A preliminary study of the synoptic conditions associated with lightning flashes over Mt. San Salvatore, Lugano, Switzerland

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ABSTRACT

A preliminary analytical study has been made of the synoptic situations associated with thunderstorms that initiate upward-moving leaders from the towers on the Mt. San Salvatore near Lugano, Switzerland. Synoptic situations at the time of the lightning occurrences were divided into six categories based on the surface weather and flow pattern during the period 1967–1969 at Lugano. Cloud thicknesses were estimated from the LFC (Level of Free Convection) and LCL (Lifting Condensation Level) from the mean sounding at Milan. Large cloud thicknesses were found to be associated with the combined upward and downward discharges and smaller cloud thicknesses were associated with only upward discharges (flashes initiated by upward moving stepped leaders). Furthermore, the large cloud thicknesses were associated with the thunderstorms that had proportionally more flashes to the surrounding countryside than to the tower itself. We offer the speculation that the difference in upward and downward discharges to the towers with associated synoptic situations may be explained on the basis of a deficiency of large raindrops which are believed to be necessary for the initiation of downward discharges.

1. Introduction

Studies of synoptic conditions associated with thunderstorms and studies on the physical characteristics of the lightning flash have been pursued for years—and always independently. The different time and spatial scales suggest that there is no reason to consider these atmospheric phenomena in any other way. And yet, observations in the 1960's at the Mt. San Salvatore Lightning Observatory suggested that certain types of lightning are associated with different synoptic situations. The latter do not need further discussion but the different types of lightning are easier understood by considering the Lightning Observatory in more detail.

The observatory was established on Mt. San Salvatore (45°58′ N, 8°55′ E) near Lugano, Switzerland in 1943 (Fig. 1). A tower was erected on the highest peak of the mountain (912 m above mean sea level) and instrumented to obtain electric current oscillograms of the lightning flash. This tower was replaced in 1958 by a new construction which serves as a lightning research station and as a radio and television tower. This tower is referred to as T1 (Berger, 1967), and was 70 m high until 1969, when its height was increased to 92 m. A second tower (T2), erected in 1950, is used only for lightning research. It is located on a second peak, at a distance approximately 400 m from T1, and its top is about 47 m lower than that of T1. T2 is 70 m high. The setting of both towers with respect to the city of Lugano is shown in Fig. 1.

Continuous operation of this observatory from the spring to fall of each year indicates that the two towers are involved in approximately 100 lightning flashes per year. These flashes may be initiated within a cloud and the resulting stepped leader propagates toward the towers to produce the characteristic branching in the direction of the ground (Fig. 2). These are the downward (cloud-to-ground) flashes which have

