Atmospheric Electricity

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Bronze statue of Benjamin Franklin by Agnes Yarnall

"Now if the fire of electricity and that of lightning be the same . . . may not the knowledge of this power . . . be of use to mankind? . . ."

—FROM FRANKLIN'S AUTOBIOGRAPHICAL WRITINGS

Thunderstorm electrification

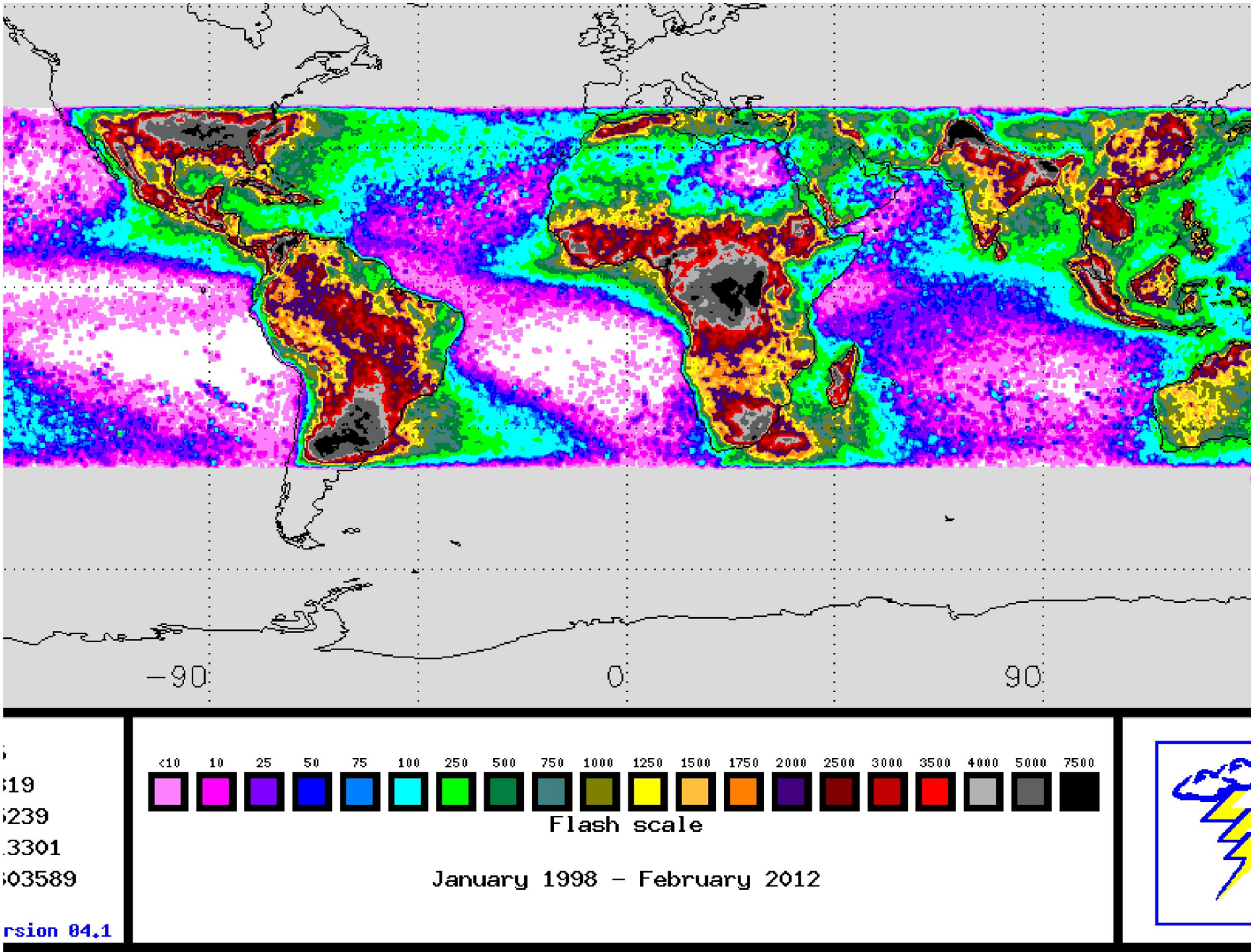
Development of thunderstorm

- The developments of thunderstorms over any region are mainly controlled by thermodynamic conditions such as CAPE and CINE.
- Moisture availability, Orogrphy , prevailing meteorological conditions and Aerosols also play important role in initiation and evolution of thunderstorm.

Geographical Distribution of Thunderstorms

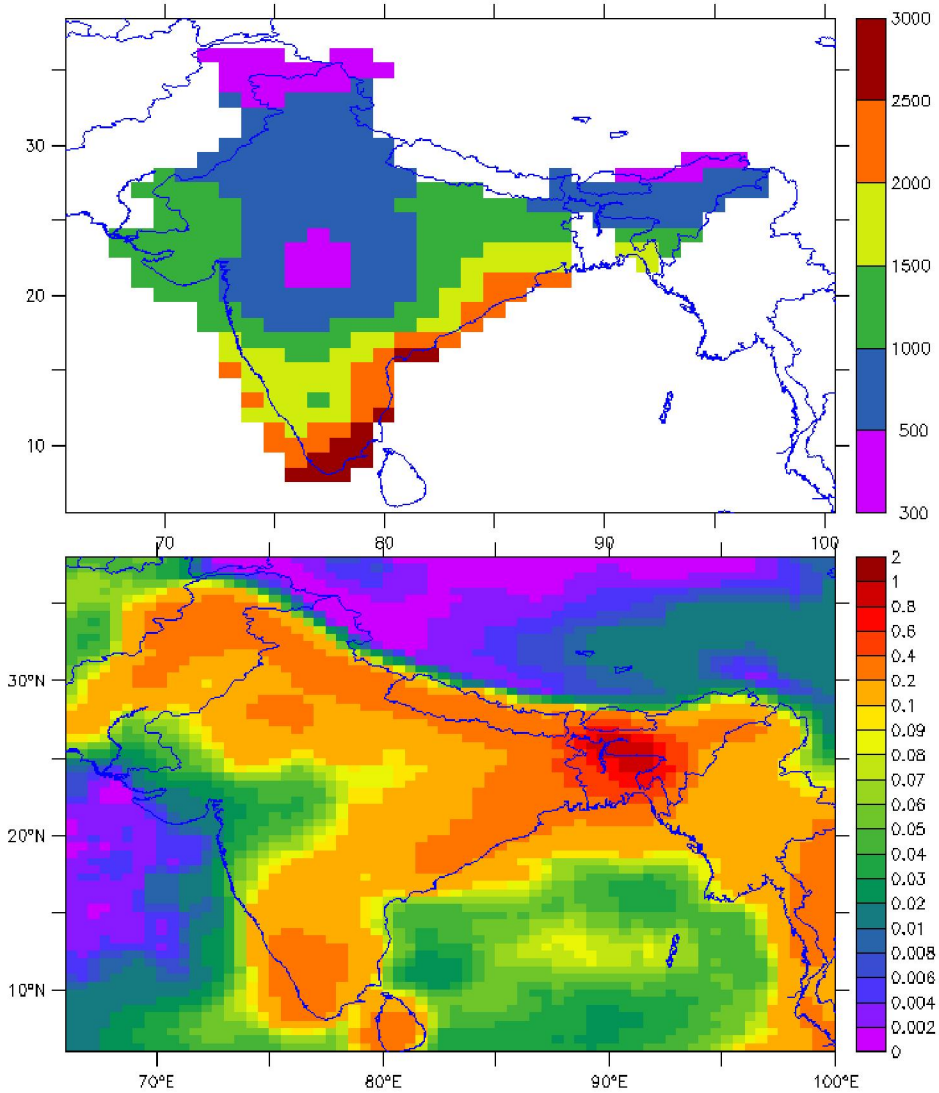
- About 2000 thunderstorms are active at any time all over the globe.
- Major regions – South Americas, Africa, Asia. Comparatively negligible activity over oceans.
- In India – maximum concentration in northeast India.
- Maximum activity in the afternoons.

