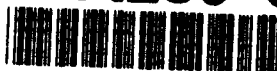


AD-A280 033 10N PAGE

Form Approved
OMB No. 0704-0188

①

Public
gathering
collection
data

Page 1 How our response, including the time for reviewing instructions, searching existing data sources, the collection of information, send comments regarding this burden estimate or any other aspect of this Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE

December 1993

3. REPORT TYPE AND DATES COVERED

Final 1 Nov 91 To 31 Mar 94

4. TITLE AND SUBTITLE

THE INITIATION OF LIGHTNING AND THE GROWTH OF ELECTRIC
FIELDS IN THUNDERSTORMS

5. FUNDING NUMBERS

F49620-92-J-0020

61102F

2310

CS

6. AUTHOR(S)

Professor John Latham

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Physics Dept.

UMIST

P.O. Box 88

Manchester M60 1QD

England

DTIC
SELECTE
JUN 06 1994
S B D8. PERFORMING ORGANIZATION
REPORT NUMBER

Phys/2 -

AFOSR-TR- 94 0317

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

European Office of Aerospace Research and Development

223/231 Old Marylebone Road / AFOSR/ML

London NW1 5TH, UK 110 Duncan Ave Suite B115

Maj Kroll

Bolling AFB DC 20332-0001

10. SPONSORING/MONITORING
AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release

- distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Further research into the glaciation of convective clouds of the type that produce lightning has revealed that the early stages of ice formation can be detected by measurement of the supercooled droplet radius - a result which also has climatological implications.

Further laboratory experiments have shown that the most effective methods of lightning initiation are likely to involve supercooled raindrops, with threshold fields around 300kV/m.

A new model of thundercloud electrification and lightning production has been developed, from which it is possible to deduce the sensitivity of lightning frequency to meteorological and cloud microphysical parameters.

DTIC QUALITY ASSURED

14. SUBJECT TERMS

Lightning, ice, corona, electric field

15. NUMBER OF PAGES

59

16. PRICE CODE

17. SECURITY CLASSIFICATION
OF REPORT

Unclassified

18. SECURITY CLASSIFICATION
OF THIS PAGE

Unclassified

19. SECURITY CLASSIFICATION
OF ABSTRACT

Unclassified

20. LIMITATION OF ABSTRACT

UL

Approved for public release;
distribution unlimited.

**THE INITIATION OF LIGHTNING AND THE GROWTH OF ELECTRIC FIELDS IN
THUNDERSTORMS**

**Second Annual Report to the European Office of Aerospace Research
and Development**

(Attn. Ms Janet Johnston)

Contract No. F49620-92-J-0020

by

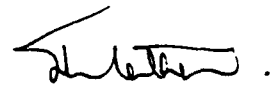
**Professor John Latham
Physics Department
UMIST
P.O. Box 88
Manchester M60 1QD
England**

December 1993

94-16601



WDB



(Professor John Latham)

94 6 3 046

22 DEC 1993

1. PREAMBLE

It was predicted, in the concluding paragraph of the First Annual Report, that the primary research focus in the second year of work under the contract, would be in three areas:-

- (1) Extension of studies of thundercloud glaciation.
- (2) Extension of laboratory studies of lightning initiation.
- (3) Development of theoretical and computational studies of thunderstorm electrification / lightning problems.

It has indeed transpired that major attention has been devoted to these three topics, with papers having been accepted for publication in (1) and (2), and a paper shortly to be submitted for publication in (3).

Section 2 of this report consists of a preprint of a paper by a colleague and myself, which has been accepted for publication in the Quarterly Journal of the Royal Meteorological Society. It is concerned with topic (1).

Section 3 of this report consists of a preprint of a paper by a colleague and myself, which will be published in the Proceedings of the First International Conference on Lightning, held in Vitrac, France in June 1992.

Section 4 of this report consists of a description of a newly developed model of thundercloud electrification and lightning, together with some specimen results. It predicts (for the first time, we believe) the frequency of lightning production as a function of significant meteorological and microphysical input parameters; and it draws on the results of research conducted earlier, under this contract.

SECTION 2. RESEARCH ON THE GLACIATION OF CONVECTIVE CLOUDS

INFLUENCE OF GLACIATION ON AN EFFECTIVE-RADIUS PARAMETERISATION

Alan M. Blyth

Department of Physics and Geophysical Research Center, New Mexico Institute
of Mining and Technology, Socorro, NM 87801, U.S.A.

John Latham

Department of Pure and Applied Physics, U.M.I.S.T., Manchester, M60 1QD.

Accession For	
NTIS GRA&I	☒
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution	
Availability Codes	
Dist	Avail and/or Special
A-1	

ABSTRACT

A recent study (Blyth and Latham 1991) of ice-free, non-precipitating sub-adiabatic cumulus clouds, involving the examination of data from multiple-penetration airborne experiments conducted in Montana and New Mexico, showed that the effective radius r_{eff} - a parameter of central relevance to global climate models - was essentially independent, at any particular level in the clouds and for any spatial scale of measurement, of the liquid water content L and the droplet concentration N (i.e. r_{eff} was independent of the extent to which the cloud was diluted by entrainment of environmental air). This finding led to the prediction that r_{eff} may be simply expressed, at any location in the clouds, by the relationship $r_{eff} = r_{ad}$, where the "adiabatic radius" r_{ad} is given by

$$r_{ad} = \left(\frac{3}{4\pi} \frac{1}{\rho_w} \frac{L_{ad}}{N_{ad}} \right)^{1/3}.$$

In this equation, ρ_w is the density of liquid water and N_{ad} and L_{ad} are the "adiabatic" values of N and L respectively. Thus the predicted "non-dimensional effective radius" is given by

$$A = \frac{r_{eff}}{r_{ad}} = 1.$$

Analysis of the airborne data for the Montanan cumuli (35 cloud penetrations) revealed that $A = 0.83 \pm 0.07$, and for the New Mexican cumuli (25 penetrations) $A = 0.93 \pm 0.05$ in reasonable agreement with the predictions.

It was mentioned in Blyth and Latham (1991) that preliminary analysis indicated that when these clouds started to glaciate (or more precisely, in those regions of the clouds where glaciation had commenced) the climatological parameter A increased.

This indication has now been subjected to further study, which forms the topic of this note.

The analysis presented herein is confined to data from airborne studies of New Mexican cumuli in the summer of 1987. The clouds were studied using the NCAR King Air cloud physics research airplane with most microphysical parameters being measured at a rate of 10 Hz, corresponding to a spatial scale of about 10 m. The plots presented herein, however, are 1 second averages. The droplet spectra were not corrected for coincidence errors discussed by Cooper (1988) and Brenguier (1989). Cooper suggested that distortions of the true spectra could occur if the measured concentration, N , is above 500 cm^{-3} , but that there could be effects if $N > 100 \text{ cm}^{-3}$. Since the parameter discussed in this paper, A , was found to be independent of N except for the lowest values it is unlikely that coincidences significantly influenced the results discussed in this paper. Furthermore, it was rare for the number concentration to exceed 500 cm^{-3} .

We were careful to eliminate spectra that were contaminated by ice particles (Gardiner and Hallett 1985) by monitoring, in regions of cloud containing ice, when

the liquid water content measured by the FSSP was more than about one and a half times that measured by the Johnson-Williams device.

The clouds were typically 2 to 3 km deep with base and summit temperatures in the ranges ? to ? and ? to ? respectively. They were generally strongly subadiabatic, the normalised liquid-water-content L/L_{ad} (penetration averages) lying generally in the range 0.2 to 0.4. Some regions were observed, however, where $L/L_{ad} \approx 1$.

Flights were made through the clouds at a variety of levels. The presence of ice in these clouds - together with the concentrations, sizes and shapes of the ice particles - was established by means of the PMS 2DC and 2DP probes.

In many cases, no ice particles were detected during penetrations in the early stages of the cloud development. In this situation, the effective radius r_{eff} was found to be essentially independent of the ratio L/L_{ad} - which parameter is an indication of the extent to which the region of cloud traversed was diluted by entrainment - and the prediction that $A = r_{eff}/r_{ad} = 1$ was approximately confirmed. This finding is illustrated in Figure 1, which is a histogram of A produced by accumulating data from many penetrations through ice free regions of 11 clouds. The average value of A was 0.91 and the standard deviation was 0.33. Deviations in r_{eff} from the adiabatic value when L/L_{ad} is low is largely responsible for the large standard deviation. There are many instances, when the number of drops has been substantially depleted due to entrainment, that the size of the remaining drops is significantly smaller. There are, however, a larger number of instances when, despite the low values of N and L/L_{ad} , the relationship $A \approx 1$ remains true.

While Bower and Choulaton (1992) also found r_{eff} to remain essentially unaffected by entrainment in a few cumulus clouds measured in Montana, they suggested that a more appropriate parameterisation for the effective radius in continental cumulus clouds is given by simply setting r_{eff} to a fixed value of between 9 and 10 μm . The overall average value of r_{eff} in ice-free regions of New Mexican cumuli is 8.5 μm , slightly outside this range, with a standard deviation of 3 μm .

Noticable changes in the parameter A began to occur when the probes revealed the presence of ice particles in the midst of the cloud.

Figure 2 presents 1 sec (100 m) average plots of L/L_{ad} against the effective radius parameter A for many penetrations made through 11 cumulus clouds. The crosses correspond to measurements made when the ice-particle concentration determined from the 2DC, $N_C = 0$, and the hollow squares relate to conditions where N_C exceeded 10 L^{-1} of air. We see from Figure 2 that although the "ice-free" points correspond to A -values close to 1.0, the A -values for 100 m cloud sections containing ice were often significantly in excess of 1.0. The trend is illustrated more clearly when data from a single cloud is examined; these data are shown in Figure 3. The values of A are larger in regions containing more than 10 L^{-1} of ice than in regions containing no ice.

Figure 4 illustrates the temporal variations of the droplet concentration N , ice particle concentration from the 2DC, N_C , liquid water content L , determined from the FSSP, and the vertical and horizontal wind for a typical penetration in this cloud. Notice that ice is present in regions of cloud with substantial amounts of liquid water content. However, the concentration of ice ($N_C \approx 20 \text{ L}^{-1}$) is 4 orders of magnitude

smaller than the concentration of cloud droplets ($N \approx 5 \times 10^5 \text{ L}^{-1}$). Figure 5 shows shadows of ice particles sampled by the 2DC collected during the penetrations shown in Figure 4. The particles are a mixture of unrimed and rimed stellars existing in a region of cloud with negligible updraught, but substantial liquid.

The physics of this effect can be understood qualitatively as follows:-

Once ice particles have been created in a supercooled region of cloud they will compete with the (generally much more numerous) cloud droplets for water vapour, in order to grow. Initially, when ice is first produced, this competition will be negligible, because the solid particles are too few and too small to exercise a significant effect. In this situation the value of A will be around or somewhat less than 1.0, as shown in Figure 1 and - in more detail - in Blyth and Latham (1991). However, as glaciation proceeds and ice particles grow in number and size the competition will become significant and perhaps eventually dominant. In this circumstance the vapour pressure in this region will fall, possibly to below the saturation value with respect to water, whilst remaining above the saturation value with respect to ice. In this latter situation, the ice particles will continue to grow while the droplets will evaporate. These strongly sub-adiabatic clouds tend to contain high concentrations of relatively small droplets produced by recent activation of entrained cloud concentration nuclei (Ref?). When the vapour pressure falls below the water saturation value these small droplets will tend to evaporate completely, producing an increase in the average droplet size and associated effective radius r_{eff} (and thus A), as observed (for example, Figures 2 and 5).

Ice particles in concentrations of a few per litre are about five orders of magnitude less numerous than the supercooled water droplets with which they coexist. However, in a slightly water supersaturated environment characteristic of these cumulus clouds before glaciation is well advanced, each one of them consumes vapour from the environment much more rapidly than individual neighbouring droplets, in part because they are aspherical and (through growing faster) larger, but principally because the supersaturation with respect to ice is much greater than that over water. Characteristic values for these enhanced-growth-rate factors are about 3 orders of magnitude in the latter case (taking -10°C as a typical temperature) and between 1 and 2 orders of magnitude in the former. Thus it is not surprising that the values of the effective-radius parameter depart from the "ice-free" theoretical value of 1 when ice crystal concentrations of a few per litre exist within the clouds.

The foregoing scenario represents only one possible way in which developing glaciation can change the water droplet characteristics of cumulus clouds, and thereby the effective radius. An alternative effect, a decrease in A below the idealised value, rather than an increase - may be produced when the supersaturation with respect to water falls (as a consequence of depletion of water vapour by the growing ice particles), without significant total evaporation of cloud droplets. In this case, the effective radius r_{eff} , and thereby A will diminish. Thus the overall influence of glaciation on r_{eff} , and hence A , will be a function of ice particle sizes and concentrations, together with the droplet size distributions, which themselves are generally influenced by entrainment. It is planned to explore this range of possibilities further, by means of modelling and more extensive data analysis.

REFERENCES

- Blyth, A. M., and J. Latham, 1991: A climatological parameterisation for cumulus clouds. *J. Atmos. Sci.*, **48**, 2367 - 2371.
- Blyth, A. M., and J. Latham, 1992: Development of ice and precipitation in New Mexican summertime cumulus clouds. Submitted to *Quart. J. Roy. Meteorol. Soc.*.
- Brenguier, J. L., 1989: Coincidence and dead-time corrections for particle counters. Part II: High concentration measurements with an FSSP. *J. Atmos. Oceanic Tech.*, **6**, 585 - 598.
- Cooper, W. A., 1988: Effects of coincidence on measurements with a forward scattering spectrometer probe. *J. Atmos. Oceanic Tech.*, **5**, 823 - 832.
- Gardiner, B. A., and J. Hallett, 1985: Degradation of in-cloud forward scattering spectrometer probe measurements in the presence of ice particles. *J. Atmos. Oceanic Tech.*, **2**, 171 - 180.

FIGURE LEGENDS

Fig. 1: Histogram of $A = r_{eff} / r_{ad}$ for all ice-free regions of cloud studied during the project.

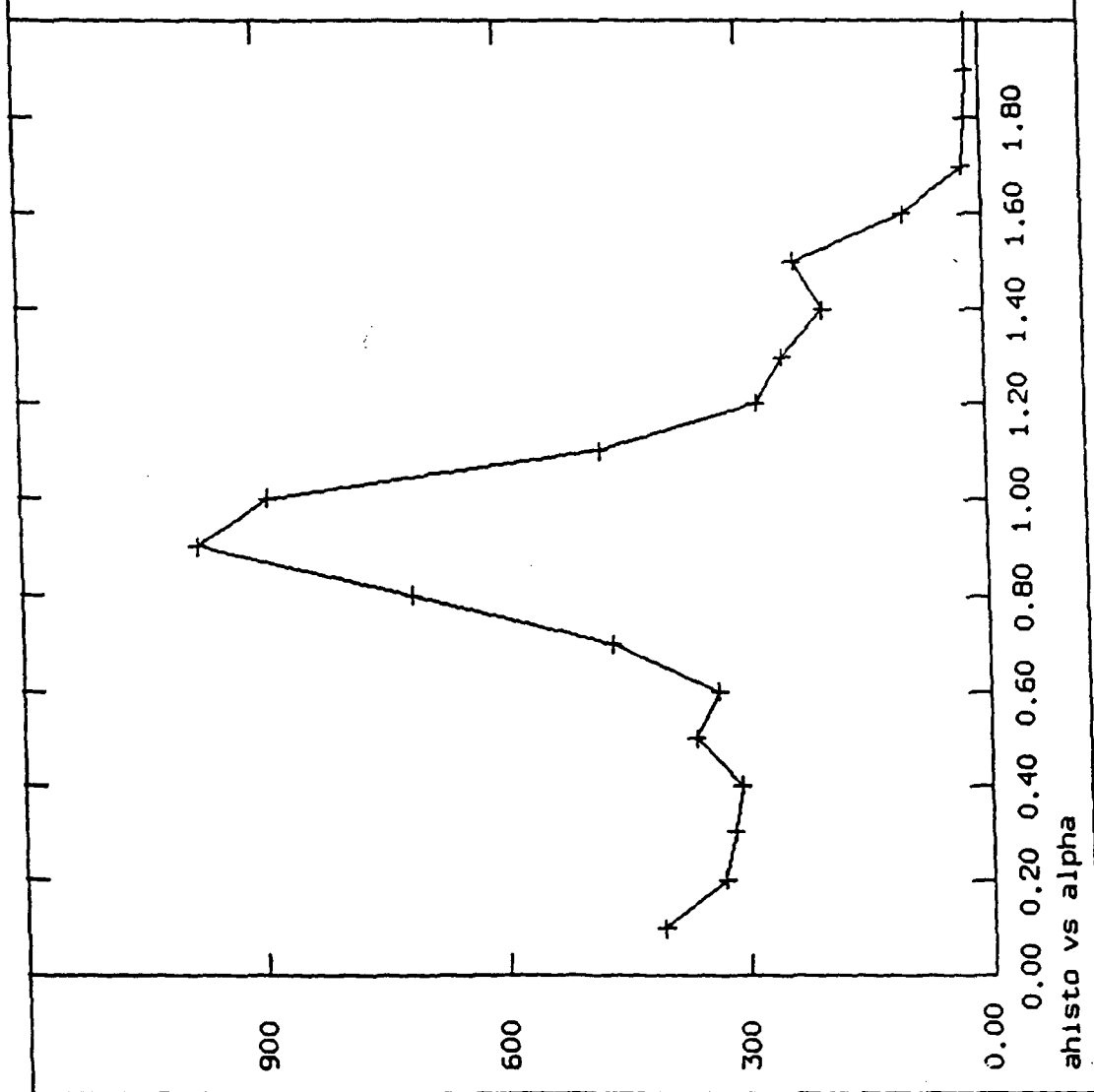
Fig. 2: Plot of A versus L/L_{ad} for regions of cloud with: $\times$ - $N_C = 0$; $\square$ - $N_C \geq 10 \text{ L}^{-1}$ from 11 cumulus clouds.