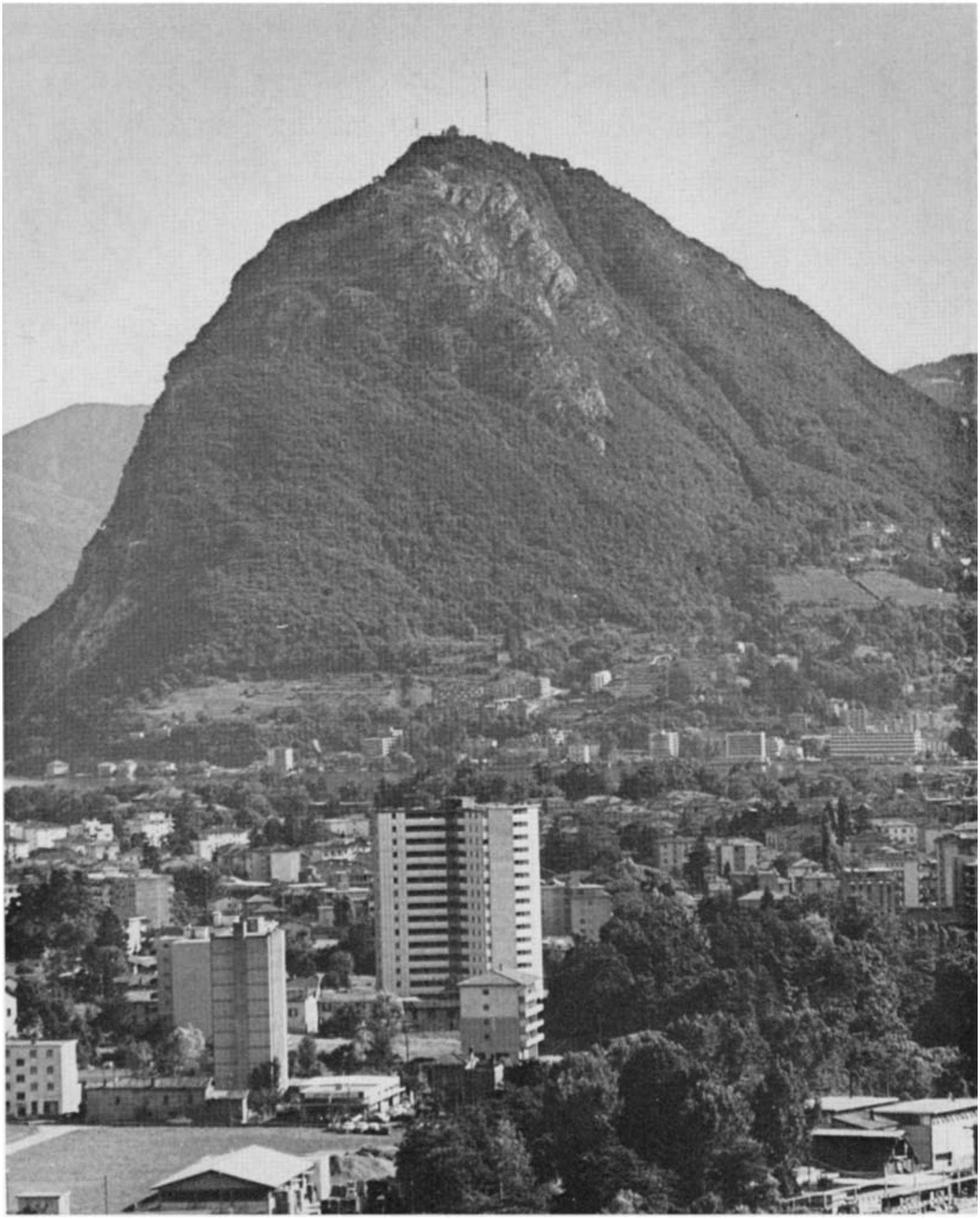

Fig. 1. Perspective of twin towers atop Mt. San Salvatore, Lugano, Switzerland.

been extensively studied and whose characteristics are summarized by Uman (1969, pp. 1–10). On the other hand, it is not so well known that flashes can be initiated or triggered by the presence of the towers. In these cases, the stepped leader propagates from the towers to the clouds to produce an upward (ground-to-cloud) flash with characteristic branching

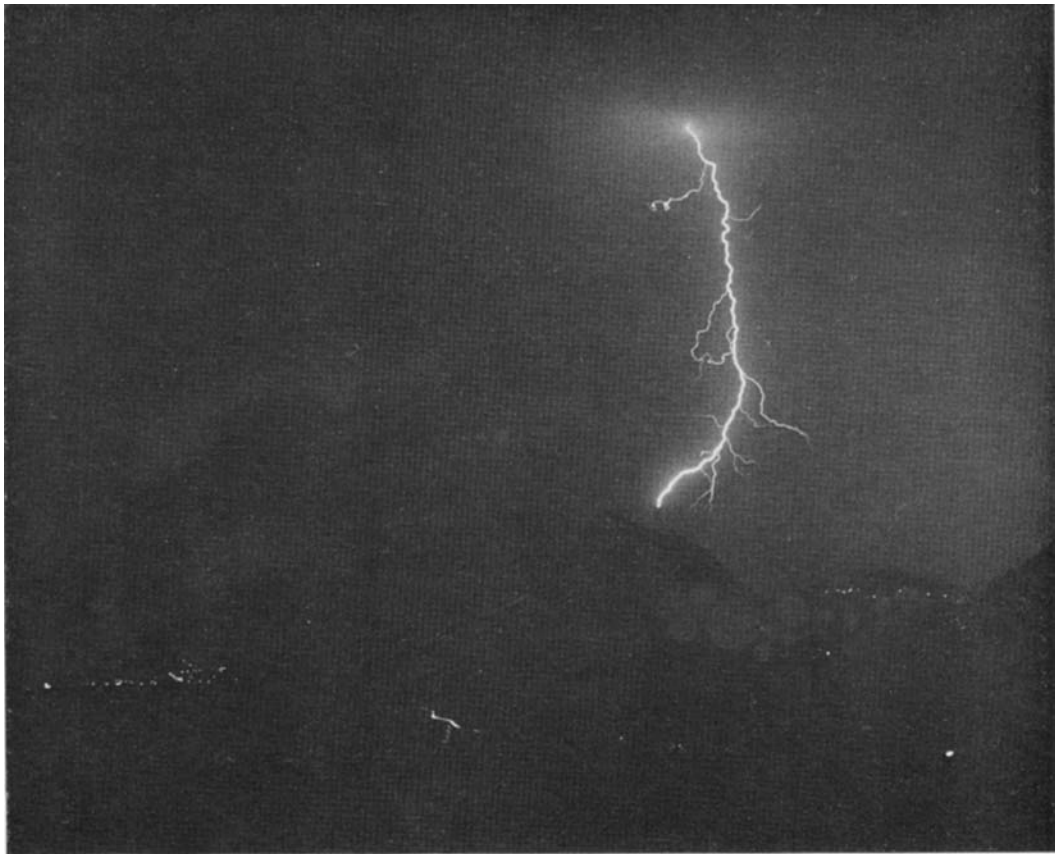

Fig. 2. Downward lightning flash (cloud-to-ground) to T2.

pointing towards the clouds (Fig. 3). These upward discharges—sometimes termed "triggered" discharges—are not unique to the Mt. San Salvatore towers but are also often observed from other tall structures such as the Empire State Building (McEachron, 1939). Triggered lightning has also occurred from planes and rockets, and the general characteristics of triggered discharges have been summarized by Pierce (1972).