Global lightning distribution



Climatology of Thunderstorms and CAPE over India

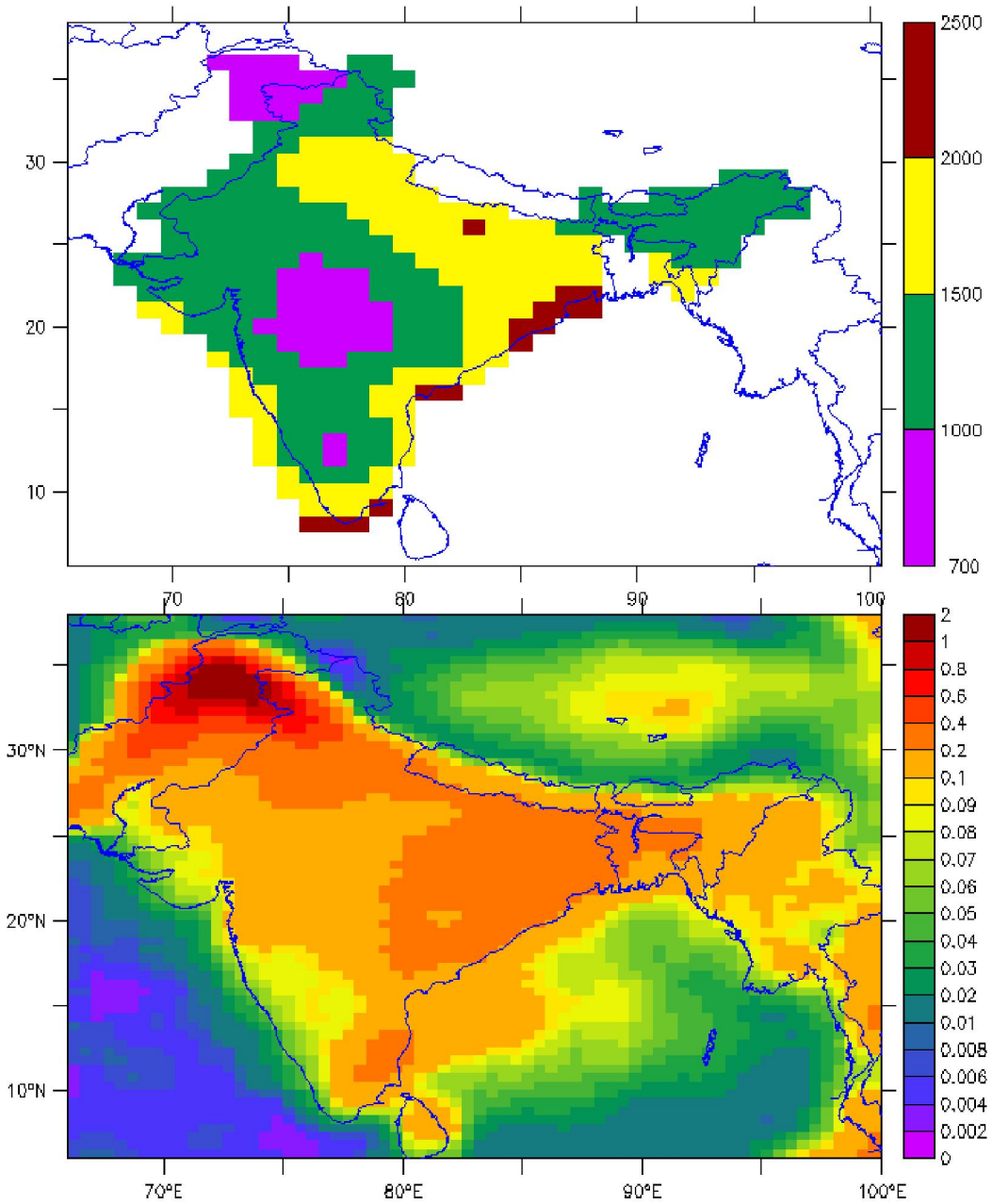
Pre-monsoon



CAPE

Lightning

Monsoon

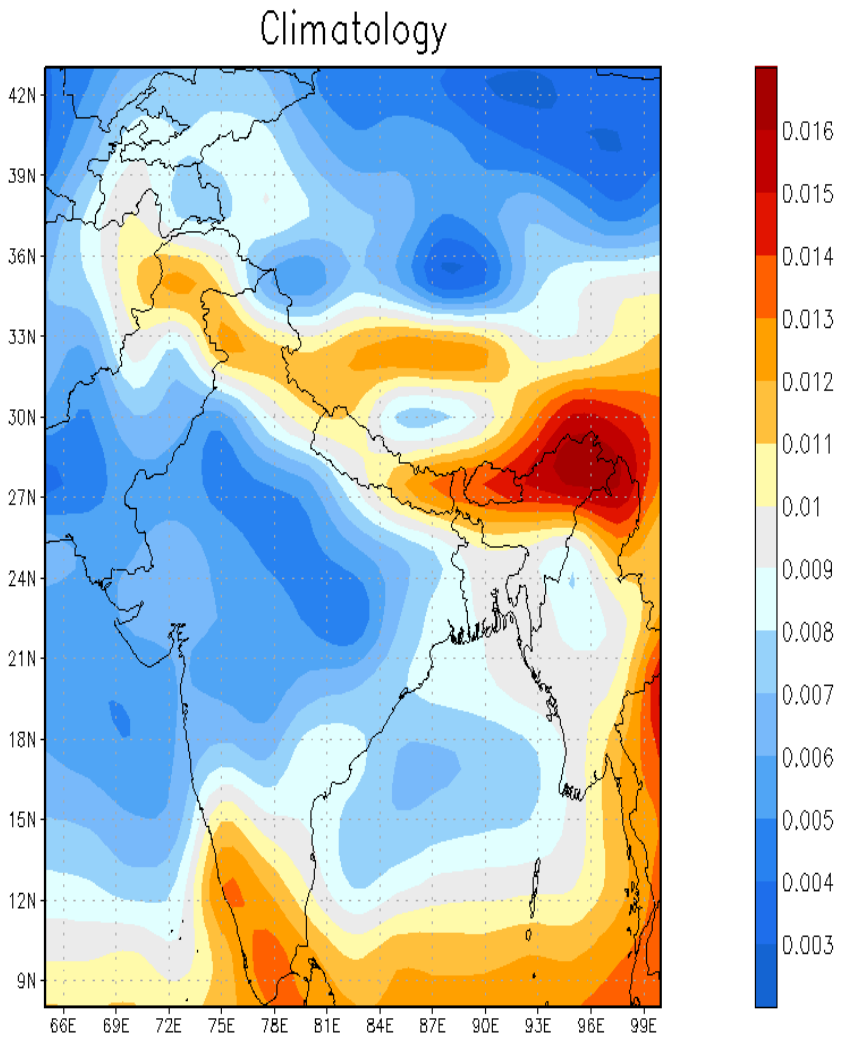


← CAPE

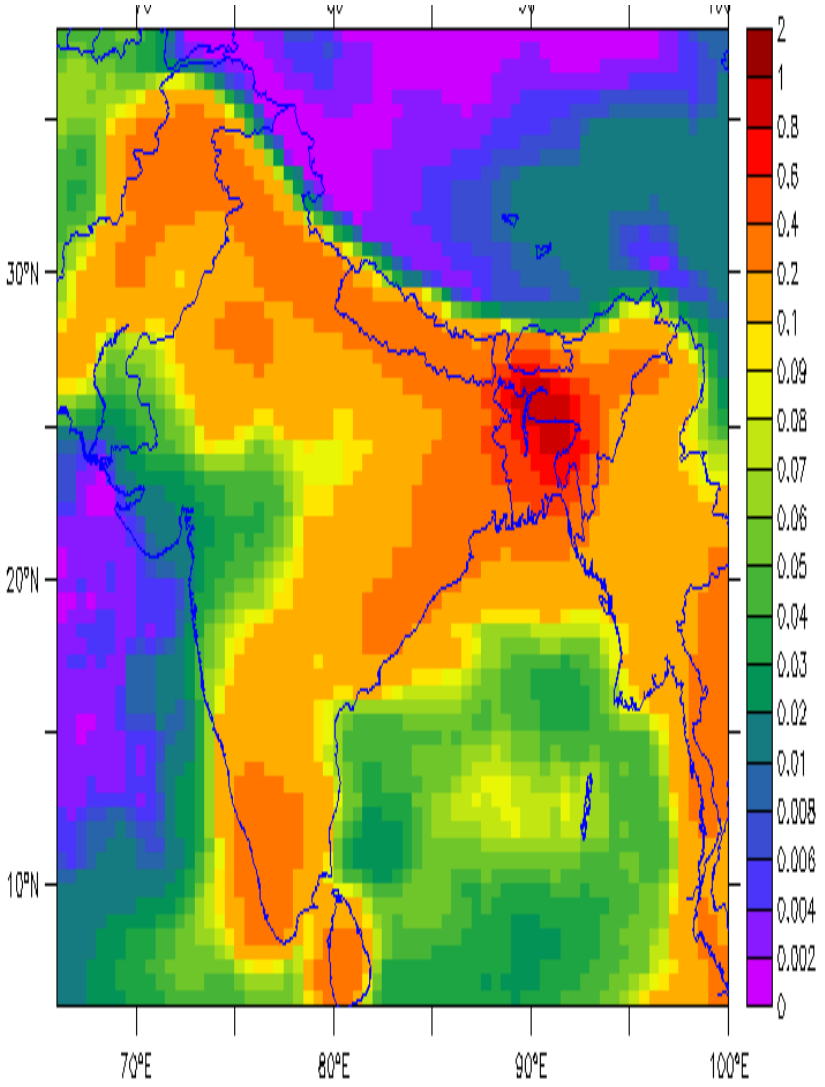
← Lightning

Specific humidity at surface

April



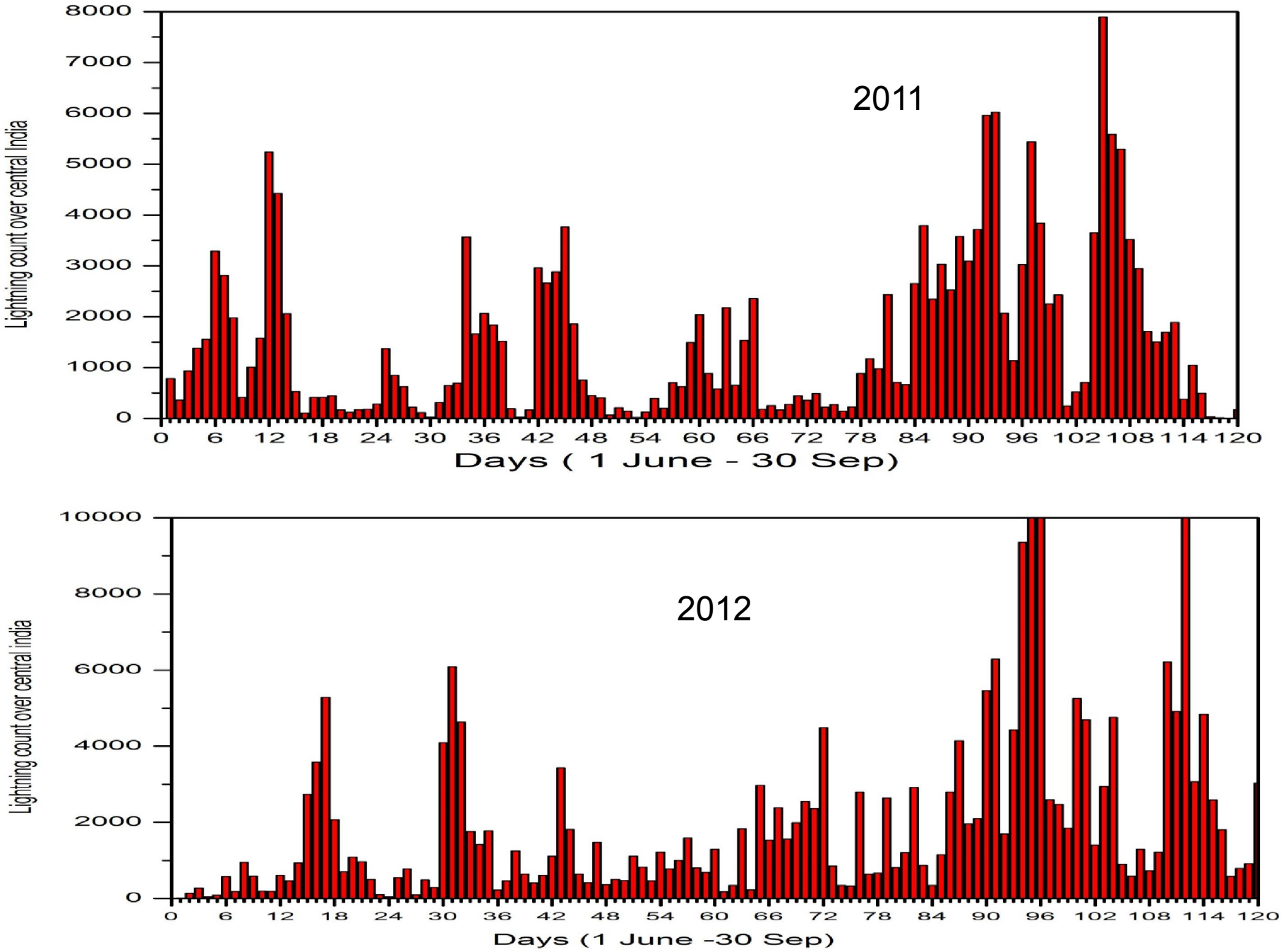
Premonsoon lightning



- During pre-monsoon moisture content dominates the thunderstorm activity rather than CAPE.

