150	168	80
11	151...200	10	0...200	178	85
12	201...250	12	0...250	190	91
13	251...300	5	0...300	195	93
14	301...400	7	0...400	202	96,5
15	401...500	4	0...500	206	98,5
16	501...600	2	0...600	208	99,5
17	601..>600	1	0..>600	209	100
		209			

p = probability of stroke intervals

T a b l e ll

Multiple upward strokes from San Salvatore 1967/68/69

47 flashes, 260 strokes and oscillograms

Pos.	No-current interval between strokes ms	Number of intervals	No-current interval between strokes ms	Number of strokes with smaller no-current-intervals		Number of strokes with greater no-current-intervals	
				n	p_1 %	n	p_2 %
0			0	0	0	210	100
1	0...10	53	0...10	53	25	157	75
2	11...20	67	0...20	120	57	90	43
3	21...30	39	0...30	159	76	51	24
4	31...40	15	0...40	174	83	36	17
5	41...50	9	0...50	183	87	27	13
6	51...60	3	0...60	186	88,5	24	11,5
7	61...70	5	0...70	191	91	19	9
8	71...80	4	0...80	195	93	15	7
9	81...90	5	0...90	200	95,5	10	4,5
10	91...100	2	0...100	202	96	8	4
11	101...125	2	0...125	204	97	6	3
12	126...150	2	0...150	206	98	4	2
13	151...175	1	0...175	207	98,5	3	1,5
14	176...200	1	0...200	208	99	2	1
15	201...250	1	0...250	209	99,5	1	0,5
16	251...300	1	0...300	210	100	0	0

p_1 = probability of smaller no-current-intervals

P_2 = probability of greater no-current-intervals

T a b l e 12

Reproduction of 3 curves, published by I.S. Stekolnikov,
Molnija, Moskau 1943
transmitted by F. Popolanski

Fig. 141: Frequency of impulses

a) Cloud to ground discharges

b) Intracloud discharges

c) Both types

Fig. 143: Frequency of intervals between strokes

—— Strokes from cloud to ground

···· Strokes between clouds

Fig. 144: Frequency of duration of the complete flash

—— Flashes from cloud to ground

.... Flashes between clouds

These curves are based on Klydonograph-figures (Lichtenberg-figures on rotating film.

T a b l e 12

Reproduction of 3 curves, published by I.S. Stekolnikov,
Molnija, Moskau 1943
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Fig. 141: Frequency of impulses

a) Cloud to ground discharges

b) Intracloud discharges

c) Both types

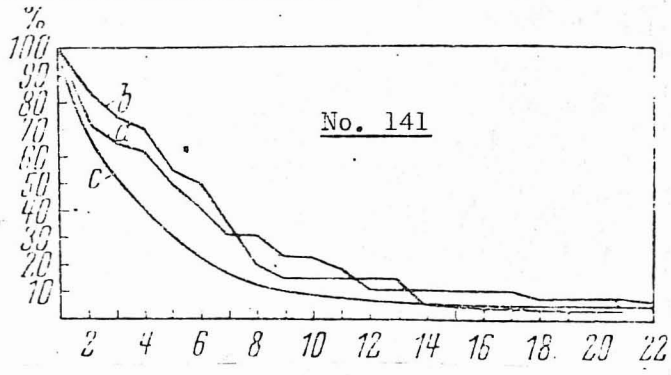


Fig. 143: Frequency of intervals between strokes

—— Strokes from cloud to ground

···· Strokes between clouds

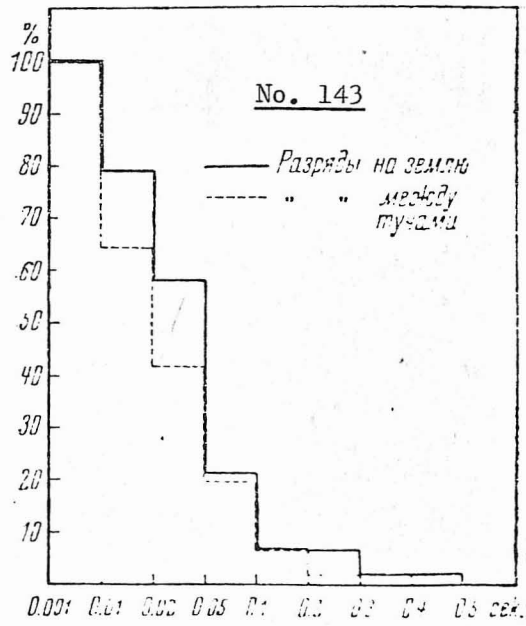
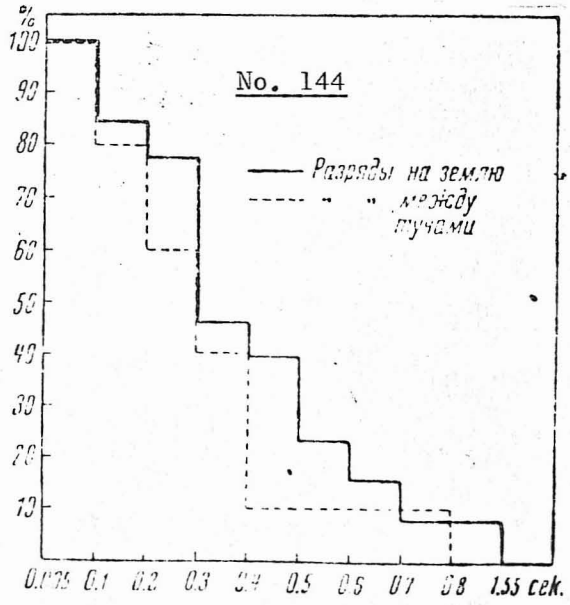


Fig. 144: Frequency of duration of the complete flash

—— Flashes from cloud to ground

.... Flashes between clouds



These curves are based on Klydonograph-figures (Lichtenberg-figures on rotating film.