Approximately 80% of the discharges involving the Mt. San Salvatore towers are upward flashes. It has been observed, however, that individual storms produce a series of strikes involving the towers which are nearly all upward flashes or all downward flashes. Observers have noted the high fraction of upward flashes which seem to be associated with frontal passages. Furthermore, the occurrence of predominately downward flashes seems to be associated with air mass thunderstorms. It is the purpose of this study to determine in fact whether there are characteristic synoptic situations which can be associated with the type of discharge involving the San Salvatore towers.

2. Data and Analysis

Climatological survey of lightning occurrence

A thunderstorm day is defined as a local calendar day on which thunder is heard (WMO, 1953). A report of distant lightning in the absence of thunder would not be counted as a thunderstorm day. Published tables by Berger (1967) show that the number of thunderstorm days for the period 1955–1963 has a mean value of 51 for March to October, the time that the observatory is normally operating. A seasonal variation is evident with a minimum frequency

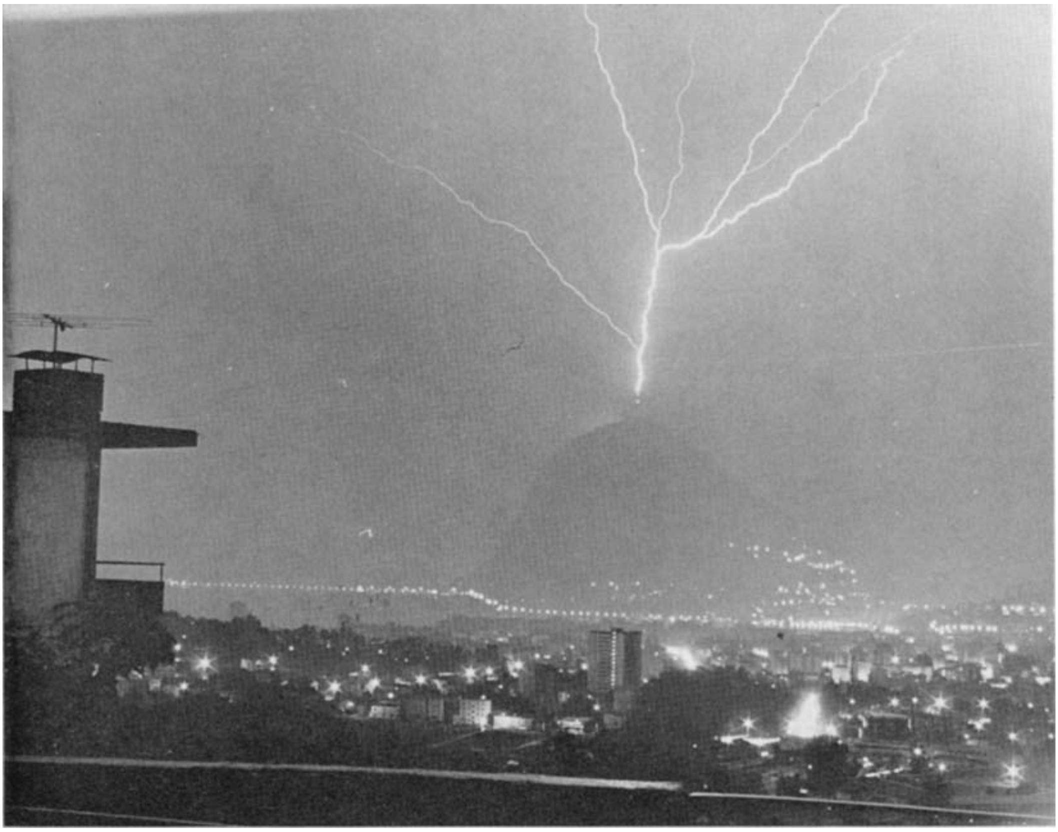

Fig. 3. Upward lightning flash (ground-to-cloud) from T1.

in the early spring and fall and the maximum frequency during the summer period.

An examination of the flashes involving the towers with respect to the direction of stepped leader propagation shows that upward flashes predominate and that T1 is hit more often than T2 (Berger, 1967).

Thunderstorms producing two or more oscillograms during the period 1967 to 1969 are divided into two different groups, frontal and non-frontal. The data used in the selection process consisted of northern hemisphere 1000–500 mb thickness charts with surface isobars analyzed at 8 mb intervals and available at 0000 and 1200 GMT; northern hemisphere surface charts analyzed at 8 mb intervals and available at 0000, 0600, 1200 and 1800 GMT and northern hemisphere 500 mb charts available at 0000 and 1200 GMT. The data source was the United Department of Commerce, Environmental Data Service, National Climatic Center, Asheville, North Carolina.