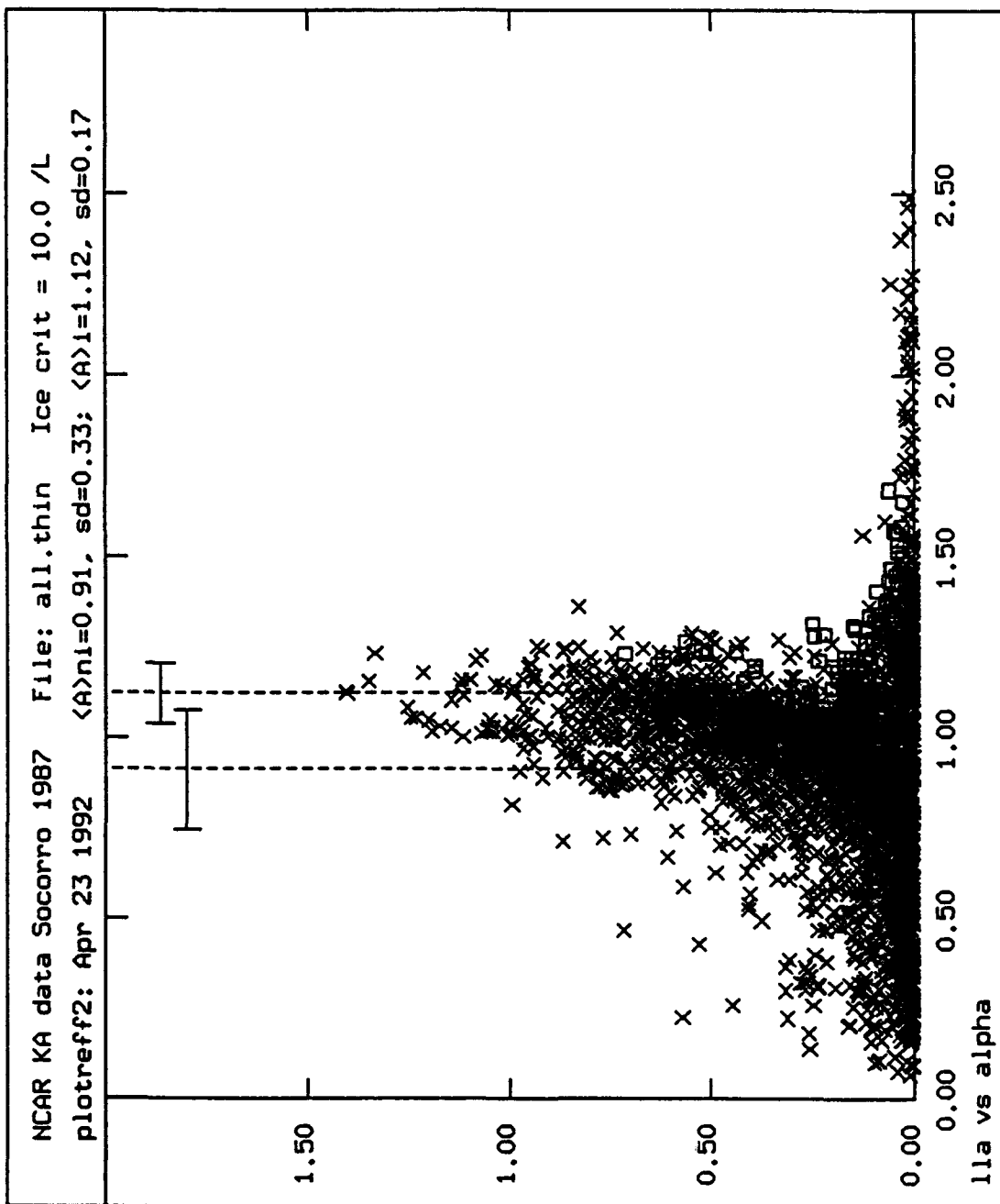
Fig. 3: Plot of A versus L/L_{ad} for regions of cloud with: $\times$ - $N_C = 0$; $\square$ - $N_C \geq 10 \text{ L}^{-1}$ from 19 August 1987.

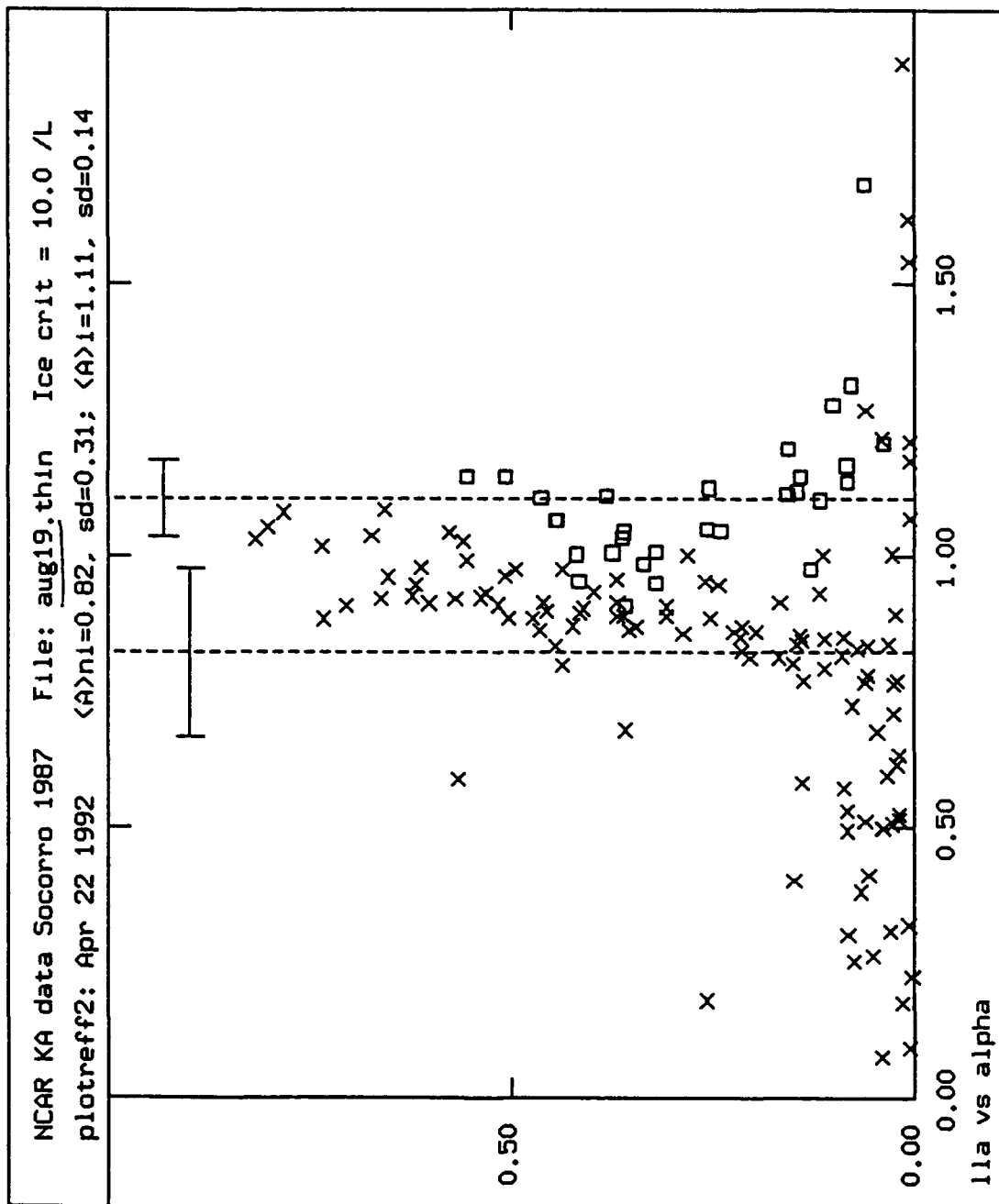
Fig. 4: Time series of, in ascending order, liquid water content, L , droplet concentration N , ice particle concentration measured by the 2DC, N_C , and the vertical and horizontal wind for a penetration made on 19 August, 1987. The wind vectors are constructed with the horizontal wind along the track of the aircraft and the vertical wind.

Fig. 5: 2D images from the 2DC and 2DP probes from the region of cloud indicated by A in Figure 4. The text under each strip of images refers to the probe, date, and beginning and end time of the images. The distance between the horizontal lines is approximately 800 and 6400 μm for the 2DC and 2DP probes respectively.

```
cdfhisto 1 ahisto  
alpha 0.1 20 0.1  
mark(alpha*1,ahisto*1,1)  
graph(alpha*1,ahisto*1,1)
```



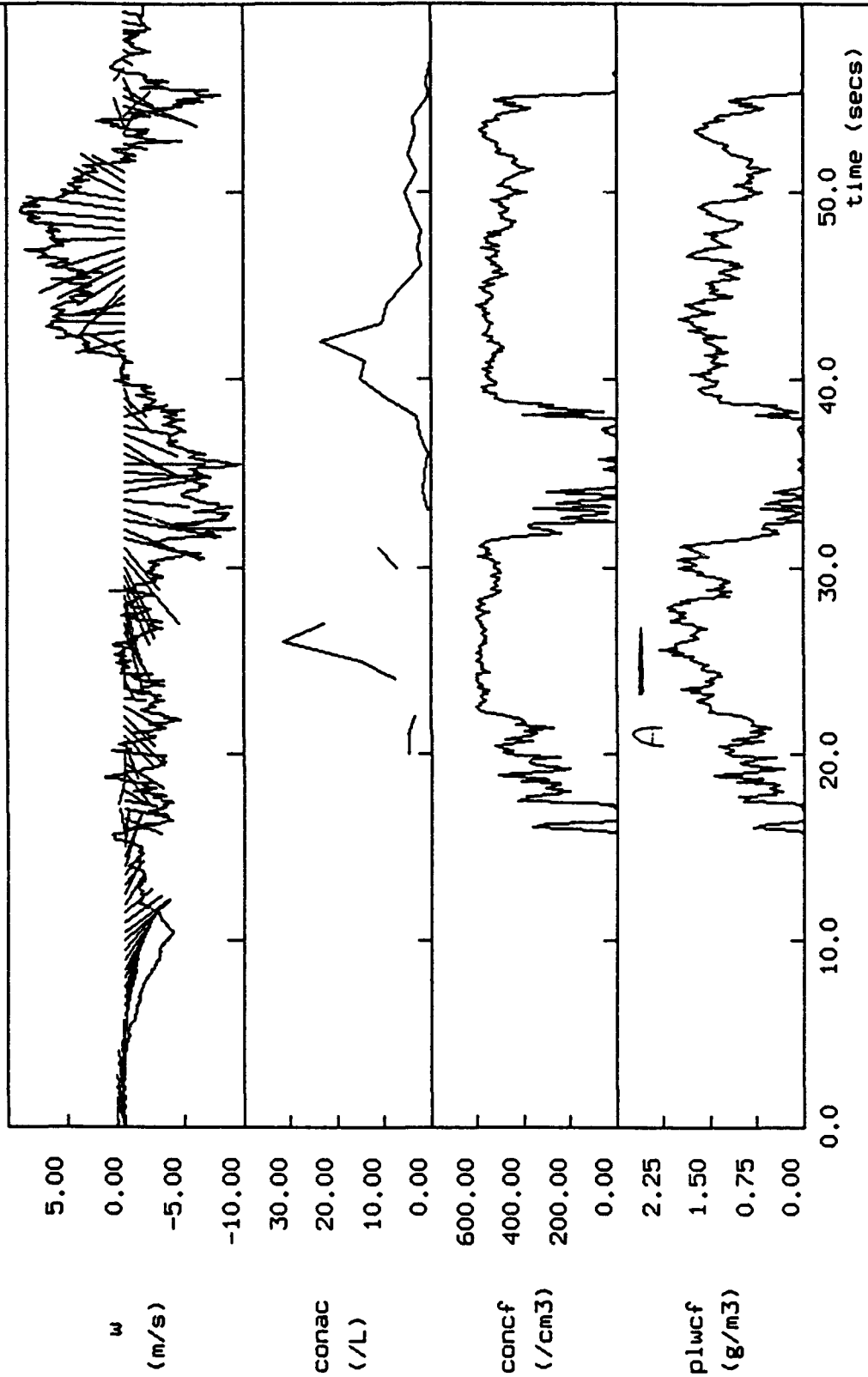




L
L^A

A

NCAR KA data: 870819 191630-191730 hdg=207, hwd1r= 291, p=436 mb



P 870819 19:16:52.140 19:16:52.849

P 870819 19:16:52.844 19:16:53.508

C 870819 19:16:52.536 19:16:53.763

P 870819 19:16:53.512 19:16:53.836

P 870819 19:16:53.836 19:16:54.029

C 870819 19:16:53.764 19:16:55.854

P 870819 19:16:54.036 19:16:54.190

C 870819 19:16:54.044 19:16:54.340

P 870819 19:16:54.192 19:16:54.365

C 870819 19:16:54.404 19:16:54.648

P 870819 19:16:54.564 19:16:54.729

C 870819 19:17:11.776 19:17:12.017

P 870819 19:17:12.372 19:17:12.497

C 870819 19:17:12.556 19:17:12.761

P 870819 19:17:13.684 19:17:13.882

C 870819 19:17:13.868 19:17:14.332

P 870819 19:17:14.448 19:17:14.835

C 870819 19:17:14.820 19:17:15.331

P 870819 19:17:15.584 19:17:16.213

C 870819 19:17:15.724 19:17:16.680

P 870819 19:17:18.084 19:17:19.034

C 870819 19:17:17.528 19:17:19.282

SECTION 3. LABORATORY RESEARCH ON LIGHTNING

LIGHTNING INITIATION IN THUNDERCLOUDS

J. Latham and L. Casalino

(Physics Dept., UMIST, PO BOX 88, Manchester M20 8NS, UK)

Macroscopic electric fields in excess of about 400kV/m probably do not exist in thunderclouds (1). The only two mechanisms which appear capable, in such fields, of producing corona - initiatory to lightning - involve protuberances on hydrometeors of precipitation dimensions; individual ice particles (2), or pairs of colliding warm raindrops (3).

Thus the threshold field E_c for corona emission depends upon the characteristics of the hydrometeors, and breakdown will not necessarily occur in a thundercloud in the region of highest field: which has hitherto been assumed in modelling studies.

The objectives of our laboratory work were to: (a) extend the range of conditions over which E_c values are known for colliding raindrops; (b) perform similar experiments for supercooled raindrops; (c) measure E_c values associated with the collisions of supercooled drops with ice particles. In addition, data from airborne studies of thunderstorms in New Mexico was examined to establish the salient hydrometeor characteristics in regions of strong field. Figures (1) and (2) illustrate the presence of both supercooled raindrops and ice particles large enough to produce corona in fields below about 400kV/m.

The laboratory experiments (a) and (b) involved the same apparatus and procedures as described in (3). The experiments (c)

utilised basically the same set-up as that described in (2), with the addition that drops fell through a hole in the upper electrode and collided with artificially produced snowflakes or hailstones mechanically suspended in a vertical electric field. The velocities of impact in these experiments were consistent with those that obtain in thunderstorms.

Figures 3,4 and 5 present data obtained in experiments (a), (b) and (c). In each case, histograms are plotted of the measured probability of corona emission as a function of the electric field E . It is seen that for all three types of interaction a significant probability exists of corona initiation in fields below 400kV/m. Photographs showed that glancing collisions produced ephemeral liquid filaments generally longer than the hydrometeor dimensions, drawn out at a shallow angle to E . Since the electrical relaxation time is substantially less than the lifetime of these conducting filaments (around 1ms) the observed corona was almost certainly emitted from their tips.

Figure 6 shows that for a constant impact parameter, the threshold field E_c for a 50% probability of corona emission was lowest at an intermediate value of impact velocity V .

References

1. Latham, J. (1981) Q.J.Roy.Met.Soc., 107, 277-298.
2. R.F. Griffiths and J. Latham, (1974), Q.J.Roy.Met.Soc., 100, 163-180.
2. J.A. Crabb and J. Latham, (1974), Q.J.Roy.Met.Soc., 100, 191-202.

Acknowledgements

The research described herein was supported by the US Office of Aerospace Research and Development, under Contract F49620-92-J-0020.