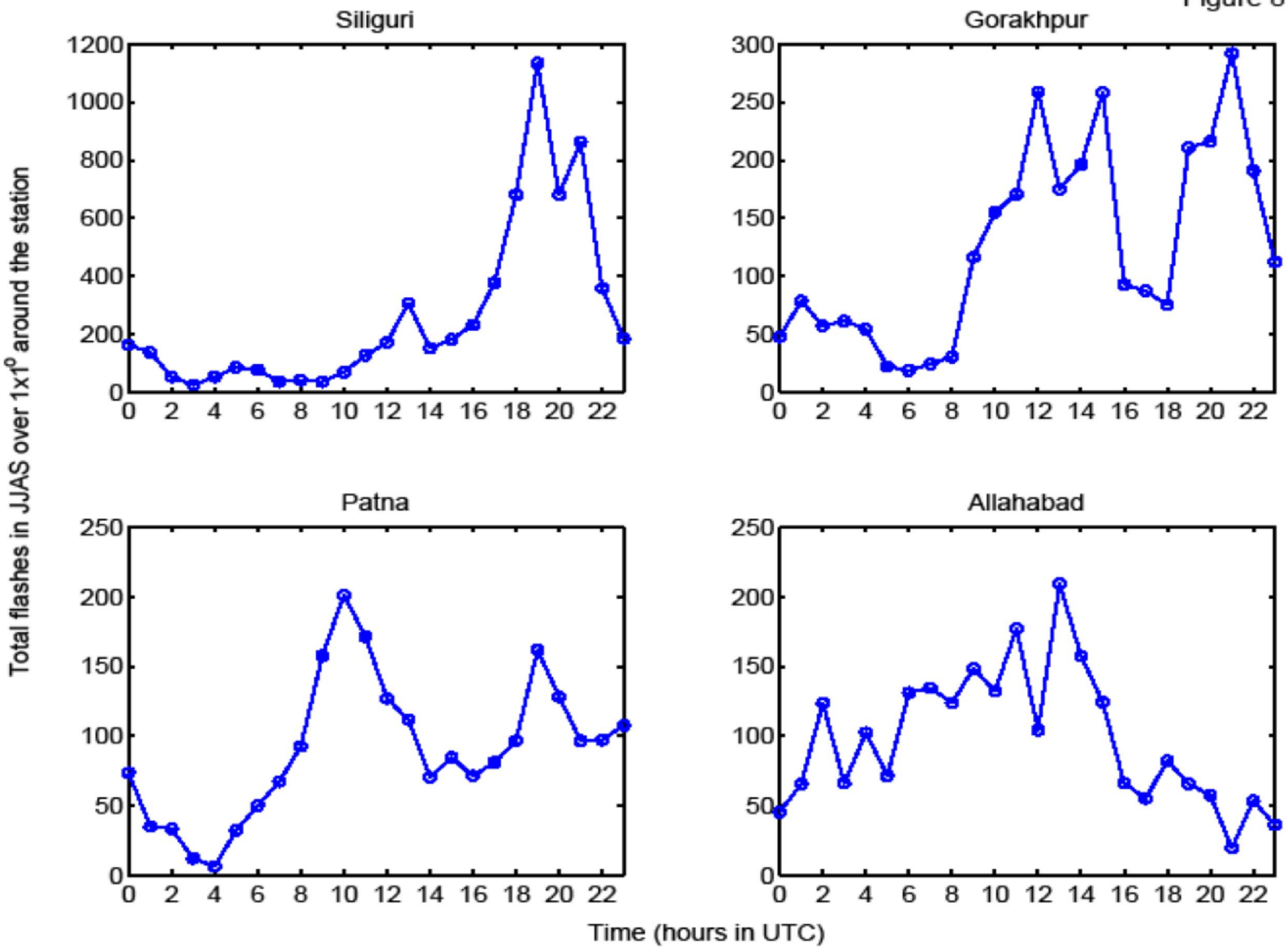
- During monsoon season, thunderstorm activity show good correlation with CAPE.

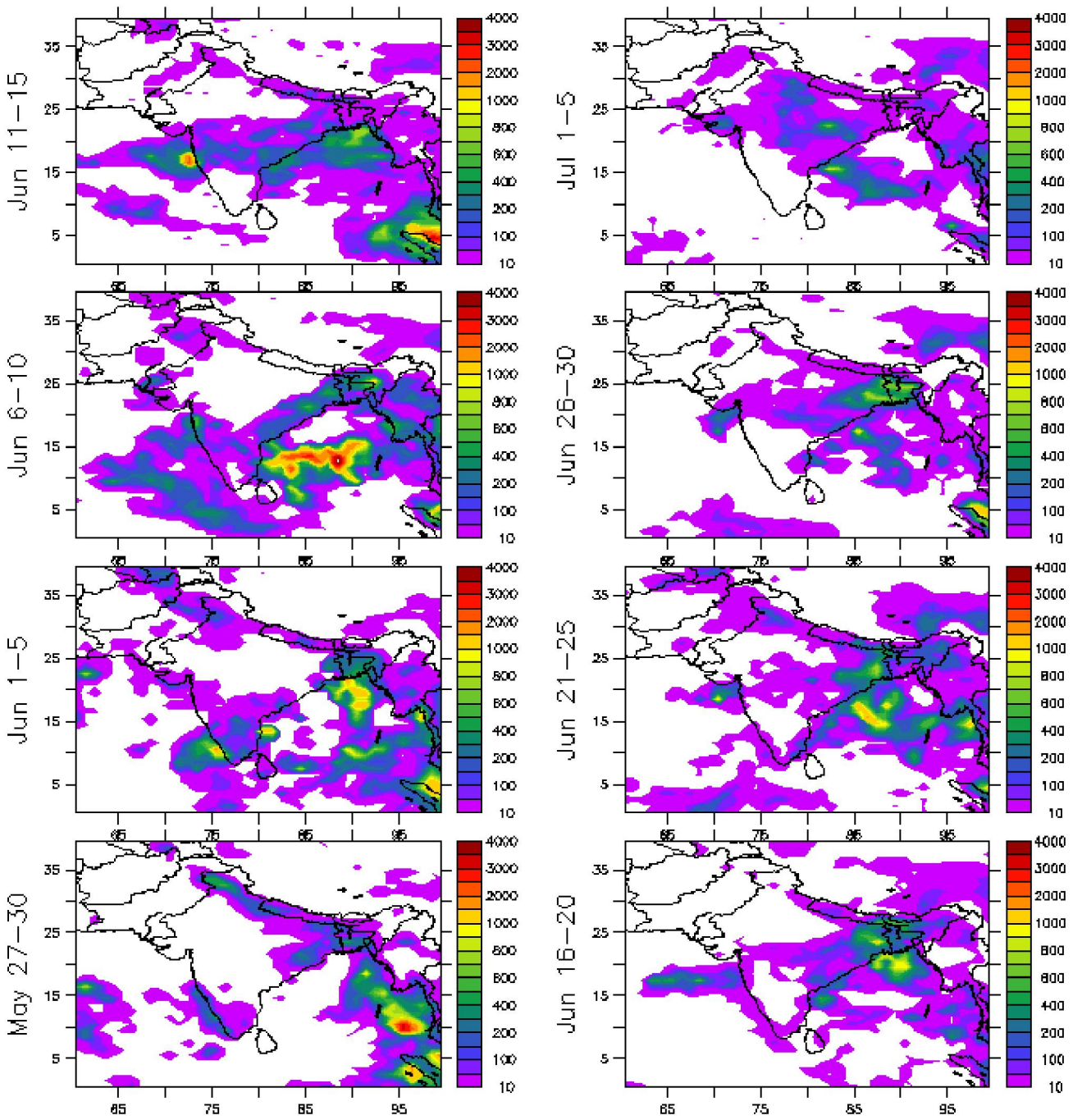
- Radiative cooling at mountain tops during night can generate moisture conversion at the foothills and trigger the deep convections.


2011
Lightning count over central India
Days (1 June - 30 Sep)
2012
Lightning count over central india
Days (1 June -30 Sep)