Frontal type thunderstorms are categorized as follows: (1) low pressure wave along the front (WCF) as defined by the existence of one closed isobar with the center of low pressure located within 200 km of the station, (2) post-cold front (POCF) in the following 3 to 12 hours after frontal passage with the front within 50 to 200 km of the station, (3) pre-cold front (PRCF) in the 3 to 12 hour period prior to frontal passage with the front within 50 to 200 km of the station, and (4) cold front passage (CFP) within three hours of the time of discharges to the tower and the front within 50 km of the station. Note that no case in category 1 is included in categories 2–4. The criteria are arbitrary and are based upon synoptic experience.

Non-frontal types are sub-divided into two categories as follows: (1) low center as defined

Table 1. *Number of thunderstorms producing more than two current oscillograms for frontal and non-frontal categories at Mt. San Salvatore (1967–1969)*

Sub-categories are described in the text

	Number	March	April	May	June	July	August	Sept.	October
Frontal Category									
WCF	6	1	1	0	1	1	1	1	0
CFP	7	0	0	2	2	1	2	0	0
PRCF	3	0	0	1	0	0	0	1	1
POCF	7	0	0	5	2	0	0	0	0
Total	23	1	1	8	5	2	3	2	1
Non-frontal									
Low	6	0	0	1	2	0	2	0	1
Air	17	0	0	4	4	4	3	1	1
Total	23	0	0	5	6	4	5	1	2

by the presence of at least one closed isobar (LOW) within 200 km of the station and no analyzed surface fronts, and (2) to the south of the eastern extension of the Atlantic subtropical anticyclone with cyclonic curvature in the surface isobars within the vicinity of the station or no well defined synoptic pattern but usually under a very weak anticyclonic regime (AIR). This latter category includes air mass type thunderstorms.

(i) Thunderstorms producing two or more current oscillograms during 1967–1969: 46 cases

The lightning data in Tables 1 and 2 were obtained from Mr H. Binz of the Mt. San Salvatore Lightning Observatory. The meteorological classifications in these tables are described above.

There are 46 thunderstorms equally divided between frontal and non-frontal types. The number of thunderstorms for different subcategories is shown in Table 1. No obvious seasonal preference for different types of thunderstorms is indicated. Air mass thunderstorms are found in 17 cases with a maximum of 12 upward flashes compared to frontal type thunderstorms in 23 cases with a maximum of 41 upward flashes. Similarly, the data indicate a larger number of lightning flashes from the towers to the cloud associated with frontal type thunderstorms and was first observed by the San Salvatore observers (Berger, private communication).

No time preference is indicated for air mass type thunderstorms although the three year sample size is small. Perhaps orographic lifting of a moist air stream from the Mediterranean along the southern slopes of the Alps serves to trigger the conditional instability in such synoptic situations. Some of these storms may drift northward in turn. This should be contrasted with the more typical late afternoon or early evening air mass type thunderstorm over the interiors of featureless continents under a maritime-tropical air flow.

The smallest category proved to be pre-cold front thunderstorms with only three cases. Evidently approaching cold fronts from the northwest of the Alps usually advance very slowly southeastward and the observatory remains in a warm sector with a very weak surface convergence that is unfavorable for orographic lifting in general.

(ii) Fifteen selected cases during 1964–1969

Many of the 46 thunderstorms discussed in the previous section produced only downward discharges to the towers or a very high percentage of downward strikes. Personal observation by one of the authors (Orville) during three summers and continuous observation by the Mt. San Salvatore observers has easily identified these cases with air mass thunderstorms. The purpose of this preliminary study, however, is to examine in detail the synoptic weather patterns associated with numerous *upward* discharges. Consequently, fifteen cases during the period 1964–1969 were selected for further study on the basis of having predominately upward discharges from the towers. The synoptic data source described earlier was supplemented by the European Surface Weather Maps published by Deutscher Wetterdienst at 0000 and 0600

Table 2. *Fifteen selected cases of tower flashes for different synoptic situations (1964–1969)*