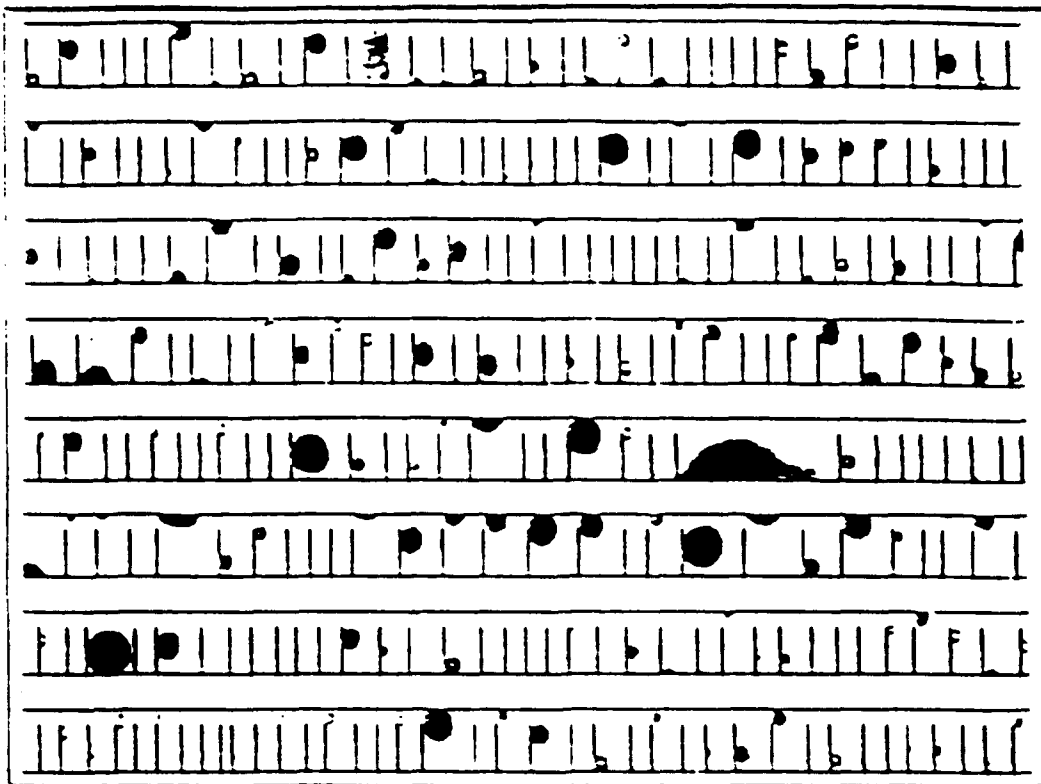
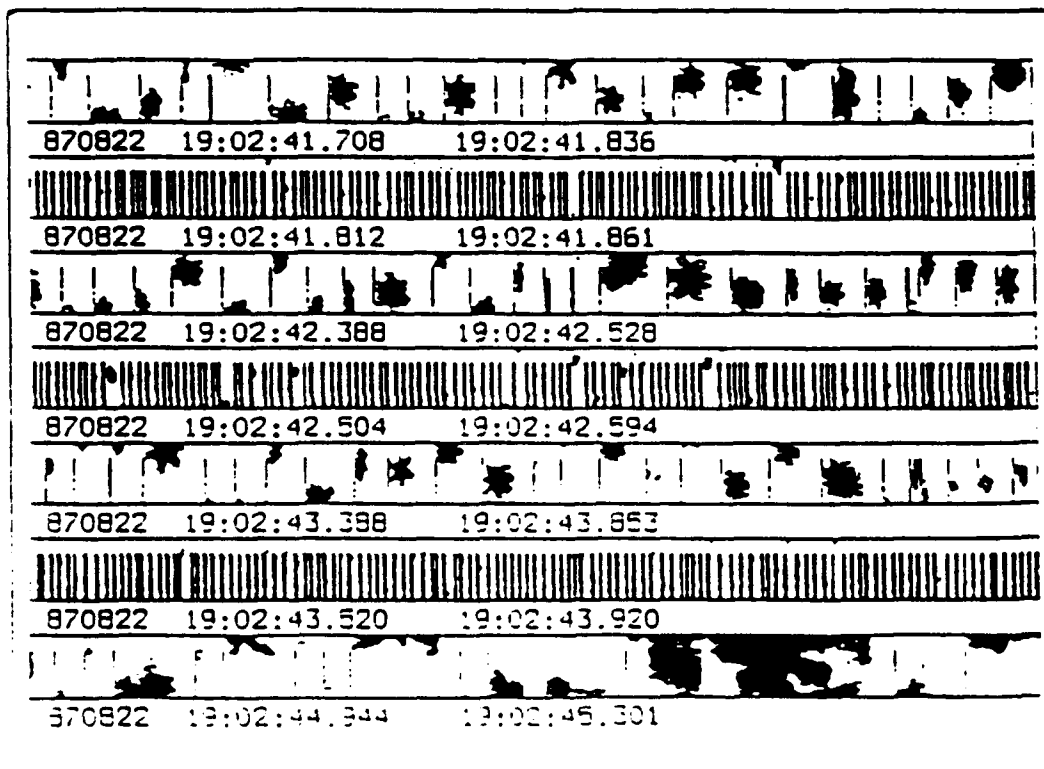
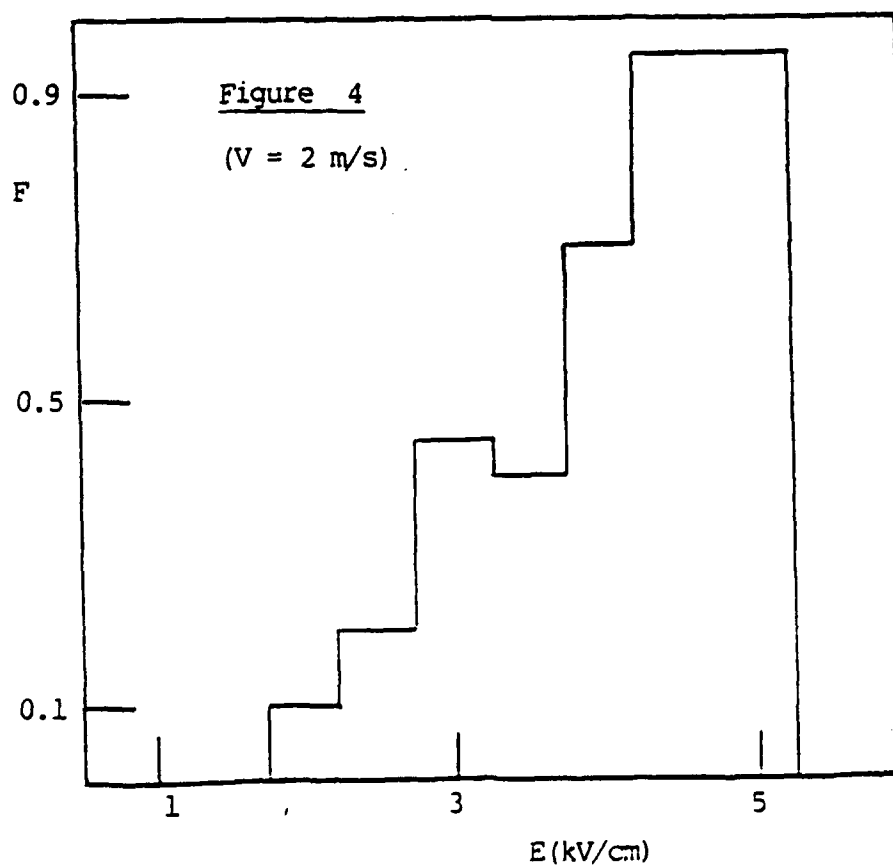
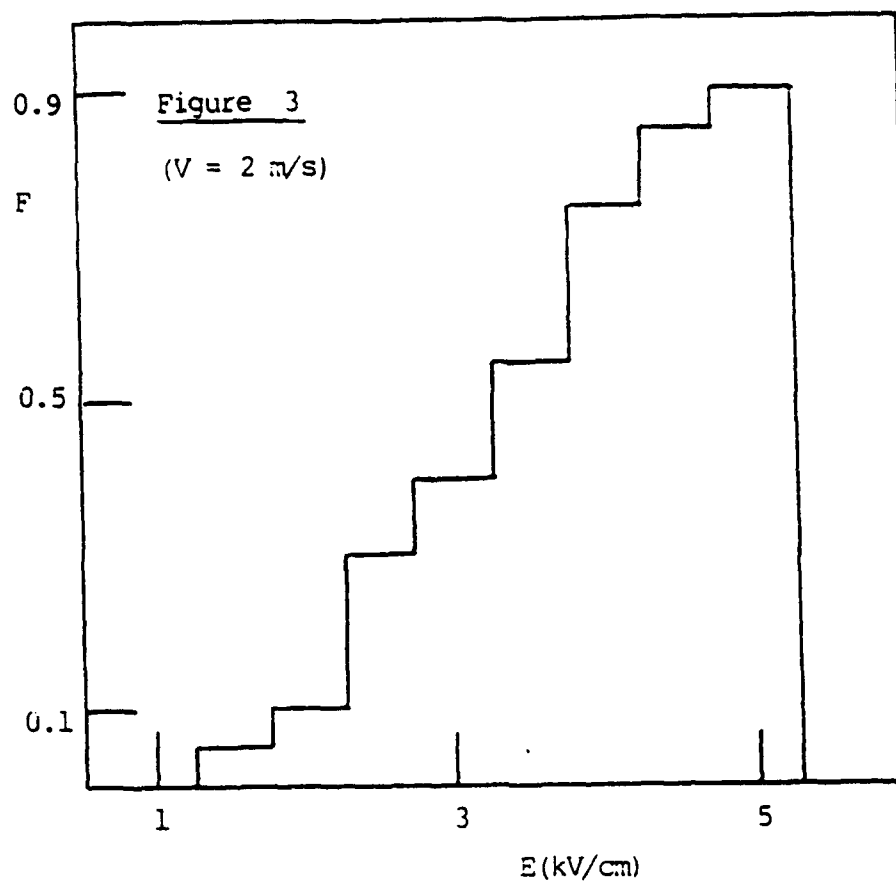
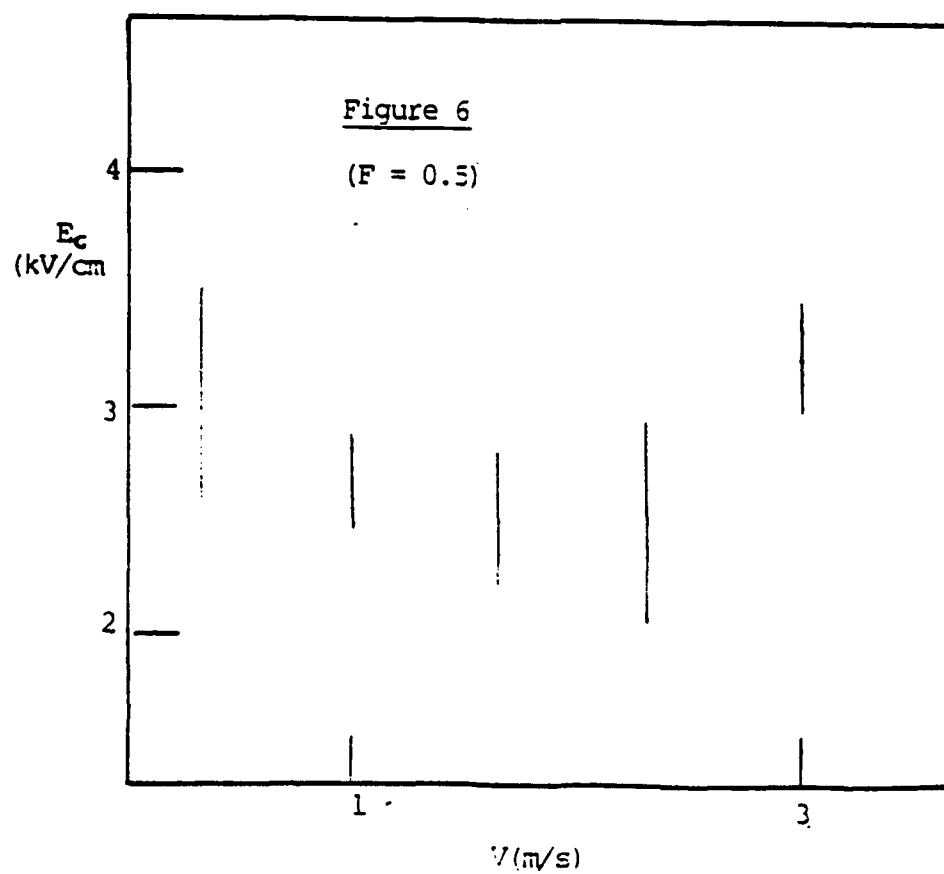
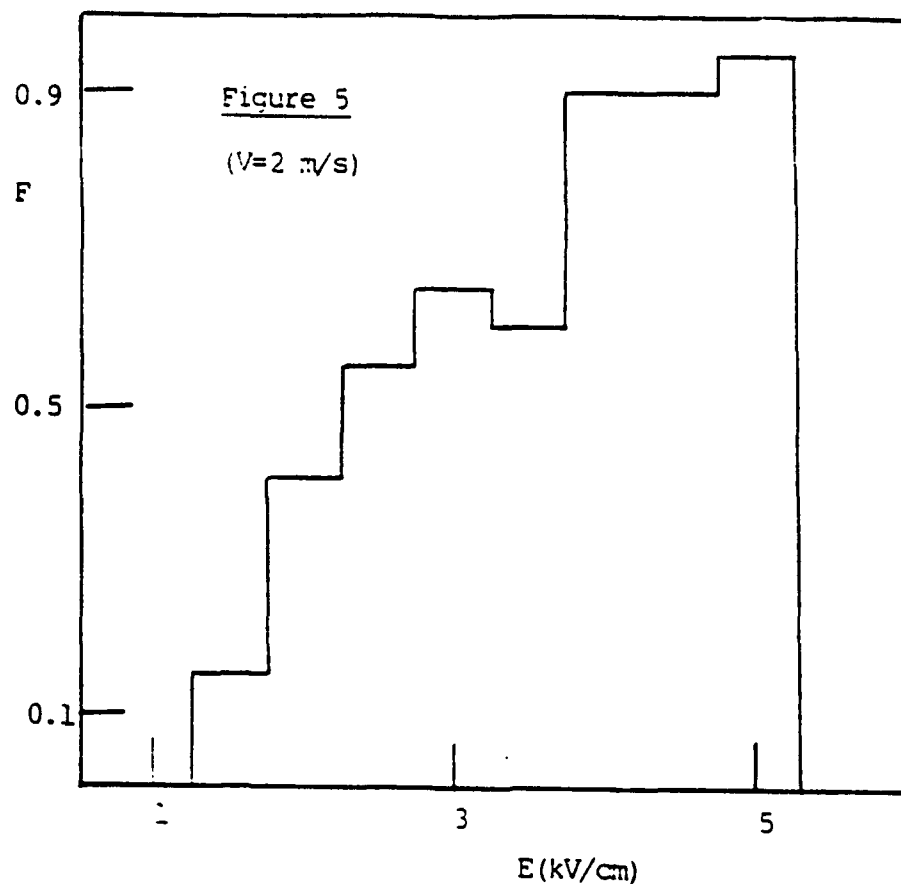


Figure 1 (1 = 0.3 mm)

Figure 2 (1 = 0.8 mm)







SECTION 4. A NEW MODEL OF THUNDERCLOUD ELECTRIFICATION AND LIGHTNING PRODUCTION

The model exists in a variety of closely related forms, a representative version of which is described in the following paragraphs.

An updraught of specified constant speed U and width W is moving continuously through an environment whose meteorological sounding is prescribed and remains fixed throughout the period covered by each cloud simulation experiment. This ascent creates a cylindrical cloud of width W , with its axis vertical, whose base is at a pressure, altitude and temperature p_b , z_b and t_b ($>0^\circ\text{C}$) respectively.

Above z_b the cloud contains droplets (corresponding to a liquid-water-content L , released by condensation), and (once the cloudy air has risen above the 0°C isotherm) ice crystals of number concentration n_x and size dx . These solid and liquid particles ascend with speed U . The variation of L with altitude z is prescribed, its sub-adiabaticity representing depletion resulting from entrainment and vapour transfer to the ice phase. The growth of the ice crystals in the ascending air is calculated from the classical diffusion equation, with a form factor F designed to represent the asphericity of the crystals.

The ice crystals originate in two ways, which can be considered to operate in isolation or conjunction:-

A. Primary Nucleation. Following the original work of Fletcher ice crystals are assumed to be formed on nuclei existing within the cloud (either in the air or in or on supercooled droplets), their number concentration n_x increasing exponentially as the

temperature falls. Thus at any level above the 0C isotherm there will exist ice crystals of a range of sizes, the smallest and most numerous having just been nucleated.

B. Secondary Nucleation. This process is based on the laboratory experiments of Hallett and Mossop, in which it was discovered that within a restricted temperature band (-3 to -8C) the freezing of supercooled water droplets accreted onto the surfaces of growing graupel or hail particles may be accompanied by the ejection of ice splinters. In our model, hailstones (discussed later) falling through this temperature band sweep out supercooled water and thereby generate ice crystals (at a rate derived from the laboratory experiments) which grow as they are swept upwards through the cloud. In this simplest possible description of the Hallett-Mossop process the ice crystal concentration n_x (in the absence of primary nucleation) is zero below the -3C isotherm, increases as the temperature falls to -8C, and remains constant at the -8C value at all lower temperatures. Provision exists within the model for taking account of further processes (including the possible role of supercooled raindrops in producing additional ice splinters and expediting rimer formation as they freeze) which enhance the rate of production of ice crystals. In treating this refinement to the basic Hallett-Mossop process use is made of the analytic treatment of Chisnell and Latham, which showed that this further enhancement of n_x can be represented by a simple exponential relationship.