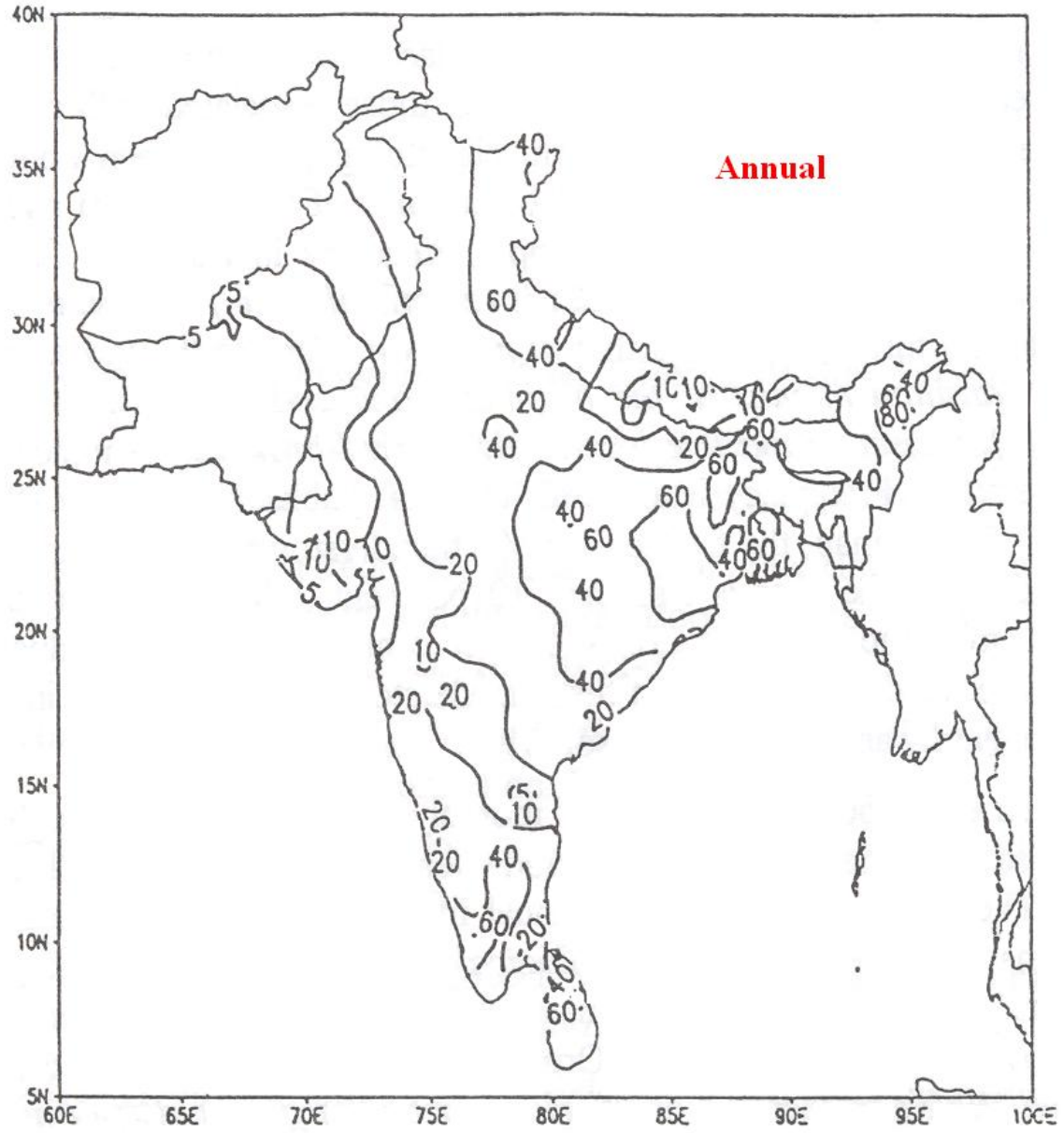
Diurnal variation of lightning

Figure 8



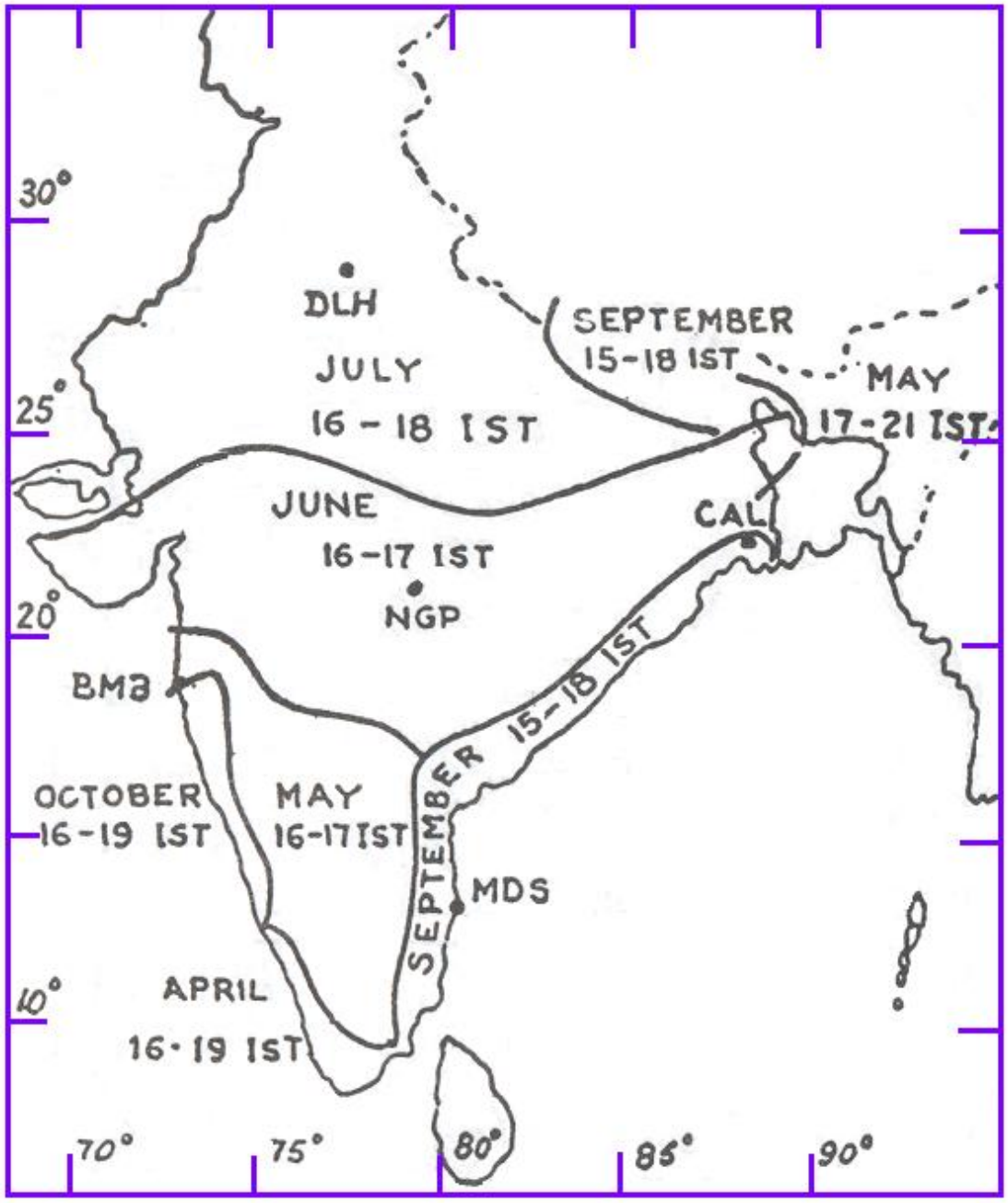


Lightning activity during monsoon progress over India (2010)



Mean annual number of thunderstorms in India and neighborhood

(After Pant and Rupa Kumar,1996).



Month and timing of maximum thunderstorm activity.

Electrical structure of thunderclouds

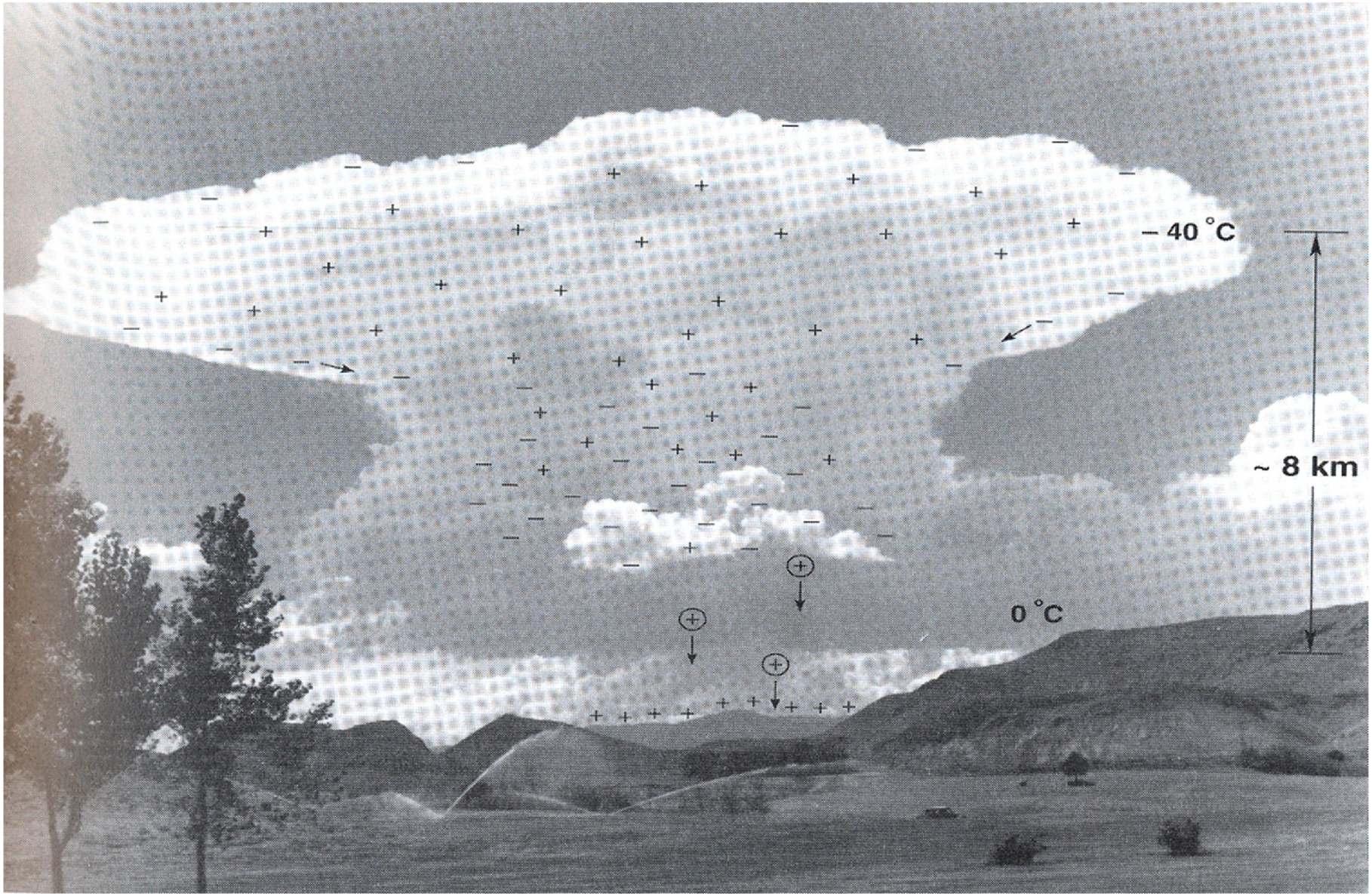
Tripole charge structure

Three charging regions

1. Upper positive charging region

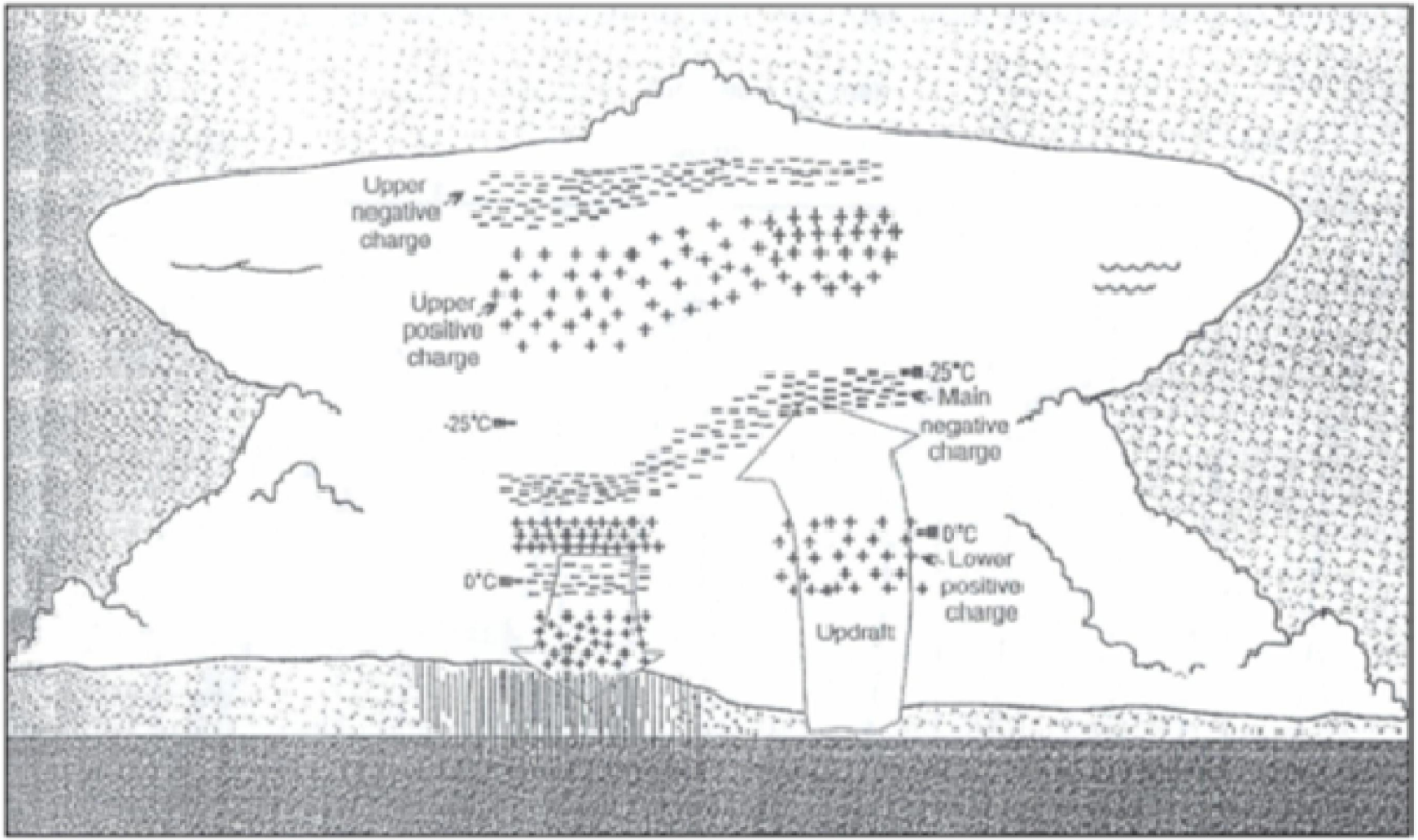
2. Main negative charge region

3. Lower positive charge centers.



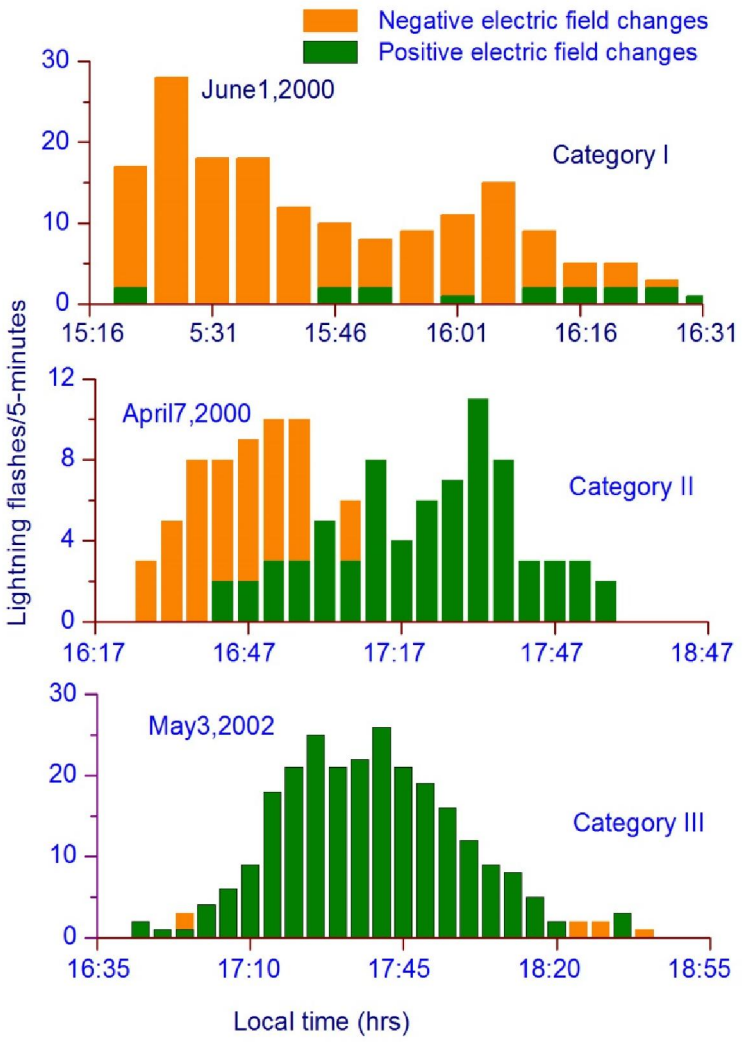
An isolated thunderstorm in central New Mexico, with a rudimentary indication of how electric charge is thought to be distributed inside and around the thundercloud, as inferred from the remote and in *situ* observations. Adapted from Krehbiel (1986).