Category	LST	Day/month/year	Flashes	Surface weather at the time of the lightning occurrence (Personal observations by H. Binz at the Mt. San Salvatore Lightning Observatory)	
				Precipitation	Wind
WCF	2235–0018	7–8 July 1969	12 upward	Rain (moderate)	NW (strong) → NE
WCF	0227–0517	7 May 1966	29 upward	Rain (moderate) 03:09 Hail (light)	N (strong)
WCF	0134–0417	15 June 1964	1 downward 17 upward	Rain (heavy to moderate)	N
CFP	0716–0752	7 July 1969	3 upward	Rain (heavy) to no rain	S (moderate)
CFP	0853–0930	17 July 1966	2 downward 6 upward	Rain (moderate)	Calm
CFP	1638–1757 2237	2 May 1967 4 Aug. 1967	2 upward 1 downward	Rain (moderate) Rain (heavy)	Calm
CFP	0003–0004	5 Aug. 1967	2 upward	Rain (light) 11:25 Rain and small hail 11:33 Rain and snow	NW
POCF	1147–1351	3 May 1967	41 upward	11:40 Rain (heavy) and hail 12:07 Snow and sleet, snow to end of storm	N (strong)
POCF	1839–1912	4 June 1968	9 upward	Rain (moderate)	ESE (moderate to strong)
PRCF	2241–0233	15–16 Oct. 1966	35 upward	Rain (moderate to heavy)	NE (moderate) → SSW (strong) → ESE
PRCF	1126–1236	2 Oct. 1967	18 upward	Rain (heavy)	Calm
PRCF	1535–2047	1 May 1967	3 downward 23 upward	Rain (light–heavy–moderate)	WNW (strong) → N (moderate) → NE
LOW	0205–0625	12 Sept. 1965	1 downward 42 upward	Rain (moderate to heavy) and hail	N
AIR	2213–0158	27–27 July 1967	2 downward 6 upward	Rain (moderate to heavy)	S (weak) → N → NW (moderate)
AIR	2244–0109	1 Oct. 1967	12 upward	Rain (moderate)	Calm

GMT. Radiosonde data were obtained from Milan (45°30′ N, 9°15′ E, about 50 km south of the lightning observatory) at 0000 and 1200 GMT. This was the closest station to the observatory for which we could obtain such data.

Composite 500 mb height charts were constructed for these cases in an effort to better understand the synoptic patterns. Fig. 4*a*, 4*b*, and 4*c* show the 500 mb height patterns 24 hours prior to, at the time of, and 24 hours after the time of lightning occurrence. A linear interpolation and inverse weighting scheme in time was used for those cases between regular radiosonde observations.

During the 48 hour period centered on the time of lightning occurrence, an initially confluent trough in the westerlies moves eastward. The southern portion of this trough intensifies leading to a diffluent pattern in the southern branch of the westerlies over northern Italy. Such synoptic patterns are often associated with active surface weather regimes. The pattern at 300 mb (not shown) is quite similar such that a strong upward increase of cyclonic vorticity advection at the time of lightning occurrence (Fig. 4*b*) suggests significant synoptic scale upward motion accompanying the surface cyclone. Active surface fronts were noted in 12 of the 15 cases (Table 2).

Table 2 summarizes the local weather and lightning conditions for the 15 cases under discussion. Upward flashes predominate across the different synoptic classifications for this rather limited sample size. No downward flashes were observed for the two post-cold front cases. Solid precipitation is observed in three cases corresponding to three out of four of the most numerous lightning flash observations. Similarly, stronger surface winds appear to be associated with more frequent flashes. This is

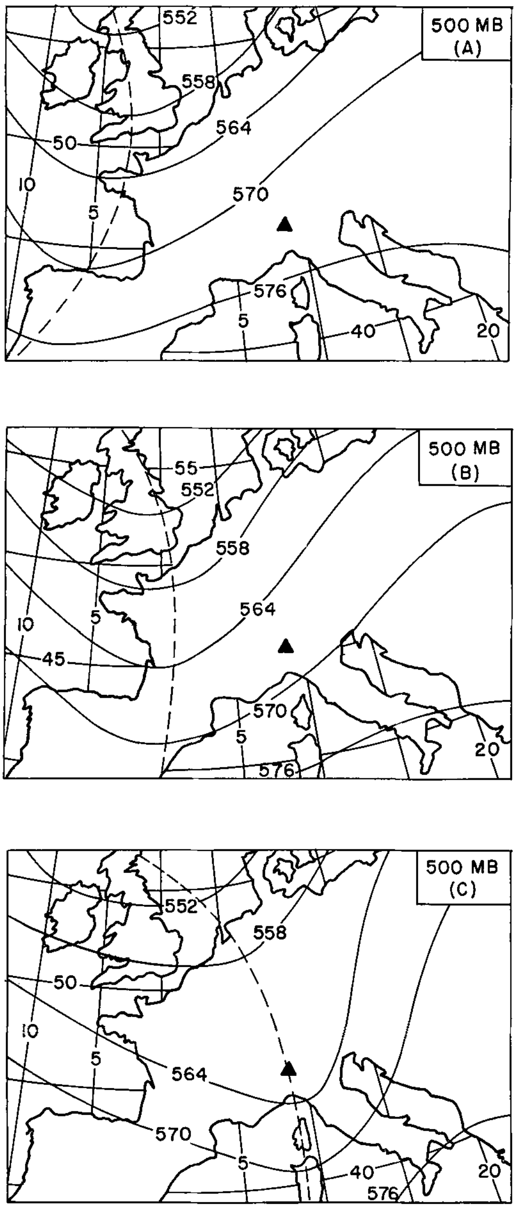

Fig. 4. Composite 500 mb charts for 24 hours prior to lightning occurrences (*a*), at time of occurrence *b*), and 24 hours after occurrence (*c*). Heights in, dekameters. Solid triangle indicates observatory location.

probably due to two effects: (1) strong upward motion induced from strong low level convergence in connection with an upper level trough, and (2) terrain induced upward motion of moist air. This strong upward motion of moist air is favorable for charge separation and the occurrence of lightning.