At some level p_i , z_i , T_i the cloud is inoculated at a specified rate F per unit area with embryonic spherical hailstones of diameter D_0 and constant density ρ . These grow ac-

cording to the classical coalescence equation by the accretion of supercooled water which freezes onto their surfaces. The hailstones have a size-dependent terminal fall-speed V and thus rise (relative to the ground) at a speed $U-V$ until they reach the balance level (p_{bal} , z_{bal} , T_{bal}), where $U-V=0$; at which point they begin to descend through cloud towards earth with a continually increasing velocity $V-U$. Hailstone growth is assumed to cease when the hydrometeors fall through the 0°C isotherm. Thus the hailstones are continually growing throughout their period in the supercooled regions of the cloud, and are monodisperse in size at all levels (except that between the levels z_i and z_{bal} there are two sizes, one for the upward-moving particles, and one for the descending ones). Throughout their journey below the 0°C isotherm, first of all through cloud and then through clear air to ground the hailstone-size is assumed to be constant.

Thus ice crystals, hailstones and supercooled water coexist within the thundercloud at all levels between z_{bal} and the isotherms located at either 0°C or -3°C (according to which of the above-mentioned glaciation mechanisms is operating). This combination of hydrometeor types is required for the effective operation of the non-inductive ice-ice collisional process of charge transfer, which is generally regarded as the mechanism most likely to be of primary importance in thunderstorm electrification. Under this mechanism, which is the only charging process considered in the present computations, the charge q separated when a rebounding collision occurs between a hailstone and an ice crystal depends sensitively on the crystal size dx and the relative fall-speed V of the hydrometeors. The quantitative relation-

ship between q , dx and V is abstracted from the laboratory experiments of Saunders and colleagues; and we adopt, from these studies, the finding that at temperatures colder than a reversal value T_{rev} the hailstone is charged negatively by rebounding collisions with crystals, and at temperatures warmer than T_{rev} the hailstones become positively charged. We do not take account in the present work of reports that T_{rev} is dependent upon L .

Thus charge transfer occurs throughout the region of the thundercloud (the interaction zone) in which ice crystals, super-cooled water droplets and hailstones coexist; and nowhere else. The parameters p_{bal} , z_{bal} and T_{bal} define the pressure, altitude and temperature respectively of the upper bound of the interaction zone; and this level - and thus the volume within which charging occurs - increases with increasing updraught speed U .

As gravitational separation of ice crystals and hailstones proceeds, with both types of particles present in the interaction zone, crystals (no hailstones) moving above the balance level into the cloud anvil, and hailstones (no crystals) falling through the base of the interaction zone, through cloud-base and ultimately to ground (where they are assumed to be neutralised), an electric field is developed, the axial component of which (E_z) is calculated over the entire vertical depth of the domain covered by the calculations i.e. from the ground up to cloud-top, whose altitude, temperature and pressure values (z_{top} , T_{top} and p_{top} respectively) are determined from the meteorological sounding.

In most (though not all) situations the ice-crystals are predominantly positively charged, with a corresponding negative

charge on the hailstones. Once air containing charged ice crystals has risen to cloud-top, subsequent charge flowing upwards through the balance level is assumed to be uniformly mixed throughout the depth of the anvil.

Under conditions of adequate charging rate the axial electric field E_z at all levels increases until, at some altitude z_{zap} (where the corresponding pressure and temperature are p_{zap} and T_{zap}) it reaches a value E_{crit} at which lightning is presumed to be initiated. E_{crit} is generally taken to be 300kV/M (references), and characteristically it is achieved within the interaction zone, near to its top.

Lightning originating at the level z_{zap} may take the form of either an intra-cloud (I-C) or a cloud-to ground (C_G) stroke.

In the case of an I-C stroke we assume that a fraction E (usually 0.1) of the (generally positive) charge in the cloud anvil is abstracted uniformly from all levels and deposited uniformly in a cylindrical region of cloud of width W and depth z_{av} (of typical value 0.5km) whose upper bound is the balance level z_{bal} . Prior to the lightning stroke this region contains both negative and positive charge, with generally a preponderance of the former. The charge transferred (Q) is assumed to be located on the small cloud particles (ice crystals or droplets) and therefore it immediately starts to move upwards at the updraught speed U . We neglect the possibility that some of it may be deposited on or captured by hailstones. We also neglect neutralisation of positive and negative charges at the same level.

In the case of a C-G lightning stroke we assume that a charge Q (generally positive) is transferred from the ground to

the above-mentioned cylindrical region of depth z_{av} , whereupon it manifests the same behaviour and is subjected to the same restrictions as the positive charge destroyed in an I-C stroke. The magnitude Q of the charge transferred in a C-G stroke is defined by the same criterion as for I-C strokes.

To determine whether a lightning stroke occurring whenever the breakdown field E_{crit} is achieved is of the I-C or C-G category, we examine the gradient of the vertical electric field E_z immediately above and below the breakdown level z_{zap} at the point when $E_z = E_{crit}$. If the gradient is smaller in the upward direction we assume that the lightning stroke is of the I-C form; whereas a C-G stroke occurs if the gradient is stronger in the downward direction. The rationale for adopting this criterion is that the corona streamers leading to lightning will grow preferentially in stronger ambient fields - from which they can derive more energy in order to facilitate their propagation.

After the lightning stroke has occurred the maximum electric field in the thundercloud is diminished, but as charging via the non-inductive process continues E_z will increase until the value E_{crit} is again achieved, and a second lightning stroke occurs. This pattern is reproduced throughout the period of the computations.

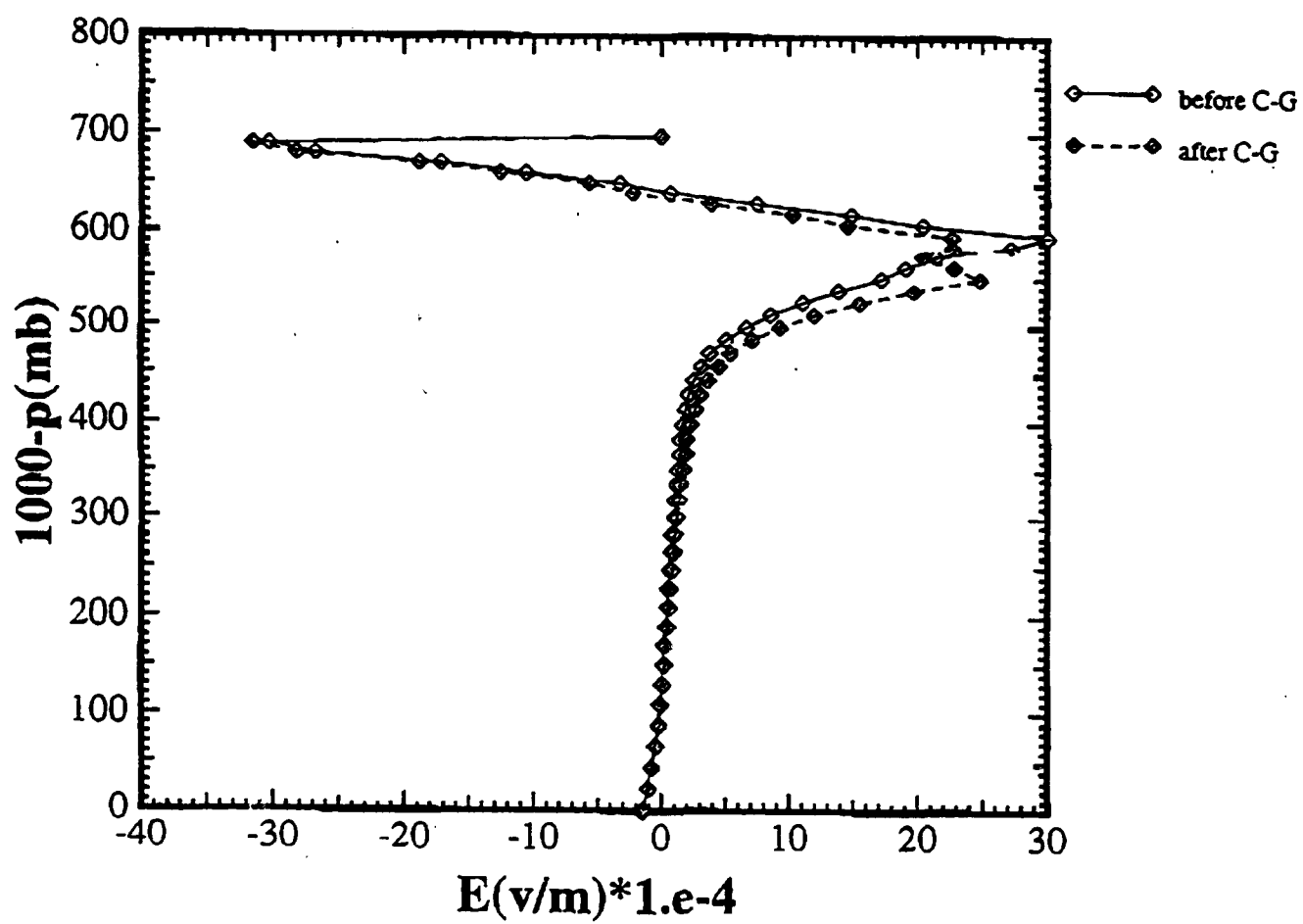
In this way, calculations are made of: times of occurrence of lightning strokes (t_1, t_2, t_3 , etc); charge transferred in each one (Q); the altitudinal variation, throughout the computational period, of axial electric field (E_z), positive charge density (Q^+), negative charge density (Q^-), precipitation current (I_p), radar reflectivity (Z), precipitation rate (p), hailstone

size (D), the number concentration (N_x) and sizes (dx) of ice crystals; and the location (p_{bal} , z_{bal} , T_{bal}) of the balance level. The above-mentioned parameters are calculated for a specified sounding, altitudinal variation of liquid-water-content (L) and glaciation mechanism; and prescribed values of updraught speed U , cloud width W , hailstone flux F and other parameters defined earlier.

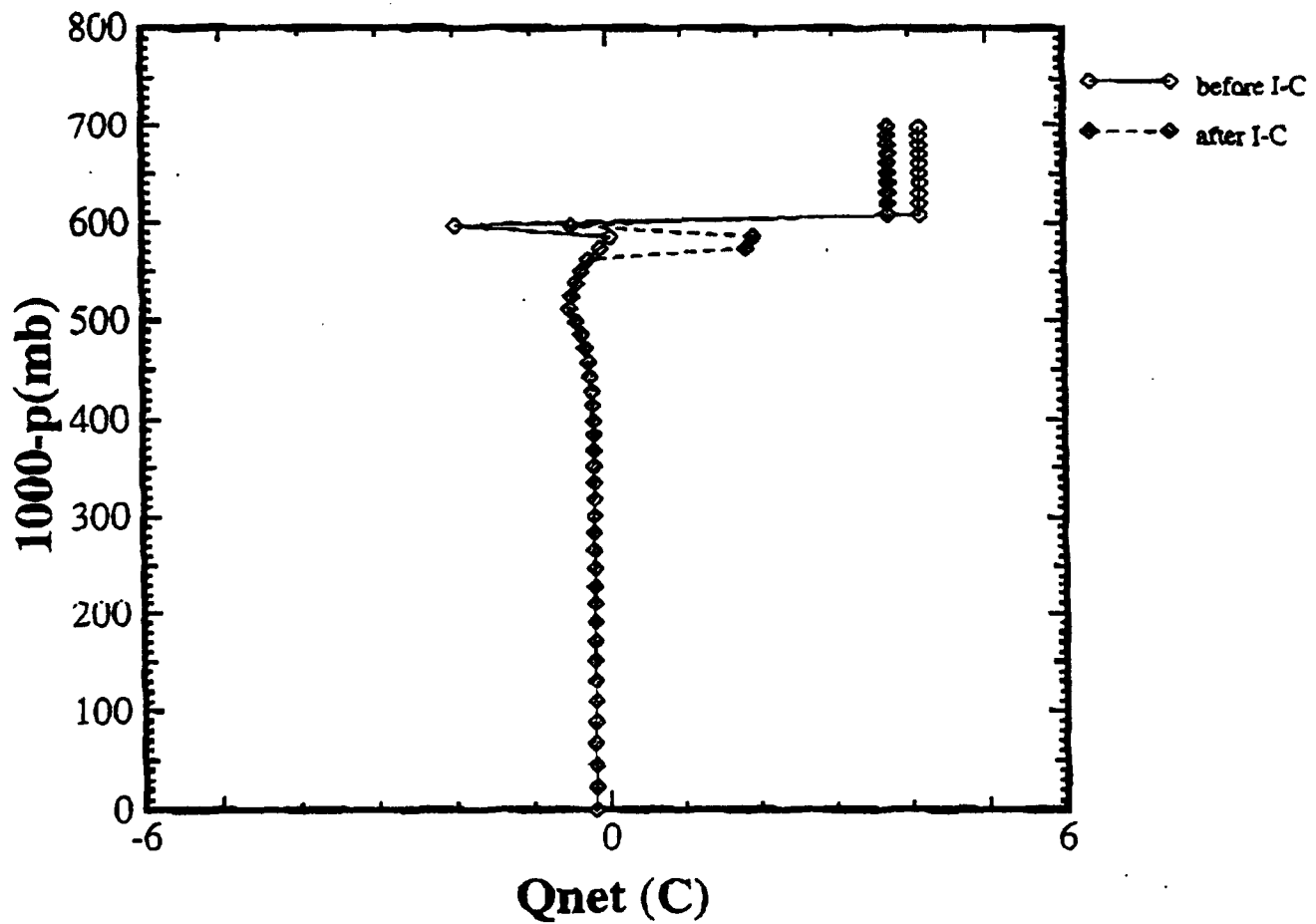
In the following nine pages we present a set of figures illustrating particular results emanating from our model, which we stress is still in a preliminary form. They show vertical field and charge profiles just before and just after breakdown, for both cloud-to-ground and inter-cloud lightning strokes; the sensitivity of predicted lightning frequency to cloud width, ice crystal concentration and (especially) updraught speed; and the close parallelism found between $1/f$ and the time of first occurrence of lightning.

This report concludes with a specimen set of output, from which it is possible to assess in detail the influence on lightning activity of parameters defined earlier in this section.