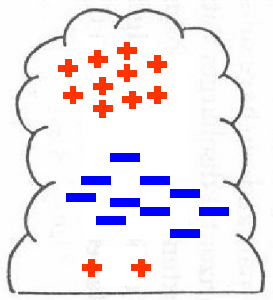
Mesoscale convective system

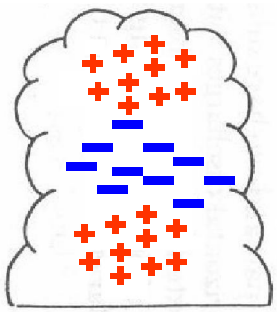


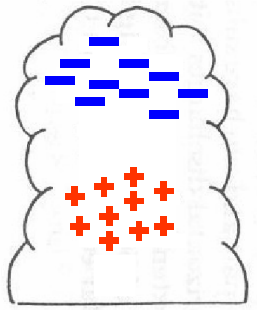
Electrical structure of Pune Thunderstorms

- Category I - Positive dipole (normal)
- Category II – Tripole
- Category III Negative dipole (inverted)







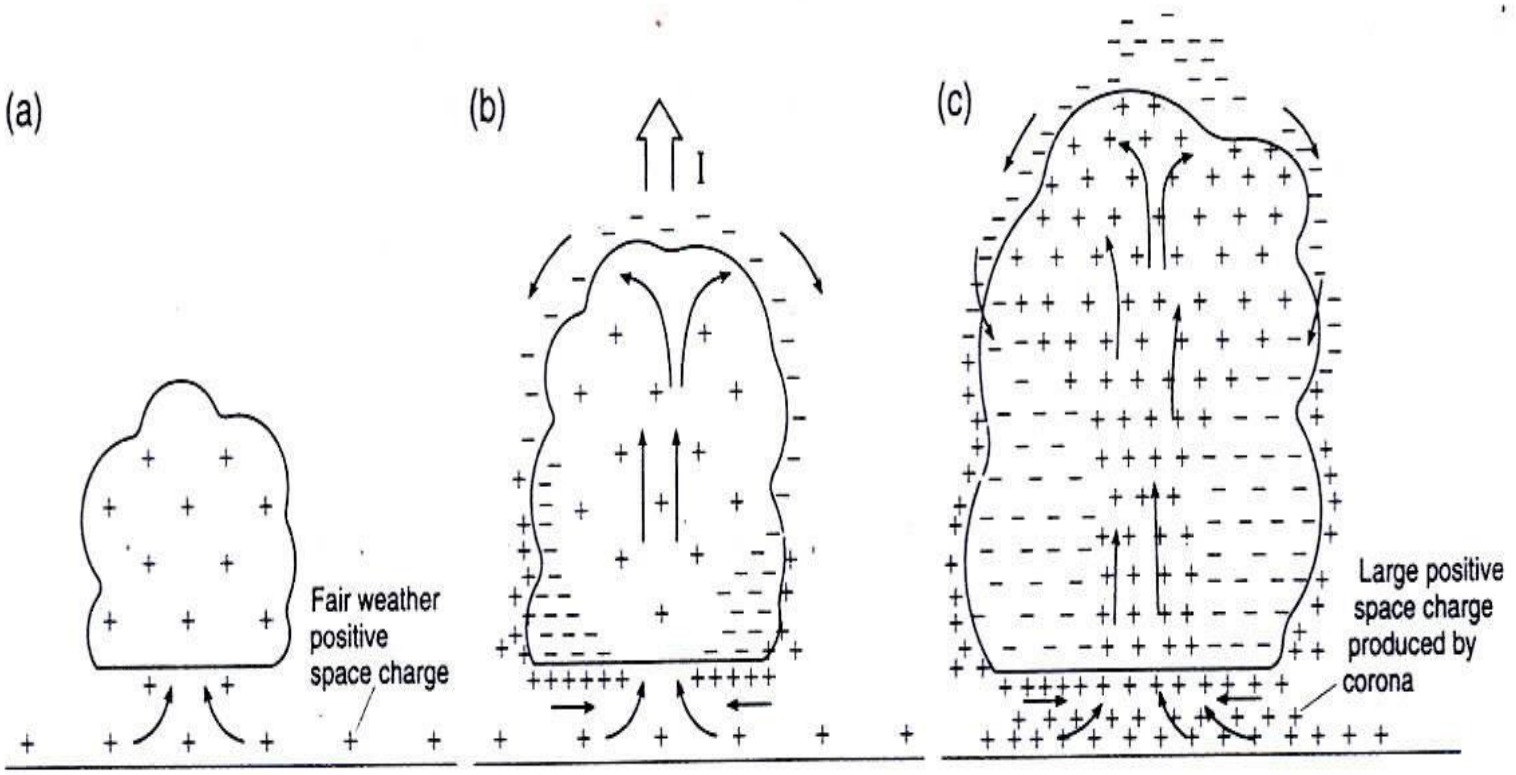


Pawar and Kamra JGR (Atmosphere) 2009

Charging Mechanisms

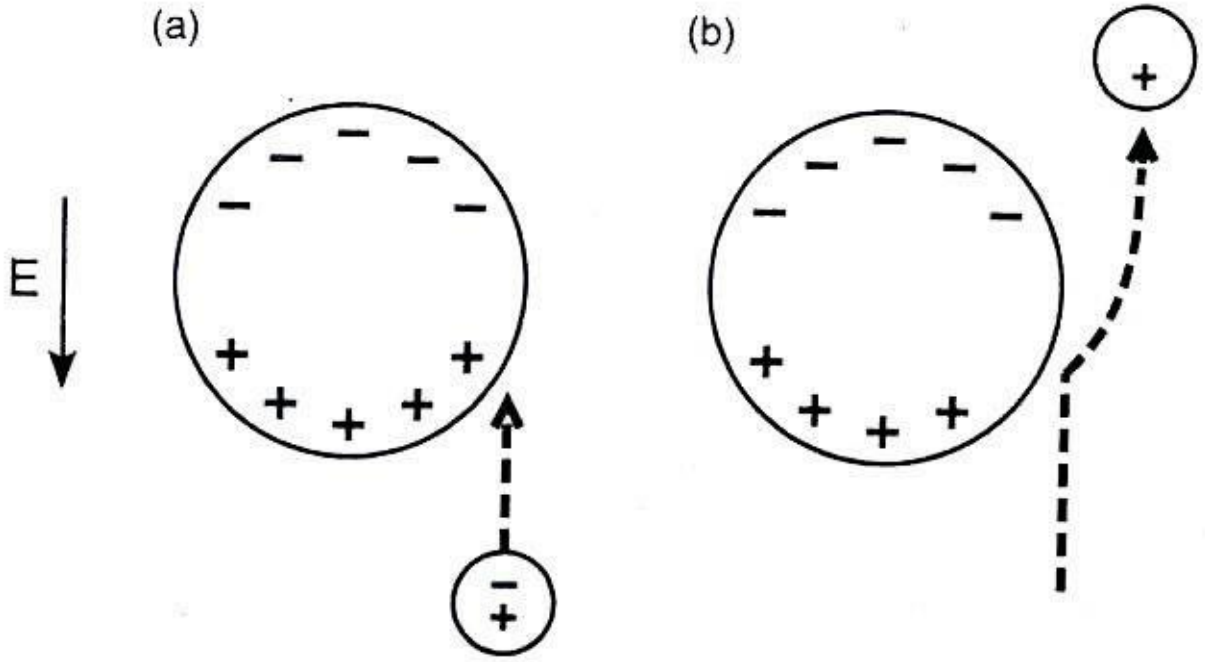
1. Convective
2. Inductive
3. Non inductive

Convective mechanism



- According to convective charging mechanism a growing cumulus cloud draws positive charge from beneath the cloud base and it is carried up in the updraft. This positive charge is carried to a region near the cloud top where negative ions from surrounding atmosphere are attracted toward cloud and get trapped on cloud particles in its boundary layer and form the screening layer. The negative charge in the screening layer is then transported down with the downward motion of screening layer and accumulates in the lower portion of the cloud.