The mean freezing level is found at 690 mb and 750 mb for cold front and post-cold front passages respectively. A maximum height of 630 mb and a minimum height of 790 mb were noted on 4 August and 3 May of 1967 respectively. The mean freezing level is found at 715 mb and the lifting condensation level (LCL) is computed as 940 mb for frontal type thunderstorms. The corresponding numbers for non-frontal type thunderstorms are 700 mb and 980 mb respectively.

(*a*) *Mean conditions for upward and combined upward and downward flashes to the towers.* Nine thunderstorm cases consisting of only upward flashes and six cases having mostly upward and a few downward flashes to the towers make up our sample. Figure 5 indicates the mean Milan soundings for both types of cases. The freezing level is found at 690 mb and the lifting condensation level is computed to be 955 mb for the combined upward–downward cases. The

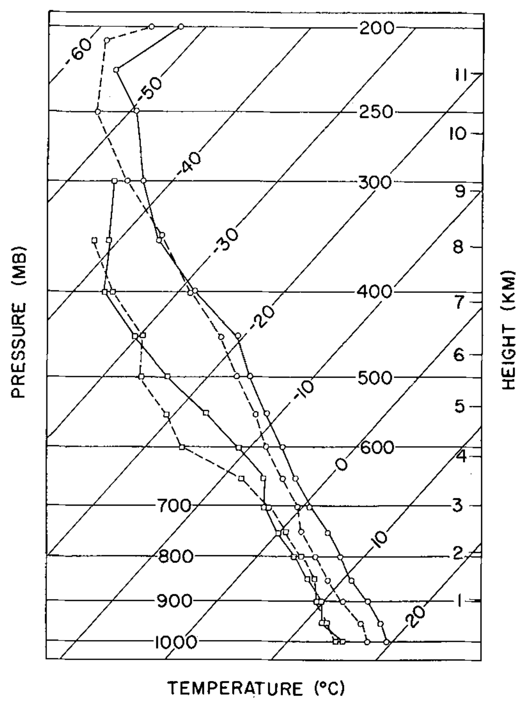

Fig. 5. Mean soundings at Milan for upward and downward flash thunderstorms (solid) and upward flash thunderstorms (dashed). Temperature is represented by open circles and dew point temperature by open squares.

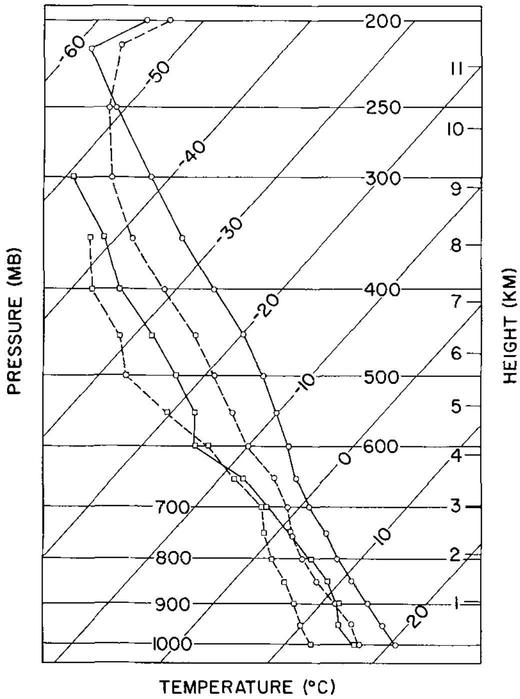

Fig. 6. Mean soundings at Milan for thunderstorms of less than 18 flashes (solid) and more than 18 flashes (dashed). Temperature is represented by open circles and dew point temperature by open squares.

corresponding numbers for the upward cases alone are 720 mb and 935 mb. In general the mean upward flash sounding is 2°C colder than the mixed flash case with the exception of the 350 mb region. Also, the air for upward flash cases alone had a higher relative humidity between 1 000 and 700 mb and a lower relative humidity between 700 mb and 500 mb than in the combined upward and downward cases.

For the upward flash cases alone, frontal or orographic lifting could readily result in cloud tops extending to approximately 6 km (as estimated from the top of the level of free convection) and cloud bases at 500 m (as estimated from the base of the level of free convection and LCL) or below the tower. Similarly for the combined upward and downward cases, cloud tops could reach approximately 8.5 km in the presence of frontal or orographic lifting although the initial energy input to trigger convection would be somewhat larger than in the upward case alone. Attempts to verify the cloud top estimates using records of the *vertical* pointing radar at Locarno-Monti, approximately 25 km from the Mt. San Salvatore, have not been possible.