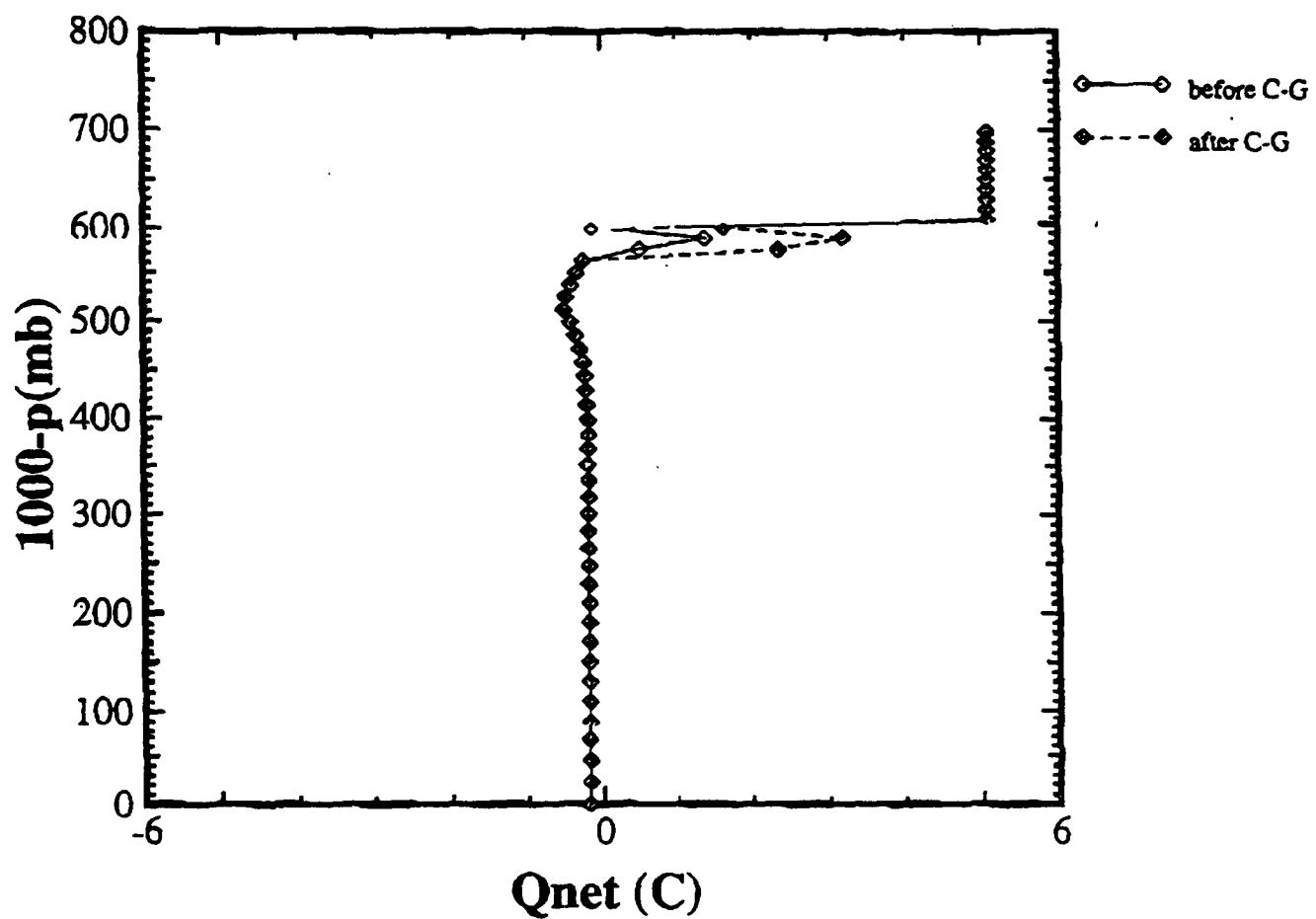
Field Change: C-G Stroke



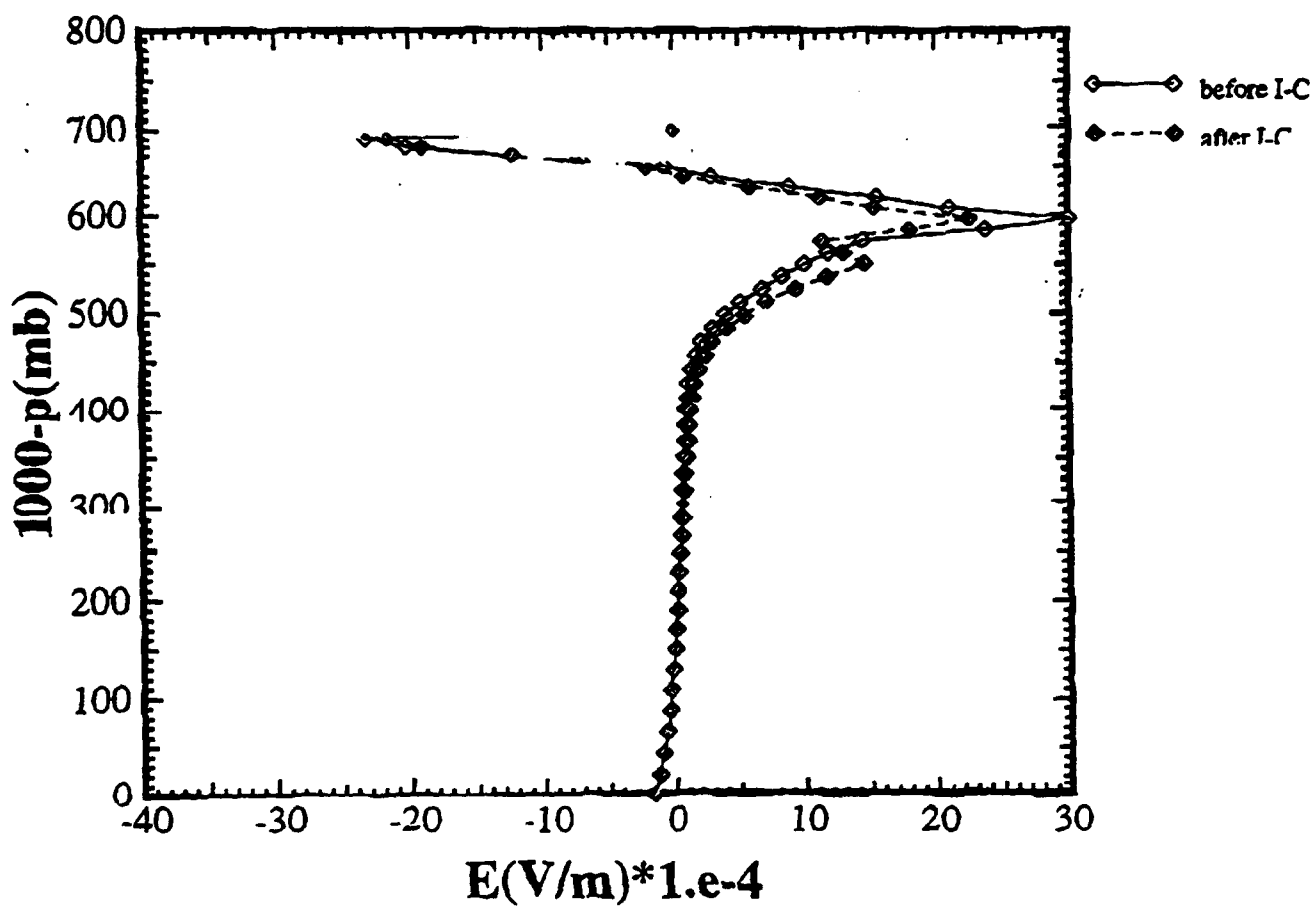
Charge Distribution Change: I-C Stroke



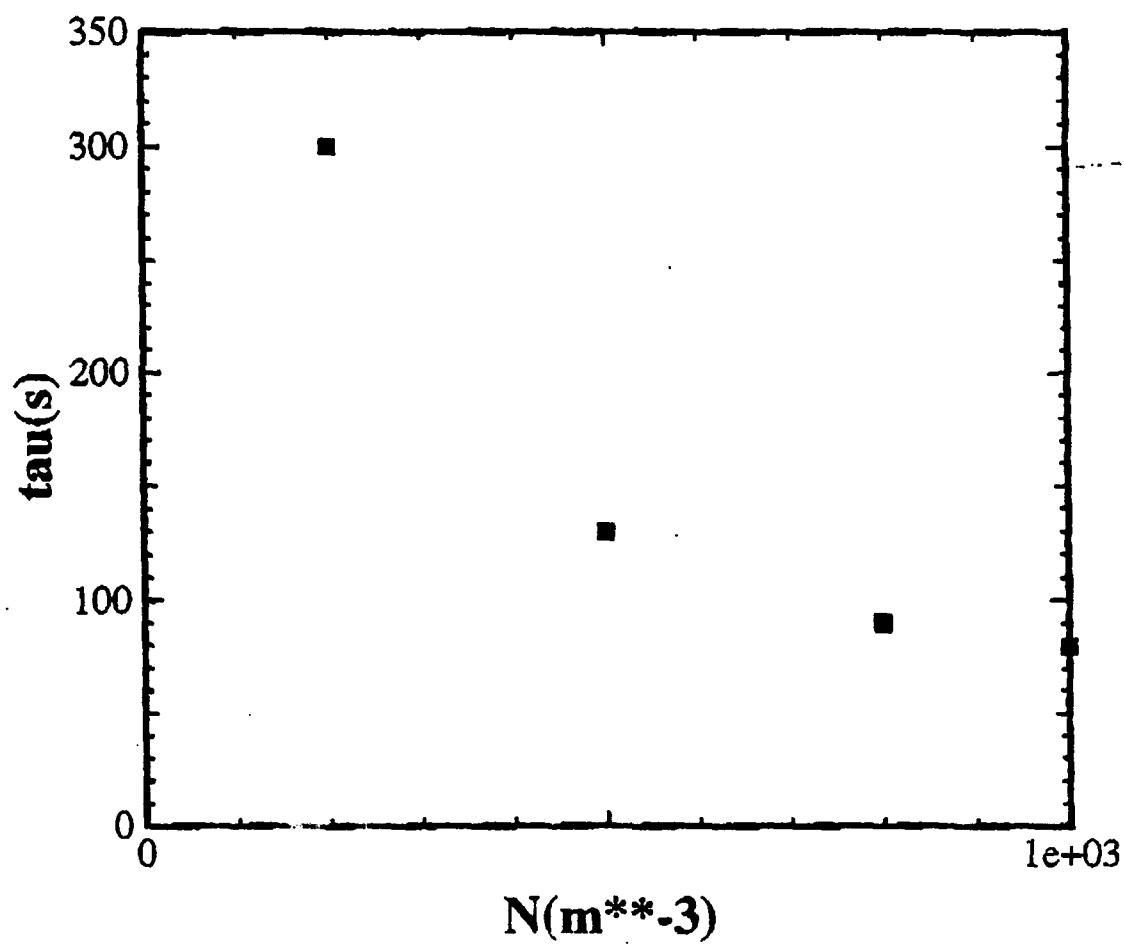
Charge Distribution Change: C-G Stroke



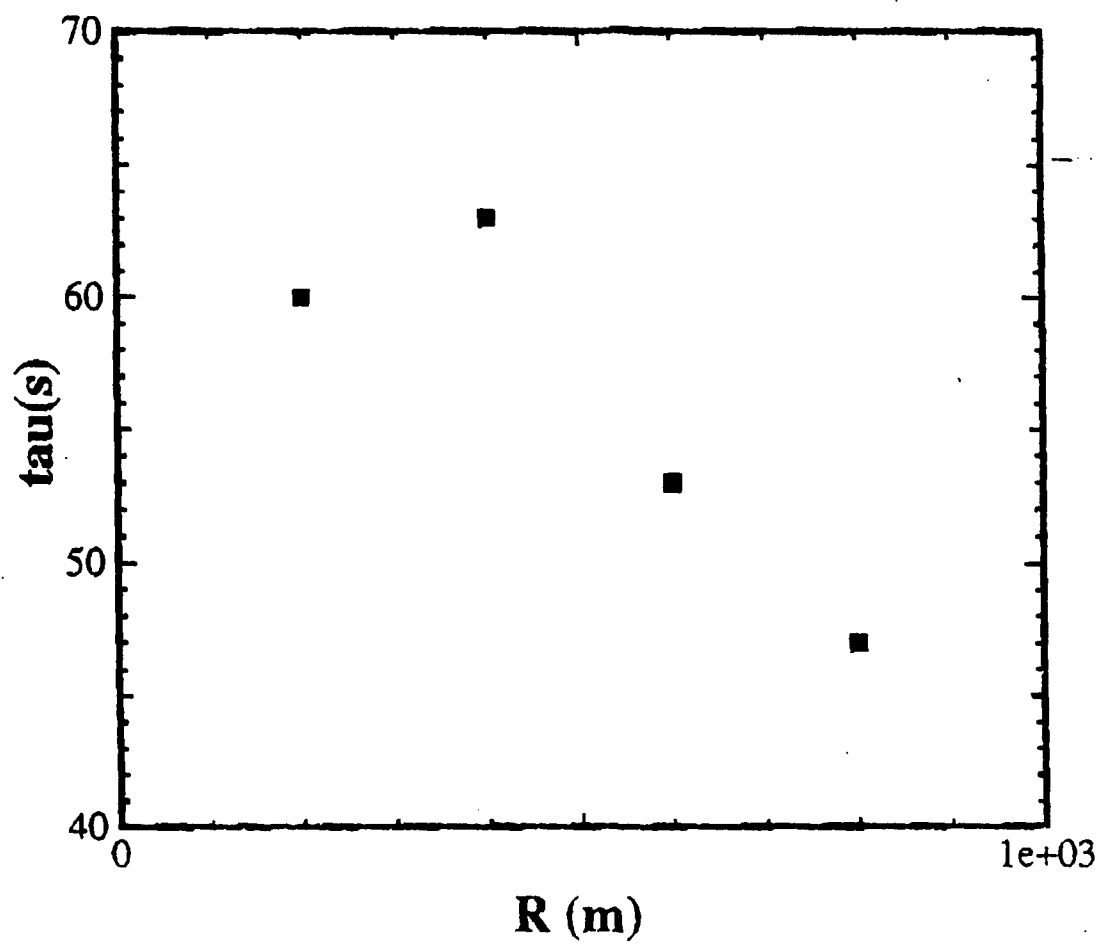
Field Change: I-C Stroke



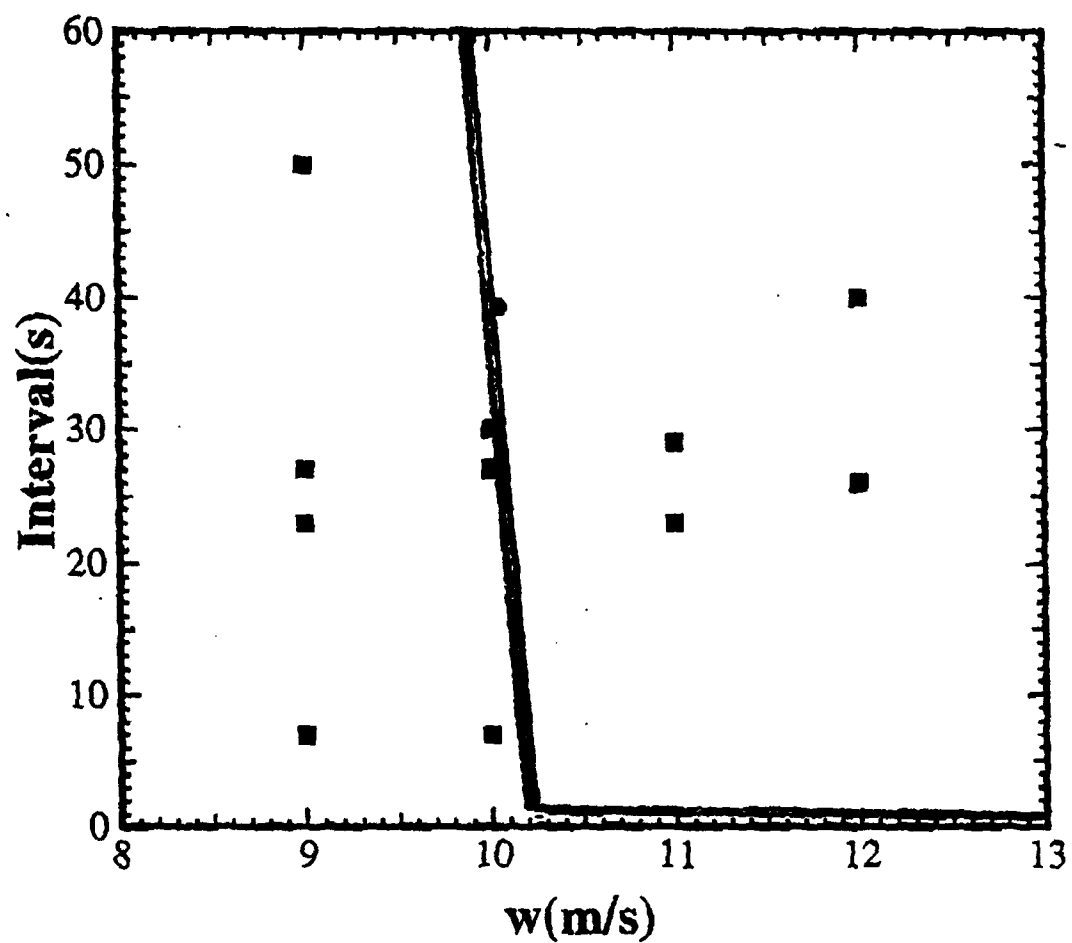
R=1000m: w=10m/s: Fletcher Run



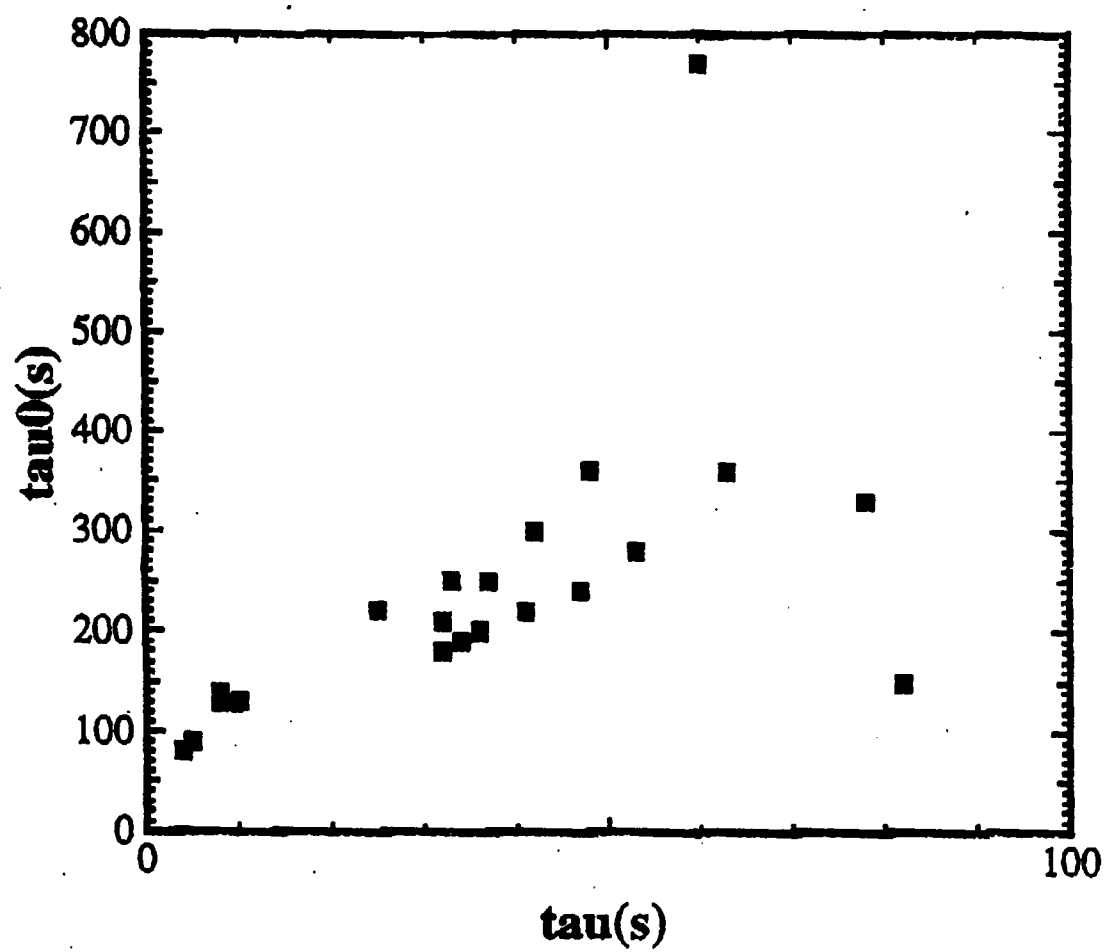
Intervals vs Cell Radius



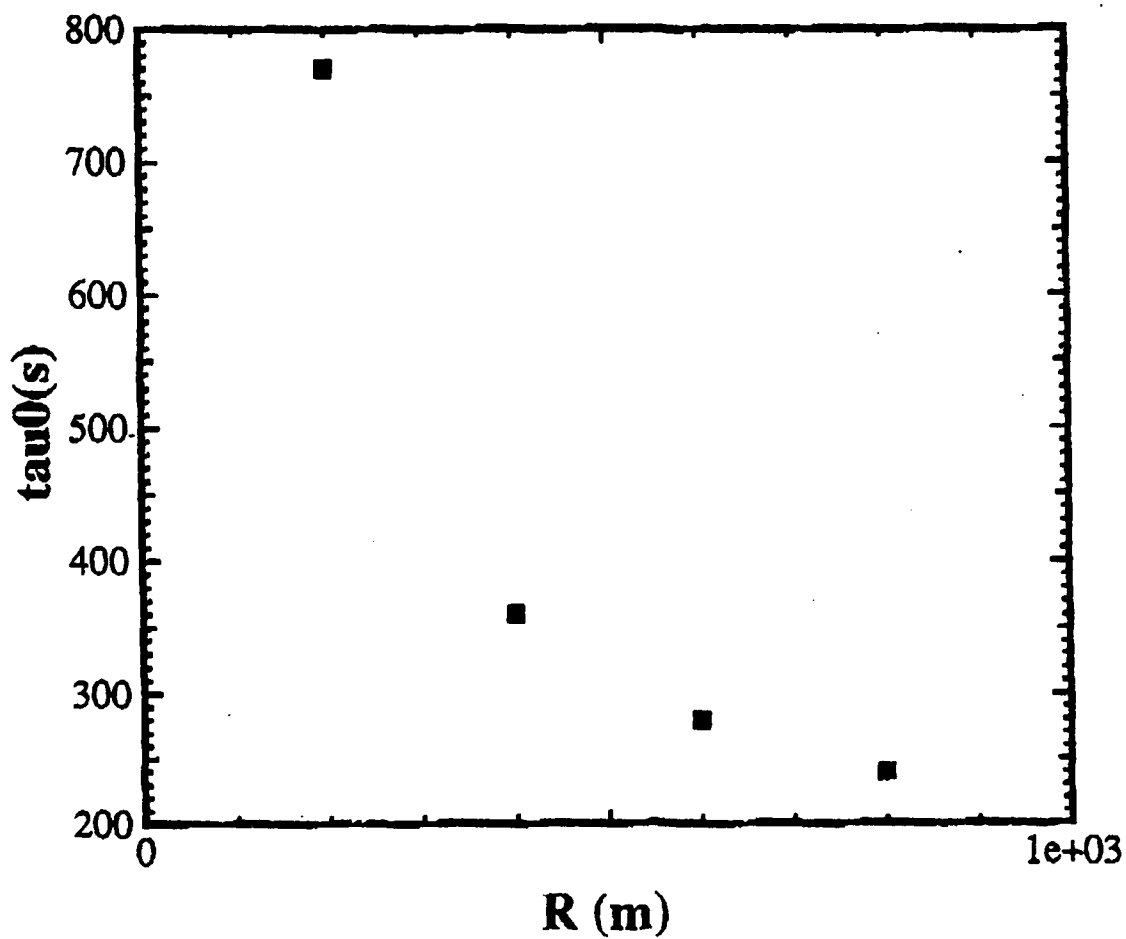
Intervals Between Strokes



Time to 1st Stroke vs Interval



Time to First Stroke



Fletcher Glaciation Run

Fletcher x 200.

Cell Radius = 1000.0 m.

updraft speed = 10.0 m/s

freezing level= 616.8 mb: balance level= 403.2mb

time step= 10.0s

Hailstone Flux = $0.500E-01 (m^{**2}-s)^{-1}$

Hail Embryo diameter= $0.800E-02$ m

Treverse= 258.0 K. $Q_1 = 0.120E-02$ kg m^{**3}

charge destroyed is 0.10 times that in a

layer 1800.0

meters deep just below cloud top.

Charge parameter== $Z_p * R_N * a^{**1.5} = 0.344E-02$

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
300.0	403.2	300.0	1.39	(I-C)	1.17
694.0	403.2	394.0	3.24	(I-C)	1.17
747.0	403.2	53.0	3.46	(I-C)	1.60
789.0	403.2	42.0	3.62	(I-C)	1.92
825.0	403.2	36.0	3.76	(I-C)	2.22
857.0	403.2	32.0	3.87	(I-C)	2.49
887.0	403.2	30.0	3.98	(I-C)	2.71
915.0	403.2	28.0	4.08	(I-C)	2.93
942.0	403.2	27.0	4.17	(I-C)	3.11
967.0	403.2	25.0	4.25	(I-C)	3.34

Calculation stopped at time= 991.0 seconds.

Total number of lightning strokes = 11

Precipitation reaches the ground at 428.0 s.

Current to ground= $0.859E+07$ fC/ m^{**2}/s

Rain intensity at the ground= 2.10 mm/hr

pressure	radar	P(mm/hr)
617.	56.8	0.679
601.	56.6	0.651
586.	56.4	0.623
571.	56.2	0.596
557.	56.0	0.570
543.	55.8	0.544
529.	55.6	0.518
515.	55.5	0.492
501.	55.3	0.467
488.	55.1	0.442
475.	54.9	0.417
463.	54.8	0.392
450.	54.7	0.367
438.	54.6	0.341

426. 54.5 0.314
 415. 55.1 0.251
 403. 60.8 0.464E-01

Fletcher Glaciation Run

Fletcher x 800.

Cell Radius = 1000.0 m.

updraft speed = 10.0 m/s

freezing level= 616.8 mb: balance level= 403.2mb

time step= 10.0s

Hailstone Flux = 0.500E-01 (m**2-s)**-1

Hail Embryo diameter= 0.800E-02 m

Treverse= 258.0 K. Ql= 0.120E-02 kg m**-3

charge destroyed is 0.10 times that in a
 meters deep just below cloud top.

layer 1800.0

Charge parameter==Zp*RN*a**1.5 = 0.137E-01

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	taug/taut
90.0	403.2	90.0	1.61	(I-C)	1.14
94.0	403.2	4.0	1.63	(I-C)	1.31
100.0	403.2	6.0	1.69	(I-C)	1.45
105.0	403.2	5.0	1.74	(I-C)	1.58
110.0	403.2	5.0	1.79	(I-C)	1.69
115.0	403.2	5.0	1.85	(I-C)	1.79
120.0	403.2	5.0	1.91	(I-C)	1.89
124.0	403.2	4.0	1.94	(I-C)	1.99
129.0	403.2	5.0	2.01	(I-C)	2.06
133.0	403.2	4.0	2.04	(I-C)	2.15

Calculation stopped at time= 138.0 seconds.

Total number of lightning strokes = 11

pressure radar P(mm/hr)

543. 54.0 0.354
 529. 55.6 0.518
 515. 55.5 0.492
 501. 55.3 0.467
 488. 55.1 0.442
 475. 54.9 0.417
 463. 54.8 0.392
 450. 54.7 0.367
 438. 54.6 0.341
 426. 54.5 0.314
 415. 55.1 0.251
 403. 60.8 0.464E-01

Fletcher Glaciation Run

Fletcher x 500.

Cell Radius = 1000.0 m.

updraft speed = 10.0 m/s

freezing level= 616.8 mb: balance level= 403.2mb

time step= 10.0s

Hailstone Flux = 0.500E-01 (m**2-s)**-1

Hail Embryo diameter= 0.800E-02 m

Treverse= 258.0 K. Ql= 0.120E-02 kg m**-3

charge destroyed is 0.10 times that in a

layer 1800.0

meters deep just below cloud top.

Charge parameter== $Zp \cdot RN \cdot a^{1.5}$ = 0.859E-02

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
130.0	403.2	130.0	1.47	(I-C)	1.15
139.0	403.2	9.0	1.53	(I-C)	1.41
149.0	403.2	10.0	1.61	(I-C)	1.60
159.0	403.2	10.0	1.70	(I-C)	1.76
168.0	403.2	9.0	1.78	(I-C)	1.90
177.0	403.2	9.0	1.86	(I-C)	2.03
186.0	403.2	9.0	1.94	(I-C)	2.13
195.0	403.2	9.0	2.02	(I-C)	2.22
203.0	403.2	8.0	2.09	(I-C)	2.34
212.0	403.2	9.0	2.18	(I-C)	2.41

Calculation stopped at time= 220.0 seconds.
Total number of lightning strokes = 11

pressure	radar	P(mm/hr)
----------	-------	----------

617.	56.8	0.679
601.	56.6	0.651
586.	56.4	0.623
571.	56.2	0.596
557.	56.0	0.570
543.	55.8	0.544
529.	55.6	0.518
515.	55.5	0.492
501.	55.3	0.467
488.	55.1	0.442
475.	54.9	0.417
463.	54.8	0.392
450.	54.7	0.367
438.	54.6	0.341
426.	54.5	0.314
415.	55.1	0.251
403.	60.8	0.464E-01

Fletcher Glaciation Run

Fletcher x 50.0

Cell Radius = 1000.0 m.

updraft speed = 10.0 m/s

freezing level= 616.8 mb: balance level= 403.2mb

time step= 10.0s

Hailstone Flux = 0.500E-01 (m**2-s)**-1

Hail Embryo diameter= 0.800E-02 m

Treverse= 258.0 K. Ql= 0.120E-02 kg m**-3

charge destroyed is 0.10 times that in a
meters deep just below cloud top.

layer 1800.0

Charge parameter== $Zp \cdot RN \cdot a^{1.5}$ = 0.859E-03

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
---------	-------	-------------	---------	------	-----------

1370.0 403.2 1370.0 1.61 (I-C) 1.17

Calculation stopped at time= 3600.0 seconds.
Total number of lightning strokes = 1

Precipitation reaches the ground at 1391.0 s.
Current to ground=-0.249E+07fC/m**2/s
Rain intensity at the ground= 2.10 mm/hr