Inductive mechanism

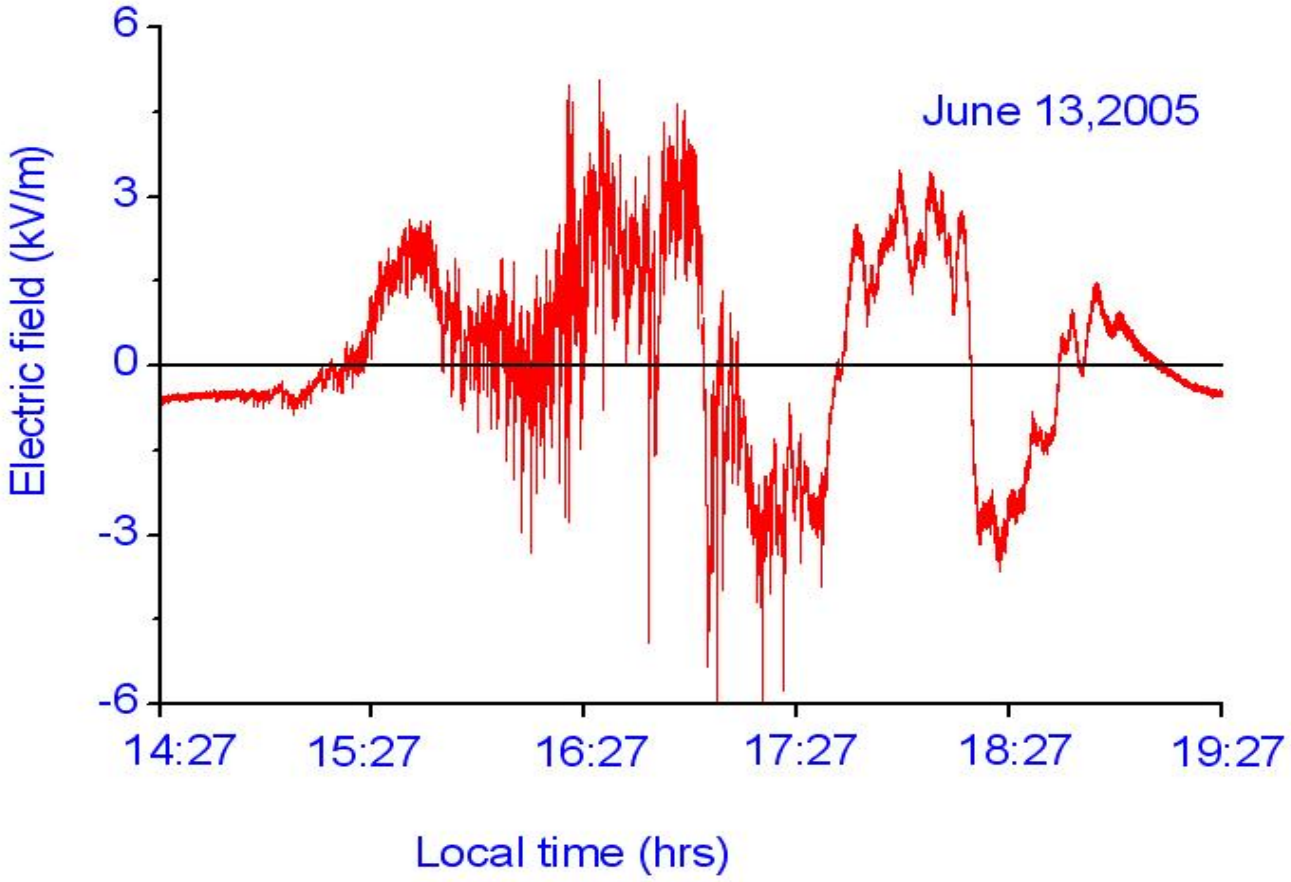


- The inductive charging mechanism is based on the existing vertical electric field to induce polarization charges in cloud particles. The collisions occurring between the falling larger cloud particles and the up-going smaller particles, transfer positive charge to small particles and negative charge to large particles. Vertical separation of large and small particles due to their differential terminal velocity under gravity then creates the positive electrical dipole in cloud.

Non-inductive charging mechanism

- These charge generating processes occur during particle collisions in which charge is transferred from one particle to other, independent of the local electric field strength. In thunderstorms, such charge transfer process leads to the observed vertical dipole when the oppositely charged particles separate under gravity.