A *tentative* conclusion is made that the larger cloud thicknesses are associated with combined upward and downward flashes while the smaller cloud thicknesses are associated with only upward flash thunderstorms. This is consistent with the observation that clouds of small vertical dimension do not have enough electrical activity to initiate a lightning flash, but can be "triggered" by the presence of a tall tower to produce an upward flash. A similar flash was triggered by the presence of the Apollo/Saturn 12 vehicle in the clouds over Cape Kennedy on 14 November 1969. Furthermore, the fact that upward and downward flashes to the towers are associated with larger cloud thicknesses is consistent with previous observations that the electrical activity of a cloud increases with its vertical extent; thus increasing the probability of a cloud initiating a flash; i.e., a downward flash to the towers.

(*b*) *Mean conditions for frequent versus non-frequent tower flashes.* A division in the data at 18 or more flashes and 12 or less is a natural separation in the data. We now examine these to see if any significant differences exist between thunderstorms. In general the flashes to the towers are recorded in a time span of less than or equal to three hours. Note that thunderstorms with more than 18 flashes to the towers are not necessarily more violent or active. Summertime observations indicate that very active thunderstorms may produce few strikes to the towers but many strikes to the surrounding areas, lake, city or side of the mountain. There are 7 cases with 18 or more flashes and 8 cases with 12 or less flashes.

The mean freezing level is 730 mb for thunderstorms with 18 or more flashes and 688 mb for thunderstorms with 12 or less flashes involving the towers. Evidently this represents a seasonal difference, as there is a higher frequency of flashes in the spring and autumn with a lower freezing level as compared to a lower frequency during the summer period with a higher freezing level (Table 2).

Mean soundings for both cases are shown in Fig. 6. It is colder throughout the troposphere for the more numerous flash cases. Similarly the moist layer extends to 600 mb for these cases as compared to 700–650 mb for the fewer flash cases. A similar computation as before suggests that cloud tops may reach 6300 m and 9000 m for both cases respectively. Again, cloud thicknesses appear to be inversely proportional to the lower flash activity with cloud bases at approximately the same height for both cases. Small cloud thicknesses are consistent with many "triggered" flashes. With large cloud thicknesses, many discharges are initiated within the clouds and strike the ground at random places; some of the strikes are, of course, to the towers.

(iii) Correlations

A study was made to determine if there was any correlation between the height of the freezing level above the towers and the number of flashes involving the towers. One hundred thunderstorms producing 786 flashes involving the towers between 1962 and 1970 were examined. The height of the freezing level was estimated from the Milan soundings. Since a sounding did not usually occur at the time of the lightning strikes, the two nearest soundings were used; one before the storm and one after.

The heights of the freezing level before and after the storm were plotted vs. the number of lightning strikes involving the towers on 100 thunderstorm days. There was no significant correlation. The 100 thunderstorm days were then classified into the following synoptic situations; cold air instability, warm air instability, cold trough aloft, cold air overrunning, cold front, warm front, and occluded front. The heights of the freezing level before and after the storm were plotted vs. the seven synoptic situations. There was no significant correlation for the fourteen plots.

Furthermore, the height of the freezing level was plotted vs. the number of strikes per hour for cold air overrunning and cold trough aloft situations; those situations producing a high density of lightning strikes. No significant correlations were found.

3. Conclusions and Discussion

The present study is not intended to be a thorough analysis of all the available synoptic data associated with the many thunderstorm days and their associated strikes to the Mt. San Salvatore towers. It does, however, analyze a reasonable fraction of the available data to put on a quantitative basis the increased frequency of upward discharges associated with cold front passages. Based on the present investigation, we can summarize our results as follows:

(1) Thunderstorms producing the most lightning flashes involving the towers are associated with frontal systems.

(2) The mean freezing level and the lifting condensation level (LCL) are lower in upward flash cases than those cases involving upward and downward flashes.

(3) Cases involving both upward and downward flashes are associated with larger cloud thicknesses relative to *only* upward flash cases which are associated with clouds of relatively smaller vertical thickness.

(4) Larger cloud thicknesses appear to be associated with thunderstorms producing *less* than 18 strikes to the towers; smaller cloud thicknesses associated with *more* than 18 strikes to the towers.

(5) Only upward flashes from the towers were found in post-cold front situations while in the other situations both directions were found.

There are no measurements taken on Mt. San Salvatore which allow us to specify the physical characteristics of the precipitation in storms producing flashes which involve the towers. We can, however, make a few qualitative observations.

The difference between upward and downward flashes is determined entirely by the point of initiation of the lightning flash. This is dependent upon the attainment of electric fields which are sufficient to cause breakdown. In a cloud, the cloud-to-ground discharge is postulated to begin with positive corona from large water drops (Loeb, 1953, 1966; Pierce, 1957). Under these conditions we would expect both downward and upward discharges involving the Salvatore towers. On the other hand, if a deficiency of large water drops exists in an electrified cloud, then we would expect a preponderance of upward discharges from the towers.