pressure	radar	P(mm/hr)
----------	-------	----------

617.	56.8	0.679
601.	56.6	0.651
586.	56.4	0.623
571.	56.2	0.596
557.	56.0	0.570
543.	55.8	0.544
529.	55.6	0.518
515.	55.5	0.492
501.	55.3	0.467
488.	55.1	0.442
475.	54.9	0.417
463.	54.8	0.392
450.	54.7	0.367
438.	54.6	0.341
426.	54.5	0.314
415.	55.1	0.251
403.	60.8	0.464E-01

Fletcher Glaciation Run

Fletcher x 0.100E+04

Cell Radius = 1000.0 m.

updraft speed = 10.0 m/s

freezing level= 616.8 mb: balance level= 403.2mb

time step= 10.0s

Hailstone Flux = 0.500E-01 (m**2-s)**-1

Hail Embryo diameter= 0.800E-02 m

Treverse= 258.0 K. Ql= 0.120E-02 kg m**-3

charge destroyed is 0.10 times that in a
meters deep just below cloud top.

layer 1800.0

Charge parameter==Zp*RN*a**1.5 = 0.172E-01

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
---------	-------	-------------	---------	------	-----------

80.0	403.2	80.0	1.78	(I-C)	1.13
81.0	403.2	1.0	1.73	(I-C)	1.28
84.0	403.2	3.0	1.74	(I-C)	1.40
88.0	403.2	4.0	1.79	(I-C)	1.50
91.0	403.2	3.0	1.81	(I-C)	1.59
95.0	403.2	4.0	1.86	(I-C)	1.68
99.0	403.2	4.0	1.92	(I-C)	1.75
102.0	403.2	3.0	1.94	(I-C)	1.83
105.0	403.2	3.0	1.97	(I-C)	1.91
109.0	403.2	4.0	2.03	(I-C)	1.97

Calculation stopped at time= 112.0 seconds.

Total number of lightning strokes = 11

pressure	radar	P(mm/hr)
----------	-------	----------

501.	52.7	0.255
488.	55.1	0.442
475.	54.9	0.417
463.	54.8	0.392
450.	54.7	0.367
438.	54.6	0.341
426.	54.5	0.314
415.	55.1	0.251
403.	60.8	0.464E-01

Fletcher Glaciation Run

Fletcher x 100.

Cell Radius = 1000.0 m.

updraft speed = 10.0 m/s

freezing level= 616.8 mb: balance level= 403.2mb

time step= 10.0s

Hailstone Flux = 0.100E-01 (m**2-s)**-1

Hail Embryo diameter= 0.800E-02 m

Treverse= 258.0 K. Ql= 0.120E-02 kg m**-3

charge destroyed is 0.10 times that in a
meters deep just below cloud top.

layer 1800.0

Charge parameter== $Zp \cdot RN \cdot a^{1.5}$ = 0.152E-02

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
---------	-------	-------------	---------	------	-----------

Calculation stopped at time= 3600.0 seconds.

Total number of lightning strokes = 0

Precipitation reaches the ground at 1580.0 s.

Current to ground=-0.995E+06fC/m**2/s

Rain intensity at the ground= 0.420 mm/hr

Hallett-Mossop Run

Hallett factor = $0.500\text{E}+15$

Cell Radius = 1000.0 m.

updraft speed = 10.0 m/s

freezing level= 616.8 mb: balance level= 403.2mb

time step= 10.0s

Hailstone Flux = $0.500\text{E}-01 \text{ (m}^2\text{-s)}^{-1}$

Hail Embryo diameter= $0.800\text{E}-02$ m

Treverse= 258.0 K. $Q_1 = 0.120\text{E}-02 \text{ kg m}^{-3}$

charge destroyed is 0.10 times that in a
meters deep just below cloud top.

layer 1800.0

Charge parameter= $=Z_p \cdot R_N \cdot a^{1.5} = 0.314\text{E}-02$

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
360.0	403.2	360.0	1.65	(I-C)	1.91
789.0	403.2	429.0	3.92	(I-C)	1.72
852.0	403.2	63.0	4.30	(I-C)	2.89
900.0	403.2	48.0	4.61	(C-G)	3.83
929.0	403.2	29.0	5.25	(C-G)	5.62
952.0	403.2	23.0	5.94	(C-G)	7.68
953.0	450.2	1.0	6.22	(I-C)	12.1
996.0	403.2	43.0	6.52	(C-G)	7.25
997.0	450.2	1.0	6.83	(C-G)	12.2
1036.0	403.2	39.0	7.88	(C-G)	9.61

Calculation stopped at time= 1037.0 seconds.

Total number of lightning strokes = 11

Precipitation reaches the ground at 482.0 s.

Current to ground= $-0.307\text{E}+08 \text{ fC/m}^2/\text{s}$

Rain intensity at the ground= 2.10 mm/hr

pressure	radar	P(mm/hr)
617.	56.8	0.679
601.	56.6	0.651
586.	56.4	0.623
571.	56.2	0.596
557.	56.0	0.570
543.	55.8	0.544
529.	55.6	0.518
515.	55.5	0.492
501.	55.3	0.467
488.	55.1	0.442
475.	54.9	0.417
463.	54.8	0.392
450.	54.7	0.367
438.	54.6	0.341
426.	54.5	0.314

415. 55.1 0.251
 403. 60.8 0.464E-01
 Hallett-Mossop Run
 Hallett factor = 0.100E+15
 Cell Radius = 1000.0 m.
 updraft speed = 10.0 m/s
 freezing level= 616.8 mb: balance level= 403.2mb
 time step= 10.0s
 Hailstone Flux = 0.500E-01 (m**2-s)**-1
 Hail Embryo diameter= 0.800E-02 m
 Treverse= 258.0 K. Ql= 0.120E-02 kg m**-3
 charge destroyed is 0.10 times that in a layer 1800.0
 meters deep just below cloud top.

Charge parameter== $Z_p \cdot R_N \cdot a^{1.5}$ = 0.627E-03

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
2420.0	403.2	2420.0	2.37	(I-C)	1.72

Calculation stopped at time= 3600.0 seconds.
 Total number of lightning strokes = 1

Precipitation reaches the ground at 1580.0 s.
 Current to ground=-0.573E+07fC/m**2/s
 Rain intensity at the ground= 2.10 mm/hr

pressure	radar	P(mm/hr)
617.	56.8	0.679
601.	56.6	0.651
586.	56.4	0.623
571.	56.2	0.596
557.	56.0	0.570
543.	55.8	0.544
529.	55.6	0.518
515.	55.5	0.492
501.	55.3	0.467
488.	55.1	0.442
475.	54.9	0.417
463.	54.8	0.392
450.	54.7	0.367
438.	54.6	0.341
426.	54.5	0.314
415.	55.1	0.251
403.	60.8	0.464E-01

Hallett-Mossop Run
 Hallett factor = 0.100E+16
 Cell Radius = 1000.0 m.
 updraft speed = 10.0 m/s
 freezing level= 616.8 mb: balance level= 403.2mb
 time step= 10.0s
 Hailstone Flux = 0.500E-01 (m**2-s)**-1
 Hail Embryo diameter= 0.800E-02 m
 Treverse= 258.0 K. Ql= 0.120E-02 kg m**-3
 charge destroyed is 0.10 times that in a layer 1800.0
 meters deep just below cloud top.