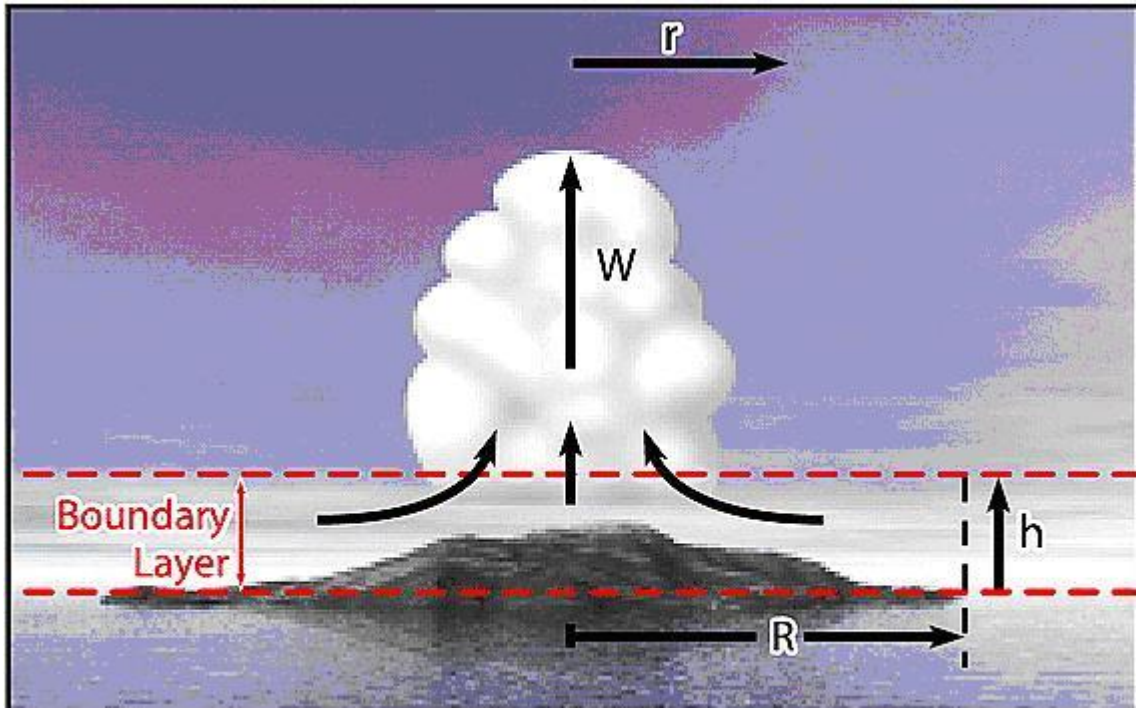
Electric field: Polarity and Magnitude



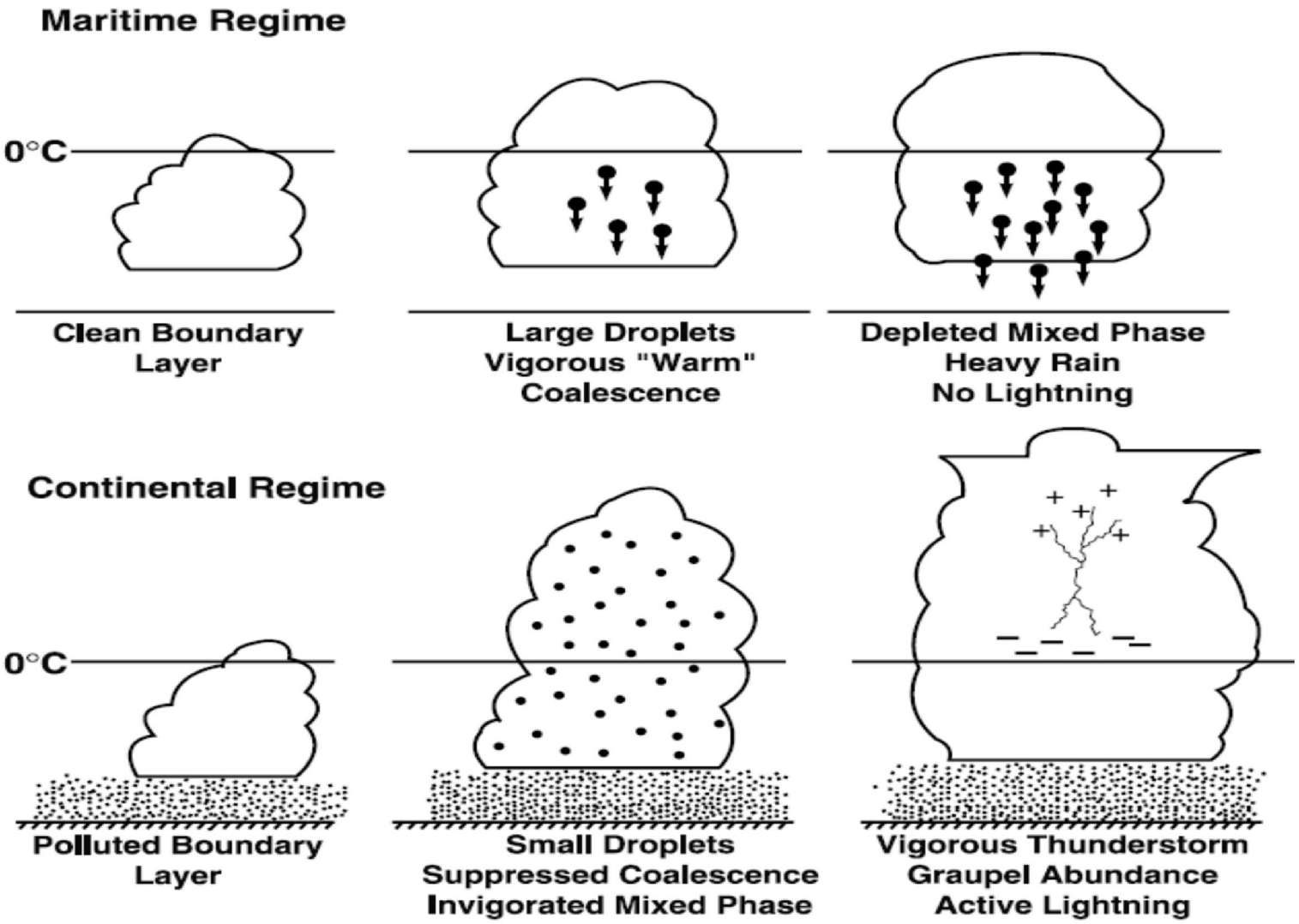
Effect of Aerosols on Lightning

Enhancement in lightning activity over big cities

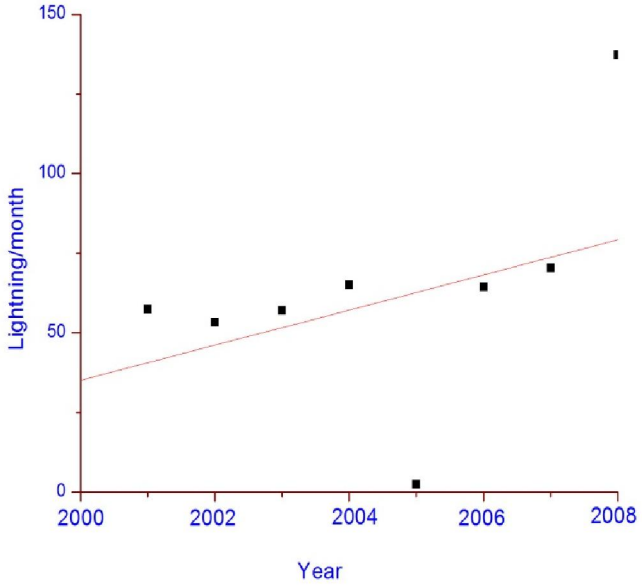
- Thermal Hypothesis

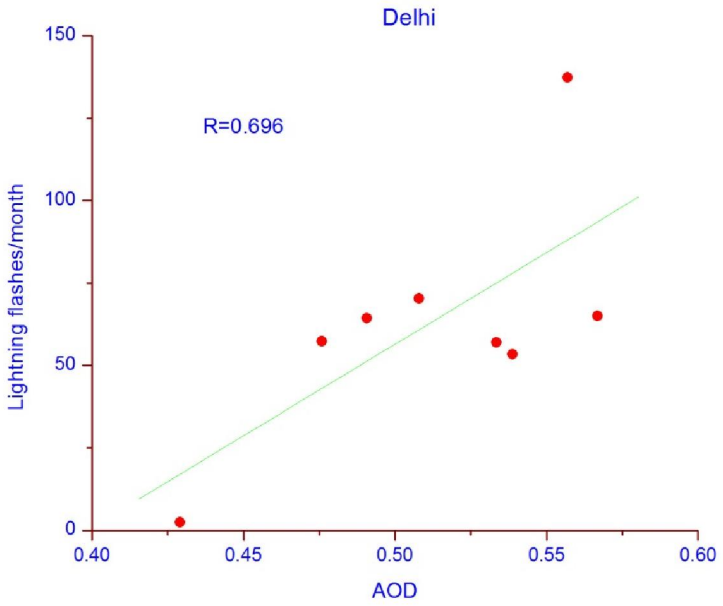


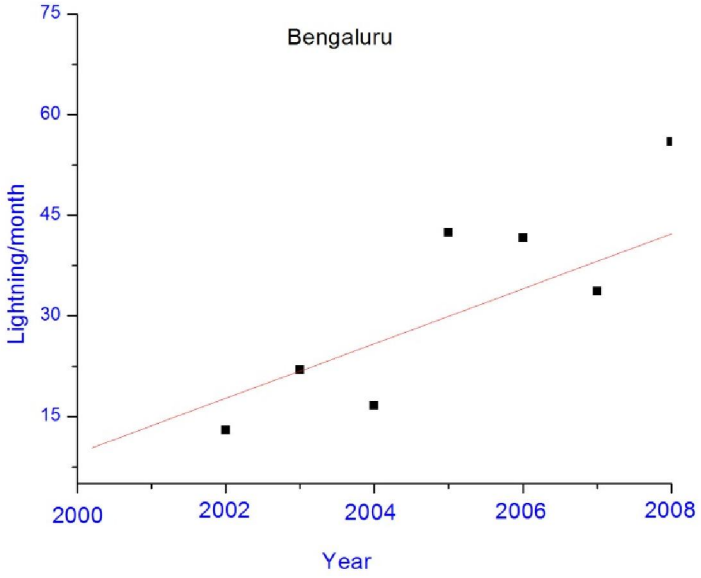
Aerosol Hypothesis

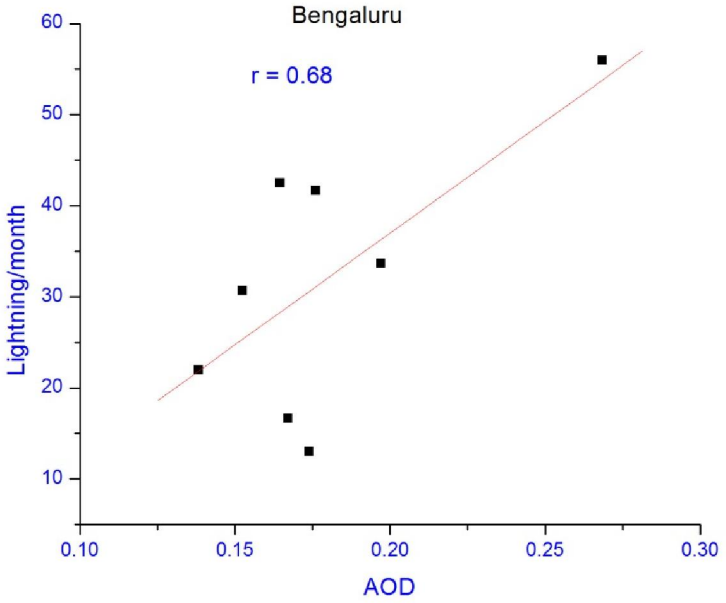


Lightning and Aerosols

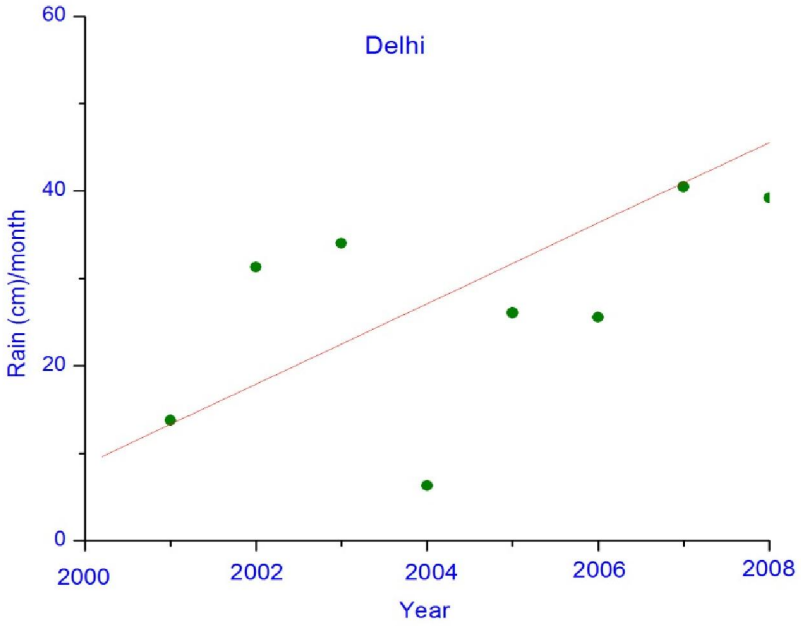


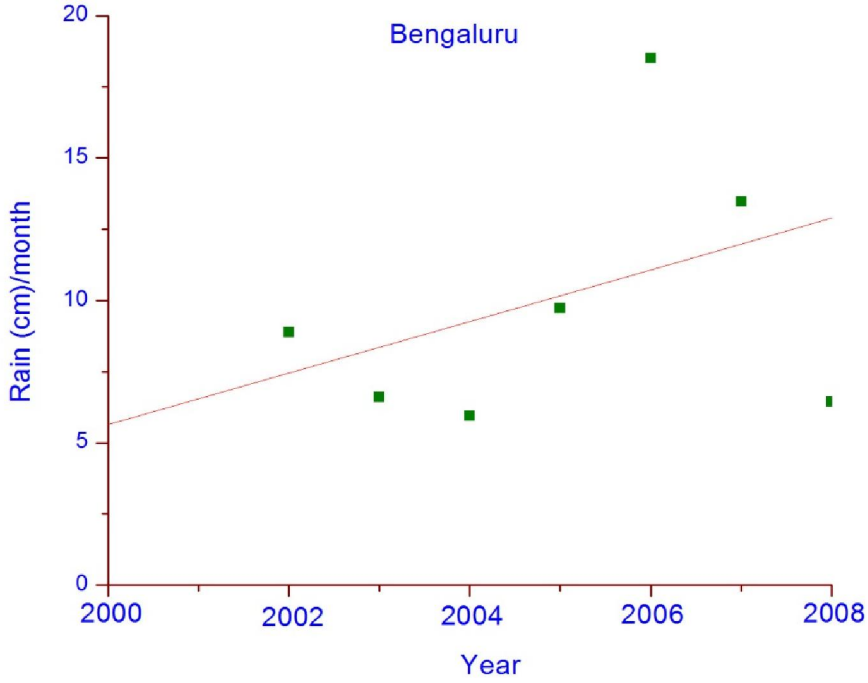






Rain



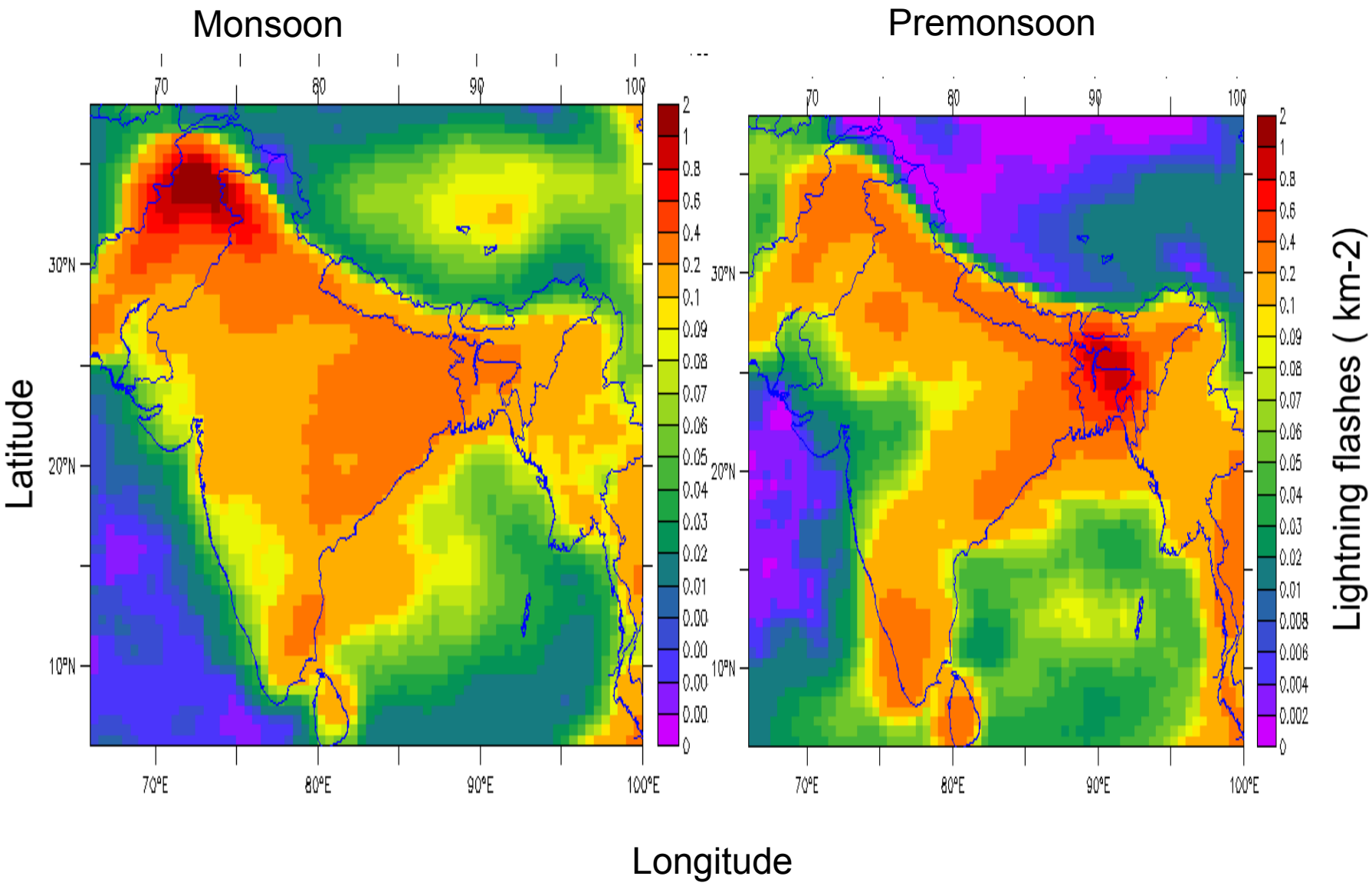


Both thermal and aerosol hypothesis are playing important role in lightning enhancement in big cities .

Aerosols show good positive correlation with lightning.

Effect of orography on lightning

Lightning Climatology over India



Types of Lightning

- About 100 discharges occur all over the globe and approximately 1/3rd of them strike the ground every second.

- 2/3 of the global lightning activity occurs in tropics.

i) **Intra-cloud discharges**

ii) **Cloud-to-ground discharges**

iii) **Cloud-to-ionosphere discharges**

(sprites, elves, blue jets)

Polarity of Charge

- Cloud-to-ground discharges mostly bring negative charge to ground – negative discharges.

- Positive discharges not uncommon, involve more energy and, perhaps, initiate cloud-to-ionosphere discharge.