Recent results have been published by Roesli & Waldvogel (1972) in which they studied the rain types of the Locarno region and developed a tentative climatology of Z–R relations. If the parameter a of the Z–R relation is interpreted in terms of the drop-size distribution a striking feature is found. The only rain type with a sizeable amount of very large drops (3–5 mm diameter) are the non-frontal local thunderstorms. All other types, including frontal thunderstorms show narrower drop-size distributions with the largest drop diameters rarely exceeding 3 mm.

Consequently, in the absence of further experimental evidence, we conclude that there is sufficient reason to suggest that varying raindrop-size distributions may be responsible for the preponderance of upward flashes in cold front passages vs. non-frontal local thunderstorms which produce numerous downward flashes and occasional upward flashes from the towers.

Of additional interest are the observations by one of the authors (Roesli) living in the Locarno region and another (Orville) during three summer field studies. Their observations, not supported by measurements, suggest that a greater proportion of intracloud discharges occur during synoptic conditions characterized by widespread rain (narrow drop-size distribution) as compared to non-frontal local thunderstorms. The significance of this observation rests on the suggestion by Berger (1967, p. 524) that upward discharges are secondary flashes and occur only in response to a distant primary flash. It is suggested that the distant flash produces a high transient electric field at the tower top that is sufficient to initiate a discharge from the tower. Consequently, synoptic situations characterized by a high proportion of intracloud discharges would be expected to produce a high proportion of upward discharges. Experiments to check Berger's interesting suggestion are now (1973) in progress at the Mt. San Salvatore Observatory.

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REFERENCES

Berger, K. 1967. Novel observations on lightning discharges: Results of research on Mount San Salvatore. *J. Frank. Inst. 283*, 478–525.

Deutscher Wetterdienst 1964–1969. Wetterlage and absolute topographic 500 mb, 1964–1969.

Loeb, L. B. 1953. Experimental contributions to knowledge of thunderstorm electricity. In *Thunderstorm electricity* (ed. H. Byers), p. 161. Univ. of Chicago Press, Chicago, Ill.

Loeb, L. B. 1966. The mechanisms of stepped and dart leaders in cloud-to-ground lightning strokes. *J. Geophys. Res. 71*, 4711–4721.

McEachron, K. B. 1939. Lightning to the Empire State Building. *J. Frank. Inst. 227*, 149–217.

Pierce, E. T. 1957. Recent advances in meteorology-lightning. *Sci. Progr. London 45*, 62–75.

Pierce, E. T. 1972. Triggered lightning and some unsuspected lightning hazards. *Naval Research Reviews 25*, No. 3, 14–28.

Roesli, H. P. & Waldvogel, A. 1972. The lower bound of accuracy of a radar raingauge. *Proceedings of the 15th Radar Meteorology Conference, Champaign-Urbana, Illinois, 10–12 Oct 1972*, pp. 181–184. Available from the American Meteorological Society, Boston, Massachusetts.

Uman, M. A. 1969. *Lightning*. McGraw-Hill, New York.

United States Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service 1964–1969. Northern Hemisphere Surface and 500 mb Charts, Northern Hemisphere Data Tabulations and Northern Hemisphere 1 000–500 mb Thickness Charts, 1964–1969.

World Meteorological Organization 1953. *World distribution of thunderstorm days. Part I.* Secretariat of the World Meteorological Organization, WMO/OMM-No. 21 TP 6, Geneva, Switzerland.

ПРЕДВАРИТЕЛЬНОЕ ИЗУЧЕНИЕ СИНОПТИЧЕСКИХ УСЛОВИЙ, СВЯЗАННЫХ СО ВСПЫШКАМИ МОЛНИЙ НАД г. САН-САЛЬВАТОРЕ (ЛУГАНО, ШВЕЙЦАРИЯ)

Проделано предварительное аналитическое изучение синоптических ситуаций, связанных с грозами, которые возбуждают движущиеся вверх лидеры от башен на г. Сан-Сальваторе вблизи Лугано, Швейцария. Синоптические ситуации во время гроз были разделены на шесть категорий в зависимости от погоды у поверхности и воздушных потоков за период 1967–1969 гг. в Лугано. Толщины облаков оценивались по уровню свободной конвекции и уровню конденсации на основе среднего зондирования в Милане. Было найдено, что большие толщины облаков связаны как с идущими вверх, так и вниз разрядами; в то же время меньшие толщины облаков связаны только с вверх идущими разрядами (вспышки, возбуждаемые движущимися вверх смещающимися лидерами). Кроме того, большие толщины облаков связаны с грозами, которые имеют пропорционально больше вспышек в окружающую местность, чем в сам город. Мы высказываем предположение, что разница разрядов вверх и вниз в зависимости от синоптической ситуации может быть объяснена недостатком больших дождевых капель, которые, как известно, необходимы для возбуждения идущих вниз разрядов.