Charge parameter==Zp*RN*a**1.5 = 0.627E-02

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
200.0	403.2	200.0	1.67	(I-C)	1.67
243.0	403.2	43.0	2.10	(I-C)	2.13
289.0	403.2	46.0	2.62	(I-C)	2.40
325.0	403.2	36.0	3.04	(I-C)	2.78
356.0	403.2	31.0	3.41	(I-C)	3.17
384.0	403.2	28.0	3.76	(I-C)	3.55
409.0	403.2	25.0	4.08	(I-C)	3.94
432.0	403.2	23.0	4.37	(I-C)	4.35
454.0	403.2	22.0	4.67	(I-C)	4.74
475.0	403.2	21.0	4.96	(C-G)	5.13

Calculation stopped at time= 491.0 seconds.

Total number of lightning strokes = 11

Precipitation reaches the ground at 338.0 s.

Current to ground=-0.352E+08fC/m**2/s

Rain intensity at the ground= 2.10 mm/hr

pressure	radar	P(mm/hr)
----------	-------	----------

617.	56.8	0.679
601.	56.6	0.651
586.	56.4	0.623
571.	56.2	0.596
557.	56.0	0.570
543.	55.8	0.544
529.	55.6	0.518
515.	55.5	0.492
501.	55.3	0.467
488.	55.1	0.442
475.	54.9	0.417
463.	54.8	0.392
450.	54.7	0.367
438.	54.6	0.341
426.	54.5	0.314
415.	55.1	0.251
403.	60.8	0.464E-01

Hallett-Mossop Run

Hallett factor = 0.450E+16

Cell Radius = 1000.0 m.

updraft speed = 10.0 m/s

freezing level= 616.8 mb: balance level= 403.2mb

time step= 10.0s

Hailstone Flux = 0.500E-01 (m**2-s)**-1

Hail Embryo diameter= 0.800E-02 m

Treverse= 258.0 K. Ql= 0.120E-02 kg m**-3

charge destroyed is 0.10 times that in a

meters deep just below cloud top.

layer 1800.0

Charge parameter==Zp*RN*a**1.5 = 0.282E-01

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
70.0	403.2	70.0	2.26	(I-C)	1.40
71.0	403.2	1.0	2.17	(I-C)	1.44
73.0	403.2	2.0	2.13	(I-C)	1.50
77.0	403.2	4.0	2.21	(I-C)	1.61
82.0	403.2	5.0	2.35	(I-C)	1.76
88.0	403.2	6.0	2.57	(I-C)	1.93
93.0	403.2	5.0	2.74	(I-C)	2.07
99.0	403.2	6.0	2.98	(I-C)	2.23
105.0	403.2	6.0	3.23	(I-C)	2.39
111.0	403.2	6.0	3.48	(I-C)	2.54

Calculation stopped at time= 117.0 seconds.
Total number of lightning strokes = 11

pressure	radar	P(mm/hr)
529.	55.8	0.533
515.	55.5	0.492
501.	55.3	0.467
488.	55.1	0.442
475.	54.9	0.417
463.	54.8	0.392
450.	54.7	0.367
438.	54.6	0.341
426.	54.5	0.314
415.	55.1	0.251
403.	60.8	0.464E-01

Hallett-Mossop Run

Hallett factor = 0.450E+16

Cell Radius = 200.0 m.

updraft speed = 10.0 m/s

freezing level= 616.8 mb: balance level= 414.6mb

time step= 10.0s

Hailstone Flux = 0.100E-01 (m**2-s)**-1

Hail Embryo diameter= 0.800E-02 m

Treverse= 258.0 K. Ql= 0.130E-02 kg m**-3

charge destroyed is 0.10 times that in a
meters deep just below cloud top.

layer 1800.0

Charge parameter==Zp*RN*a**1.5 = 0.453E-02

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	taug/taut
770.0	414.6	770.0	0.228	(I-C)	1.58
3304.0	414.6	2534.0	0.940	(I-C)	1.57
3402.0	414.6	98.0	0.991	(C-G)	3.05
3462.0	414.6	60.0	1.13	(C-G)	6.89
3508.0	414.6	46.0	1.28	(C-G)	11.1
3547.0	414.6	39.0	1.45	(C-G)	15.6
3581.0	414.6	34.0	1.63	(C-G)	20.7

Calculation stopped at time= 3600.0 seconds.

Total number of lightning strokes = 7

Precipitation reaches the ground at 845.0 s.

Current to ground=-0.407E+08fC/m**2/s

Rain intensity at the ground= 0.430 mm/hr

pressure	radar	P(mm/hr)
617.	49.9	0.138
601.	49.7	0.132
586.	49.5	0.126
571.	49.3	0.120
557.	49.0	0.115
543.	48.8	0.109
529.	48.6	0.103
515.	48.4	0.978E-01
501.	48.3	0.923E-01
488.	48.1	0.869E-01
475.	47.9	0.814E-01
463.	47.7	0.760E-01
450.	47.6	0.704E-01
438.	47.6	0.645E-01
426.	48.0	0.511E-01
415.	53.6	0.881E-02

Hallett-Mossop Run

Hallett factor = 0.450E+16

Cell Radius = 400.0 m.

updraft speed = 10.0 m/s

freezing level= 616.8 mb: balance level= 414.6mb

time step= 10.0s

Hailstone Flux = 0.100E-01 (m**2-s)**-1

Hail Embryo diameter= 0.800E-02 m

Treverse= 258.0 K. Ql= 0.130E-02 kg m**-3

charge destroyed is 0.10 times that in a
meters deep just below cloud top.

layer 1800.0

Charge parameter==Zp*RN*a**1.5 = 0.906E-02

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
360.0	414.6	360.0	0.419	(I-C)	1.89
1192.0	414.6	832.0	1.39	(I-C)	1.57
1271.0	414.6	79.0	1.51	(I-C)	2.59
1334.0	414.6	63.0	1.61	(I-C)	3.45
1389.0	414.6	55.0	1.71	(C-G)	4.21
1427.0	414.6	38.0	1.95	(C-G)	6.13
1459.0	414.6	32.0	2.22	(C-G)	8.25
1487.0	414.6	28.0	2.51	(C-G)	10.6
1512.0	414.6	25.0	2.83	(C-G)	13.3
1513.0	462.6	1.0	2.97	(I-C)	21.7

Calculation stopped at time= 1551.0 seconds.

Total number of lightning strokes = 11

Precipitation reaches the ground at 476.0 s.

Current to ground=-0.496E+08fC/m**2/s

Rain intensity at the ground= 0.430 mm/hr

pressure	radar	P(mm/hr)
617.	49.9	0.138
601.	49.7	0.132
586.	49.5	0.126
571.	49.3	0.120
557.	49.0	0.115
543.	48.8	0.109
529.	48.6	0.103
515.	48.4	0.978E-01
501.	48.3	0.923E-01
488.	48.1	0.869E-01
475.	47.9	0.814E-01
463.	47.7	0.760E-01
450.	47.6	0.704E-01
438.	47.6	0.645E-01
426.	48.0	0.511E-01
415.	53.6	0.881E-02

Hallett-Mossop Run

Hallett factor = 0.450E+16

Cell Radius = 600.0 m.

updraft speed = 10.0 m/s

freezing level= 616.8 mb: balance level= 414.6mb
time step= 10.0s
Hailstone Flux = 0.100E-01 (m**2-s)**-1
Hail Embryo diameter= 0.800E-02 m
Treverse= 258.0 K. Ql= 0.130E-02 kg m**-3
charge destroyed is 0.10 times that in a layer 1800.0
meters deep just below cloud top.

Charge parameter==Zp*RN*a**1.5 = 0.136E-01

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
280.0	414.6	280.0	0.703	(I-C)	1.80
702.0	414.6	422.0	1.86	(I-C)	1.57
771.0	414.6	69.0	2.07	(I-C)	2.39
824.0	414.6	53.0	2.24	(I-C)	3.11
870.0	414.6	46.0	2.41	(I-C)	3.73
911.0	414.6	41.0	2.56	(I-C)	4.33
948.0	414.6	37.0	2.70	(C-G)	4.97
975.0	414.6	27.0	3.08	(C-G)	6.41
999.0	414.6	24.0	3.49	(C-G)	8.07
1021.0	414.6	22.0	3.96	(C-G)	9.88

Calculation stopped at time= 1022.0 seconds.
Total number of lightning strokes = 11

Precipitation reaches the ground at 404.0 s.
Current to ground=-0.433E+08fC/m**2/s
Rain intensity at the ground= 0.430 mm/hr

pressure	radar	P(mm/hr)
617.	49.9	0.138
601.	49.7	0.132
586.	49.5	0.126
571.	49.3	0.120
557.	49.0	0.115
543.	48.8	0.109
529.	48.6	0.103
515.	48.4	0.978E-01
501.	48.3	0.923E-01
488.	48.1	0.869E-01
475.	47.9	0.814E-01
463.	47.7	0.760E-01
450.	47.6	0.704E-01
438.	47.6	0.645E-01
426.	48.0	0.511E-01
415.	53.6	0.881E-02

Hallett-Mossop Run

Hallett factor = 0.450E+16

Cell Radius = 800.0 m.

updraft speed = 10.0 m/s

freezing level= 616.8 mb: balance level= 414.6mb

time step= 10.0s

Hailstone Flux = 0.100E-01 (m**2-s)**-1

Hail Embryo diameter= 0.800E-02 m

Treverse= 258.0 K. Ql= 0.130E-02 kg m**-3

charge destroyed is 0.10 times that in a layer 1800.0
meters deep just below cloud top.

Charge parameter== $Z_p \cdot R_N \cdot a^{**1.5}$ = 0.181E-01

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
240.0	414.6	240.0	1.04	(I-C)	1.75
474.0	414.6	234.0	2.25	(I-C)	1.64
536.0	414.6	62.0	2.57	(I-C)	2.27
583.0	414.6	47.0	2.82	(I-C)	2.85
624.0	414.6	41.0	3.06	(I-C)	3.35
660.0	414.6	36.0	3.28	(I-C)	3.88
693.0	414.6	33.0	3.49	(I-C)	4.38
724.0	414.6	31.0	3.70	(C-G)	4.86
746.0	414.6	22.0	4.21	(C-G)	6.11
766.0	414.6	20.0	4.77	(C-G)	7.51

ulation stopped at time= 767.0 seconds.
al number of lightning strokes = 11

Precipitation reaches the ground at 368.0 s.
Current to ground=-0.380E+08fC/m**2/s
Rain intensity at the ground= 0.430 mm/hr

pressure	radar	P(mm/hr)
617.	49.9	0.138
601.	49.7	0.132
586.	49.5	0.126
571.	49.3	0.120
557.	49.0	0.115
543.	48.8	0.109
529.	48.6	0.103
515.	48.4	0.978E-01
501.	48.3	0.923E-01
488.	48.1	0.869E-01
475.	47.9	0.814E-01
463.	47.7	0.760E-01
450.	47.6	0.704E-01
438.	47.6	0.645E-01
426.	48.0	0.511E-01
415.	53.6	0.881E-02

Hallett-Mossop Run

Hallett factor = 0.450E+16

Cell Radius = 1000.0 m.

updraft speed = 10.0 m/s

freezing level= 616.8 mb: balance level= 392.0mb

time step= 10.0s

Hailstone Flux = 0.100E-01 (m**2-s)**-1

Hail Embryo diameter= 0.800E-02 m

Treverse= 258.0 K. Q1= 0.110E-02 kg m**-3

charge destroyed is 0.10 times that in a

layer 1800.0

meters deep just below cloud top.

Charge parameter== $Z_p \cdot R_N \cdot a^{1.5} = 0.272E-01$

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
190.0	392.0	190.0	1.59	(I-C)	1.62
227.0	392.0	37.0	1.95	(I-C)	2.09
266.0	392.0	39.0	2.38	(I-C)	2.39
300.0	392.0	34.0	2.78	(I-C)	2.74
330.0	392.0	30.0	3.16	(I-C)	3.14
357.0	392.0	27.0	3.51	(I-C)	3.53
381.0	392.0	24.0	3.84	(I-C)	3.95
404.0	392.0	23.0	4.16	(I-C)	4.34
425.0	392.0	21.0	4.46	(I-C)	4.75
445.0	392.0	20.0	4.76	(C-G)	5.16

Calculation stopped at time= 460.0 seconds.

Total number of lightning strokes = 11

Precipitation reaches the ground at 340.0 s.

Current to ground=-0.317E+08fC/m**2/s

Rain intensity at the ground= 0.407 mm/hr

pressure	radar	P(mm/hr)
617.	49.7	0.133
601.	49.5	0.127
586.	49.3	0.122
571.	49.2	0.117
557.	49.0	0.113
543.	48.8	0.108
529.	48.6	0.103
515.	48.5	0.984E-01
501.	48.3	0.938E-01
488.	48.1	0.892E-01
475.	48.0	0.846E-01
463.	47.9	0.801E-01
450.	47.7	0.755E-01
438.	47.6	0.709E-01
426.	47.6	0.661E-01
415.	47.6	0.611E-01

403. 48.2 0.495E-01
 392. 54.1 0.979E-02

Fletcher Glaciation Run

Fletcher x 0.100E+04

Cell Radius = 1000.0 m.

updraft speed = 10.0 m/s

freezing level= 616.8 mb: balance level= 392.0mb

time step= 10.0s

Hailstone Flux = 0.100E-01 (m**2-s)**-1

Hail Embryo diameter= 0.800E-02 m

Treverse= 258.0 K. Ql= 0.110E-02 kg m**-3

charge destroyed is 0.10 times that in a
 meters deep just below cloud top.

layer 1800.0

Charge parameter==Zp*RN*a**1.5 = 0.375E-01

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
130.0	392.0	130.0	1.53	(I-C)	1.15
131.0	392.0	1.0	1.48	(I-C)	1.46
138.0	392.0	7.0	1.53	(I-C)	1.65
146.0	392.0	8.0	1.60	(I-C)	1.79
154.0	392.0	8.0	1.67	(I-C)	1.92
161.0	392.0	7.0	1.73	(I-C)	2.04
168.0	392.0	7.0	1.79	(I-C)	2.15
175.0	392.0	7.0	1.85	(I-C)	2.25
182.0	392.0	7.0	1.91	(I-C)	2.34
189.0	392.0	7.0	1.97	(I-C)	2.42

Calculation stopped at time= 195.0 seconds.

Total number of lightning strokes = 11

pressure	radar	P(mm/hr)
571.	48.9	0.111
557.	49.0	0.113
543.	48.8	0.108
529.	48.6	0.103
515.	48.5	0.984E-01
501.	48.3	0.938E-01
488.	48.1	0.892E-01
475.	48.0	0.846E-01
463.	47.9	0.801E-01
450.	47.7	0.755E-01
438.	47.6	0.709E-01
426.	47.6	0.661E-01
415.	47.6	0.611E-01
403.	48.2	0.495E-01
392.	54.1	0.979E-02

Hallett-Mossop Run

Hallett factor = 0.450E+16

Cell Radius = 1000.0 m.

updraft speed = 9.0 m/s

freezing level= 616.8 mb: balance level= 403.2mb

time step= 10.0s

Hailstone Flux = 0.100E-01 (m**2-s)**-1

Hail Embryo diameter= 0.800E-02 m

Treverse= 258.0 K. Ql= 0.650E-03 kg m**-3
charge destroyed is 0.10 times that in a layer 1800.0
meters deep just below cloud top.

Charge parameter==Zp*RN*a**1.5 = 0.285E-01

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	taug/taut
250.0	403.2	250.0	1.56	(I-C)	1.53
283.0	403.2	33.0	1.78	(I-C)	2.08
319.0	403.2	36.0	2.07	(I-C)	2.43
352.0	403.2	33.0	2.35	(I-C)	2.73
383.0	403.2	31.0	2.62	(I-C)	3.04
411.0	403.2	28.0	2.87	(I-C)	3.37
437.0	403.2	26.0	3.12	(I-C)	3.71
462.0	403.2	25.0	3.36	(I-C)	4.04
486.0	403.2	24.0	3.60	(I-C)	4.36
509.0	403.2	23.0	3.84	(I-C)	4.68

Calculation stopped at time= 531.0 seconds.
Total number of lightning strokes = 11

Precipitation reaches the ground at 459.0 s.
Current to ground=-0.256E+08fC/m**2/s
Rain intensity at the ground= 0.286 mm/hr

pressure	radar	P(mm/hr)
617.	46.3	0.751E-01
601.	46.2	0.726E-01
586.	46.1	0.701E-01
571.	46.0	0.677E-01
557.	45.9	0.653E-01
543.	45.8	0.629E-01
529.	45.7	0.605E-01
515.	45.6	0.581E-01
501.	45.5	0.557E-01
488.	45.4	0.534E-01
475.	45.3	0.510E-01
463.	45.3	0.485E-01
450.	45.3	0.460E-01
438.	45.3	0.435E-01
426.	45.4	0.407E-01
415.	46.4	0.342E-01
403.	52.7	0.970E-02

Fletcher Glaciation Run
Fletcher x 0.100E+04
Cell Radius = 1000.0 m.
updraft speed = 9.0 m/s
freezing level= 616.8 mb: balance level= 403.2mb
time step= 10.0s
Hailstone Flux = 0.100E-01 (m**2-s)**-1
Hail Embryo diameter= 0.800E-02 m
Treverse= 258.0 K. Ql= 0.650E-03 kg m**-3
charge destroyed is 0.10 times that in a layer 1800.0
meters deep just below cloud top.

Charge parameter== $Zp \cdot RN \cdot a^{1.5} = 0.174E-01$

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
330.0	403.2	330.0	1.32	(I-C)	1.14
398.0	403.2	68.0	1.58	(I-C)	1.27
507.0	403.2	109.0	2.02	(I-C)	1.19
585.0	403.2	78.0	2.32	(I-C)	1.29
643.0	403.2	58.0	2.53	(I-C)	1.48
690.0	403.2	47.0	2.70	(I-C)	1.70
731.0	403.2	41.0	2.84	(I-C)	1.91
768.0	403.2	37.0	2.96	(I-C)	2.11
802.0	403.2	34.0	3.08	(I-C)	2.30
834.0	403.2	32.0	3.18	(I-C)	2.47

Calculation stopped at time= 864.0 seconds.
Total number of lightning strokes = 11

Precipitation reaches the ground at 531.0 s.
Current to ground=-0.797E+07fC/m**2/s
Rain intensity at the ground= 0.286 mm/hr

pressure	radar	P(mm/hr)
617.	46.3	0.751E-01
601.	46.2	0.726E-01
586.	46.1	0.701E-01
571.	46.0	0.677E-01
557.	45.9	0.653E-01
543.	45.8	0.629E-01
529.	45.7	0.605E-01
515.	45.6	0.581E-01
501.	45.5	0.557E-01
488.	45.4	0.534E-01
475.	45.3	0.510E-01
463.	45.3	0.485E-01
450.	45.3	0.460E-01
438.	45.3	0.435E-01
426.	45.4	0.407E-01
415.	46.4	0.342E-01
403.	52.7	0.970E-02

Fletcher Glaciation Run
Fletcher x 0.100E+04
Cell Radius = 1000.0 m.
updraft speed = 9.0 m/s
freezing level= 616.8 mb: balance level= 392.0mb
time step= 10.0s
Hailstone Flux = 0.100E-01 (m**2-s)**-1
Hail Embryo diameter= 0.800E-02 m
Treverse= 258.0 K. Ql= 0.600E-03 kg m**-3
charge destroyed is 0.10 times that in a layer 1800.0
meters deep just below cloud top.

Charge parameter== $Zp \cdot RN \cdot a^{1.5} = 0.429E-01$

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
---------	-------	-------------	---------	------	-----------

140.0	392.0	140.0	1.42	(I-C)	1.13
148.0	392.0	8.0	1.46	(I-C)	1.38
157.0	392.0	9.0	1.52	(I-C)	1.57
165.0	392.0	8.0	1.57	(I-C)	1.75
173.0	392.0	8.0	1.62	(I-C)	1.89
180.0	392.0	7.0	1.66	(I-C)	2.03
187.0	392.0	7.0	1.71	(I-C)	2.15
194.0	392.0	7.0	1.76	(I-C)	2.26
200.0	392.0	6.0	1.79	(I-C)	2.38
206.0	392.0	6.0	1.82	(I-C)	2.49

Calculation stopped at time= 212.0 seconds.

Total number of lightning strokes = 11

pressure	radar	P(mm/hr)
----------	-------	----------

529.	43.1	0.337E-01
515.	45.6	0.582E-01
501.	45.5	0.560E-01
488.	45.4	0.538E-01
475.	45.3	0.516E-01
463.	45.3	0.494E-01
450.	45.3	0.472E-01
438.	45.3	0.449E-01
426.	45.3	0.425E-01
415.	45.5	0.399E-01
403.	46.5	0.338E-01
392.	52.9	0.102E-01

Hallett-Mossop Run

Hallett factor = 0.450E+16

Cell Radius = 1000.0 m.

updraft speed = 9.0 m/s

freezing level= 616.8 mb: balance level= 392.0mb

time step= 10.0s

Hailstone Flux = 0.100E-01 (m**2-s)**-1

Hail Embryo diameter= 0.800E-02 m

Treverse= 258.0 K. Ql= 0.600E-03 kg m**-3

charge destroyed is 0.10 times that in a

layer 1800.0

meters deep just below cloud top.

Charge parameter==Zp*RN*a**1.5 = 0.311E-01

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
---------	-------	-------------	---------	------	-----------

220.0	392.0	220.0	1.52	(I-C)	1.50
242.0	392.0	22.0	1.66	(I-C)	1.99
270.0	392.0	28.0	1.90	(I-C)	2.38
295.0	392.0	25.0	2.12	(I-C)	2.69
319.0	392.0	24.0	2.35	(I-C)	2.99
342.0	392.0	23.0	2.58	(I-C)	3.29
364.0	392.0	22.0	2.81	(I-C)	3.60
385.0	392.0	21.0	3.05	(I-C)	3.92
405.0	392.0	20.0	3.27	(I-C)	4.25
424.0	392.0	19.0	3.49	(I-C)	4.59

Calculation stopped at time= 443.0 seconds.

Total number of lightning strokes = 11

Precipitation reaches the ground at 442.0 s.

Current to ground=-0.226E+08fC/m**2/s

Rain intensity at the ground= 0.280 mm/hr

pressure	radar	P(mm/hr)
----------	-------	----------

617.	46.3	0.739E-01
601.	46.2	0.716E-01
586.	46.1	0.693E-01
571.	46.0	0.671E-01
557.	45.8	0.648E-01
543.	45.7	0.626E-01
529.	45.7	0.604E-01
515.	45.6	0.582E-01
501.	45.5	0.560E-01
488.	45.4	0.538E-01
475.	45.3	0.516E-01
463.	45.3	0.494E-01
450.	45.3	0.472E-01
438.	45.3	0.449E-01
426.	45.3	0.425E-01
415.	45.5	0.399E-01
403.	46.5	0.338E-01
392.	52.9	0.102E-01

Fletcher Glaciation Run

Fletcher x 0.100E+04

Cell Radius = 1000.0 m.

updraft speed = 12.0 m/s

freezing level= 616.8 mb: balance level= 403.2mb

time step= 10.0s

Hailstone Flux = 0.100E-01 (m**2-s)**-1

Hail Embryo diameter= 0.800E-02 m

Treverse= 258.0 K. Ql= 0.270E-02 kg m**-3

charge destroyed is 0.10 times that in a
meters deep just below cloud top.

layer 1800.0

Charge parameter==Zp*RN*a**1.5 = 0.121E-01

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
210.0	403.2	210.0	1.42	(I-C)	1.22
546.0	403.2	336.0	3.76	(I-C)	1.22
587.0	403.2	41.0	4.00	(I-C)	1.70
619.0	403.2	32.0	4.19	(I-C)	2.07
647.0	403.2	28.0	4.34	(I-C)	2.37
673.0	403.2	26.0	4.48	(C-G)	2.59
689.0	403.2	16.0	5.00	(C-G)	3.61
702.0	403.2	13.0	5.55	(C-G)	4.73
712.0	414.6	10.0	6.10	(C-G)	6.17
724.0	403.2	12.0	6.52	(C-G)	6.03

Calculation stopped at time= 725.0 seconds.

Total number of lightning strokes = 11

Precipitation reaches the ground at 300.0 s.
 Current to ground=-0.652E+08fC/m**2/s
 Rain intensity at the ground= 1.17 mm/hr

pressure	radar	P(mm/hr)
----------	-------	----------

617.	55.9	0.363
601.	55.6	0.344
586.	55.3	0.325
571.	55.0	0.306
557.	54.7	0.289
543.	54.4	0.271
529.	54.1	0.255
515.	53.8	0.238
501.	53.5	0.222
488.	53.2	0.207
475.	52.9	0.192
463.	52.6	0.176
450.	52.3	0.162
438.	52.0	0.146
426.	51.7	0.131
415.	51.6	0.972E-01
403.	56.4	0.971E-02

Hallett-Mossop Run

Hallett factor = 0.450E+16

Cell Radius = 1000.0 m.

updraft speed = 12.0 m/s

freezing level= 616.8 mb: balance level= 403.2mb

time step= 10.0s

Hailstone Flux = 0.100E-01 (m**2-s)**-1

Hail Embryo diameter= 0.800E-02 m

Treverse= 258.0 K. Ql= 0.270E-02 kg m**-3

charge destroyed is 0.10 times that in a
 meters deep just below cloud top.

layer 1800.0

Charge parameter==Zp*RN*a**1.5 = 0.200E-01

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	taug/taut
150.0	403.2	150.0	1.79	(I-C)	1.97
244.0	586.2	94.0	3.33	(I-C)	2.34
245.0	586.2	1.0	3.01	(I-C)	2.12
327.0	403.2	82.0	4.04	(I-C)	2.18
368.0	403.2	41.0	4.71	(I-C)	2.91
400.0	403.2	32.0	5.28	(C-G)	3.62
420.0	403.2	20.0	6.18	(C-G)	4.81
421.0	450.2	1.0	6.49	(C-G)	6.98
446.0	403.2	25.0	7.47	(C-G)	5.62
447.0	450.2	1.0	7.85	(C-G)	8.25

Calculation stopped at time= 448.0 seconds.

Total number of lightning strokes = 11

Precipitation reaches the ground at 246.0 s.

Current to ground=-0.239E+09fC/m**2/s

Rain intensity at the ground= 1.17 mm/hr

pressure	radar	P(mm/hr)
----------	-------	----------

617.	55.9	0.363
601.	55.6	0.344
586.	55.3	0.325
571.	55.0	0.306
557.	54.7	0.289
543.	54.4	0.271
529.	54.1	0.255
515.	53.8	0.238
501.	53.5	0.222
488.	53.2	0.207
475.	52.9	0.192
463.	52.6	0.176
450.	52.3	0.162
438.	52.0	0.146
426.	51.7	0.131
415.	51.6	0.972E-01
403.	56.4	0.971E-02

Fletcher Glaciation Run

Fletcher x 0.100E+04

Cell Radius = 1000.0 m.

updraft speed = 11.0 m/s

freezing level= 616.8 mb: balance level= 403.2mb

time step= 10.0s

Hailstone Flux = 0.100E-01 (m**2-s)**-1

Hail Embryo diameter= 0.800E-02 m

Treverse= 258.0 K. Ql= 0.190E-02 kg m**-3

charge destroyed is 0.10 times that in a
meters deep just below cloud top.

layer 1800.0

Charge parameter==Zp*RN*a**1.5 = 0.118E-01

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
---------	-------	-------------	---------	------	-----------

1830.0	403.2	1830.0	3.51	(C-G)	1.93
2488.0	403.2	658.0	5.13	(C-G)	1.93
2521.0	403.2	33.0	5.67	(C-G)	7.62
2522.0	426.2	1.0	6.05	(C-G)	27.1
2523.0	450.2	1.0	6.06	(C-G)	26.2
2575.0	414.6	52.0	6.94	(C-G)	17.3
2576.0	450.2	1.0	6.98	(I-C)	18.6
2620.0	414.6	44.0	7.46	(C-G)	23.0
2621.0	450.2	1.0	7.51	(C-G)	24.3
2622.0	475.2	1.0	7.56	(C-G)	25.5

Calculation stopped at time= 2623.0 seconds.

Total number of lightning strokes = 11

Precipitation reaches the ground at 1210.0 s.

Current to ground=-0.143E+08fC/m**2/s

Rain intensity at the ground= 0.634 mm/hr

pressure	radar	P(mm/hr)
----------	-------	----------

617.	53.0	0.230
------	------	-------

601.	52.8	0.219
586.	52.5	0.208
571.	52.3	0.197
557.	52.0	0.187
543.	51.8	0.177
529.	51.5	0.167
515.	51.3	0.158
501.	51.0	0.148
488.	50.7	0.139
475.	50.5	0.130
463.	50.3	0.121
450.	50.0	0.111
438.	49.8	0.102
426.	49.7	0.927E-01
415.	49.9	0.711E-01
403.	48.4	0.197E-02

Hallett-Mossop Run

Hallett factor = 0.450E+16

Cell Radius = 1000.0 m.

updraft speed = 11.0 m/s

freezing level= 616.8 mb: balance level= 403.2mb

time step= 10.0s

Hailstone Flux = 0.100E-01 (m**2-s)**-1

Hail Embryo diameter= 0.800E-02 m

Treverse= 258.0 K. Ql= 0.190E-02 kg m**-3

charge destroyed is 0.10 times that in a

layer 1800.0

meters deep just below cloud top.

Charge parameter==Zp*RN*a**1.5 = 0.222E-01

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	taug/taut
180.0	403.2	180.0	1.71	(I-C)	1.85
307.0	403.2	127.0	3.30	(I-C)	2.13
349.0	403.2	42.0	3.86	(I-C)	2.82
381.0	403.2	32.0	4.28	(I-C)	3.38
409.0	403.2	28.0	4.67	(C-G)	3.87
427.0	403.2	18.0	5.36	(C-G)	4.89
444.0	403.2	17.0	6.14	(C-G)	5.96
445.0	450.2	1.0	6.45	(I-C)	8.32
473.0	403.2	28.0	6.76	(C-G)	5.83
474.0	450.2	1.0	7.10	(C-G)	8.43

Calculation stopped at time= 475.0 seconds.

Total number of lightning strokes = 11

Precipitation reaches the ground at 283.0 s.

Current to ground=-0.601E+08fC/m**2/s

Rain intensity at the ground= 0.634 mm/hr

pressure	radar	P(mm/hr)
617.	53.0	0.230
601.	52.8	0.219
586.	52.5	0.208
571.	52.3	0.197
557.	52.0	0.187

543.	51.8	0.177
529.	51.5	0.167
515.	51.3	0.158
501.	51.0	0.148
488.	50.7	0.139
475.	50.5	0.130
463.	50.3	0.121
450.	50.0	0.111
438.	49.8	0.102
426.	49.7	0.927E-01
415.	49.9	0.711E-01
403.	55.1	0.933E-02

Fletcher Glaciation Run

Fletcher x 0.100E+04

Cell Radius = 1000.0 m.

updraft speed = 10.0 m/s

freezing level= 616.8 mb: balance level= 403.2mb

time step= 10.0s

Hailstone Flux = 0.100E-01 (m**2-s)**-1

Hail Embryo diameter= 0.800E-02 m

Treverse= 258.0 K. Ql= 0.120E-02 kg m**-3

charge destroyed is 0.10 times that in a

layer 1800.0

meters deep just below cloud top.

Charge parameter==Zp*RN*a**1.5 = 0.152E-01

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	taug/taut
300.0	403.2	300.0	1.39	(I-C)	1.17
694.0	403.2	394.0	3.24	(I-C)	1.17
747.0	403.2	53.0	3.46	(I-C)	1.60
789.0	403.2	42.0	3.62	(I-C)	1.92
825.0	403.2	36.0	3.76	(I-C)	2.22
857.0	403.2	32.0	3.87	(I-C)	2.49
887.0	403.2	30.0	3.98	(I-C)	2.71
915.0	403.2	28.0	4.08	(I-C)	2.93
942.0	403.2	27.0	4.17	(I-C)	3.11
967.0	403.2	25.0	4.25	(I-C)	3.34

Calculation stopped at time= 991.0 seconds.

Total number of lightning strokes = 11

Precipitation reaches the ground at 428.0 s.

Current to ground=-0.859E+07fC/m**2/s

Rain intensity at the ground= 0.420 mm/hr

pressure	radar	P(mm/hr)
617.	49.8	0.136
601.	49.6	0.130
586.	49.4	0.125
571.	49.2	0.119
557.	49.0	0.114
543.	48.8	0.109
529.	48.7	0.104
515.	48.5	0.985E-01
501.	48.3	0.934E-01

488.	48.1	0.884E-01
475.	48.0	0.835E-01
463.	47.8	0.784E-01
450.	47.7	0.734E-01
438.	47.6	0.682E-01
426.	47.6	0.628E-01
415.	48.1	0.503E-01
403.	53.9	0.927E-02

Hallett-Mossop Run

Hallett factor = 0.450E+16

Cell Radius = 1000.0 m.

updraft speed = 10.0 m/s

freezing level= 616.8 mb: balance level= 403.2mb

time step= 10.0s

Hailstone Flux = 0.100E-01 (m**2-s)**-1

Hail Embryo diameter= 0.800E-02 m

Treverse= 258.0 K. Q1= 0.120E-02 kg m**-3

charge destroyed is 0.10 times that in a

layer 1800.0

meters deep just below cloud top.

Charge parameter==Zp*RN*a**1.5 = 0.250E-01

Time(s)	p(mb)	Interval(s)	Qzap(C)	Type	tauq/taut
220.0	403.2	220.0	1.67	(I-C)	1.70
284.0	403.2	64.0	2.29	(I-C)	2.07
337.0	403.2	53.0	2.84	(I-C)	2.41
378.0	403.2	41.0	3.28	(I-C)	2.83
411.0	403.2	33.0	3.63	(I-C)	3.28
441.0	403.2	30.0	3.97	(I-C)	3.68
468.0	403.2	27.0	4.28	(I-C)	4.11
493.0	403.2	25.0	4.58	(I-C)	4.54
517.0	403.2	24.0	4.87	(C-G)	4.95
534.0	403.2	17.0	5.55	(C-G)	5.99

Calculation stopped at time= 535.0 seconds.

Total number of lightning strokes = 11

Precipitation reaches the ground at 356.0 s.

Current to ground=-0.347E+08fC/m**2/s

Rain intensity at the ground= 0.420 mm/hr

pressure	radar	P(mm/hr)
617.	49.8	0.136
601.	49.6	0.130
586.	49.4	0.125
571.	49.2	0.119
557.	49.0	0.114
543.	48.8	0.109
529.	48.7	0.104
515.	48.5	0.985E-01
501.	48.3	0.934E-01
488.	48.1	0.884E-01
475.	48.0	0.835E-01
463.	47.8	0.784E-01
450.	47.7	0.734E-01