Structure of cloud-to-ground discharges

i) Stepped leader

ii) Return stroke

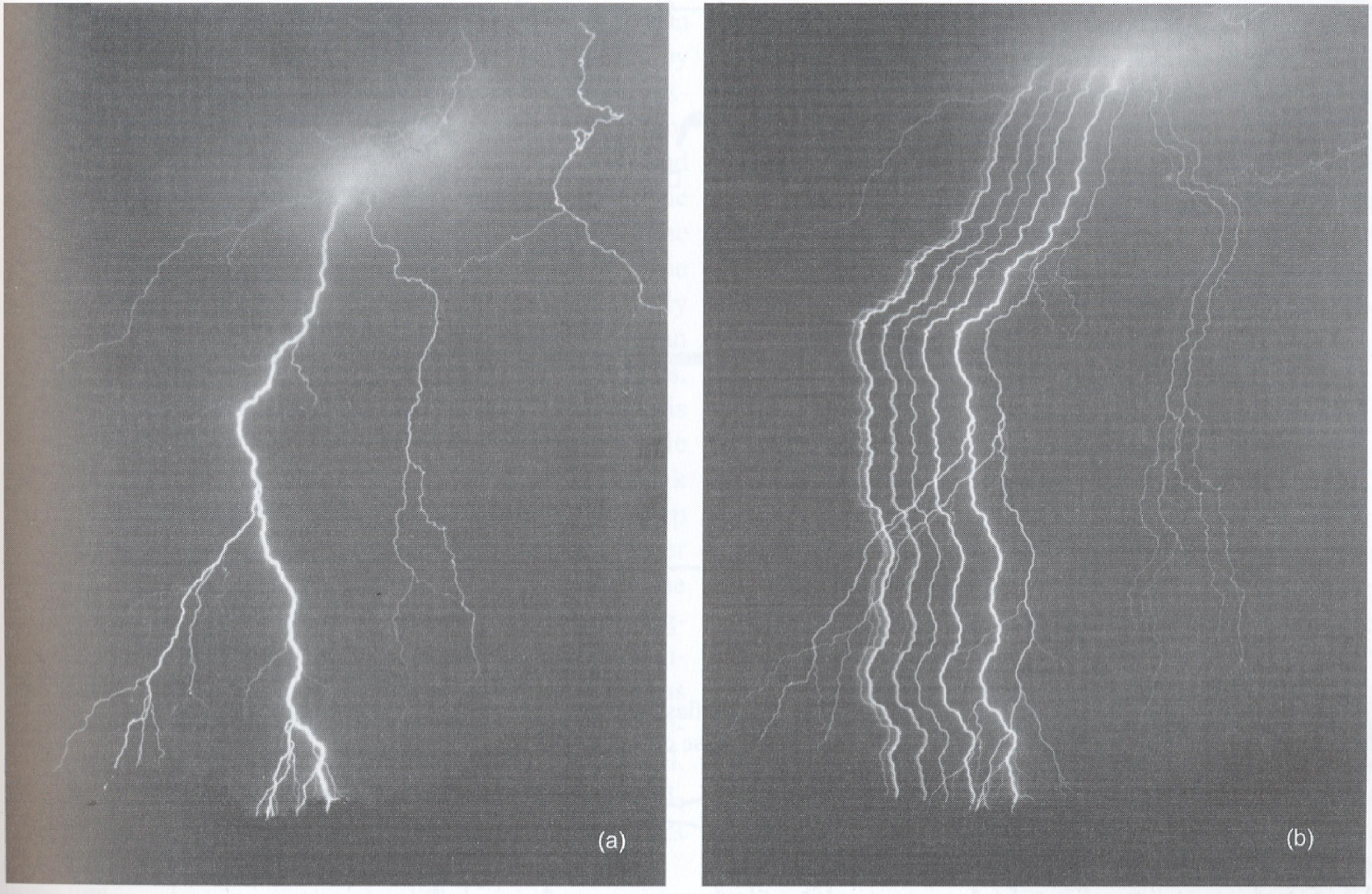
iii) Dart leader

(a) Strokes – up to 26 observed

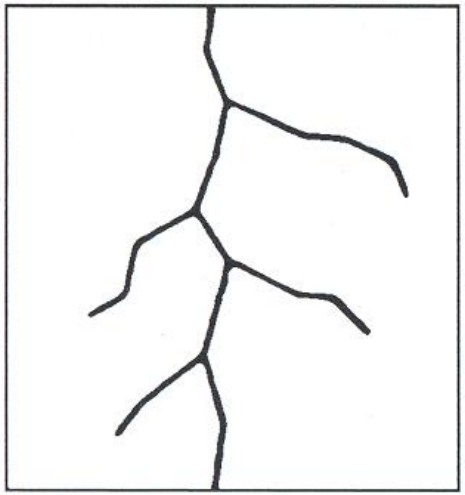
(b) Streamers from ground objects

(c) Junction process

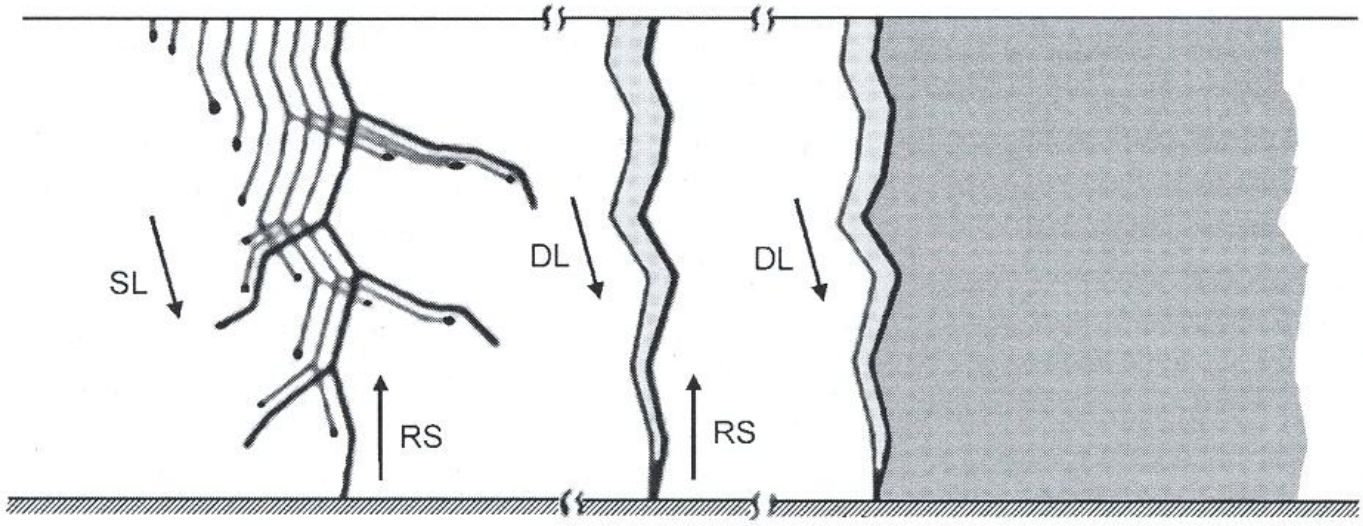
(d) Continuing currents – 100-200A for ~ 100s.



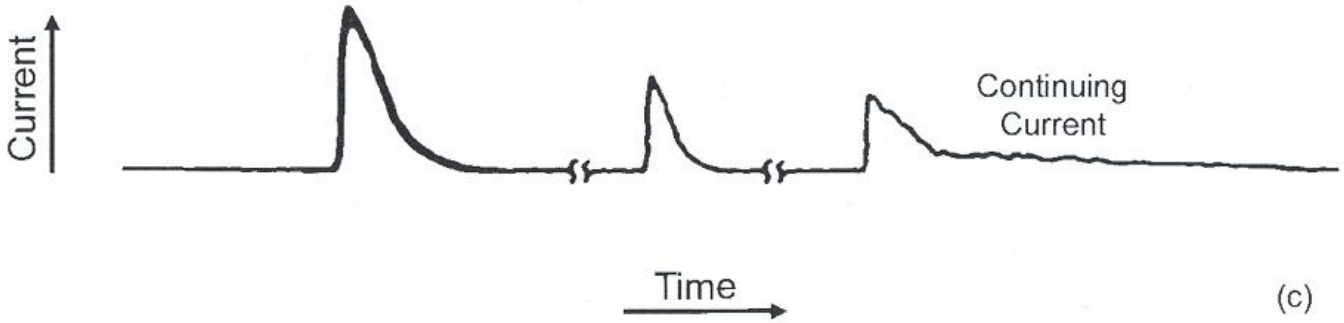
A lightning flash that appears to have at least seven (perhaps as many as 10) separate ground strike points: (a) still-camera photograph, (b) moving-camera photograph. Some of the strike points are associated with separate branches of the same stroke while others are associated with the fact that different strokes may take different paths to ground. The first and the second strokes exhibit unconnected branches. The second and the third strokes, second and third from the right on the streaked photograph, are brighter than the first stroke, on the far right. Adapted from Hendry (1993).



(a)

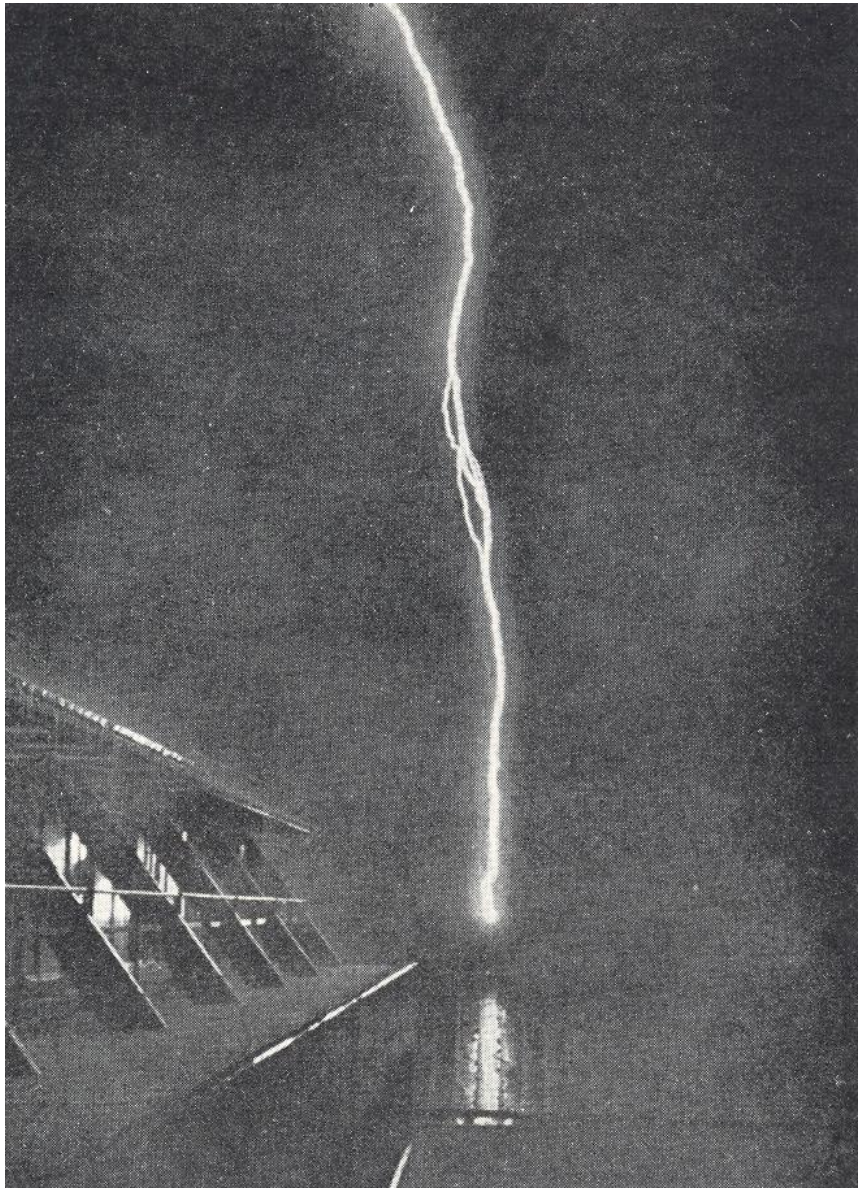


(b)



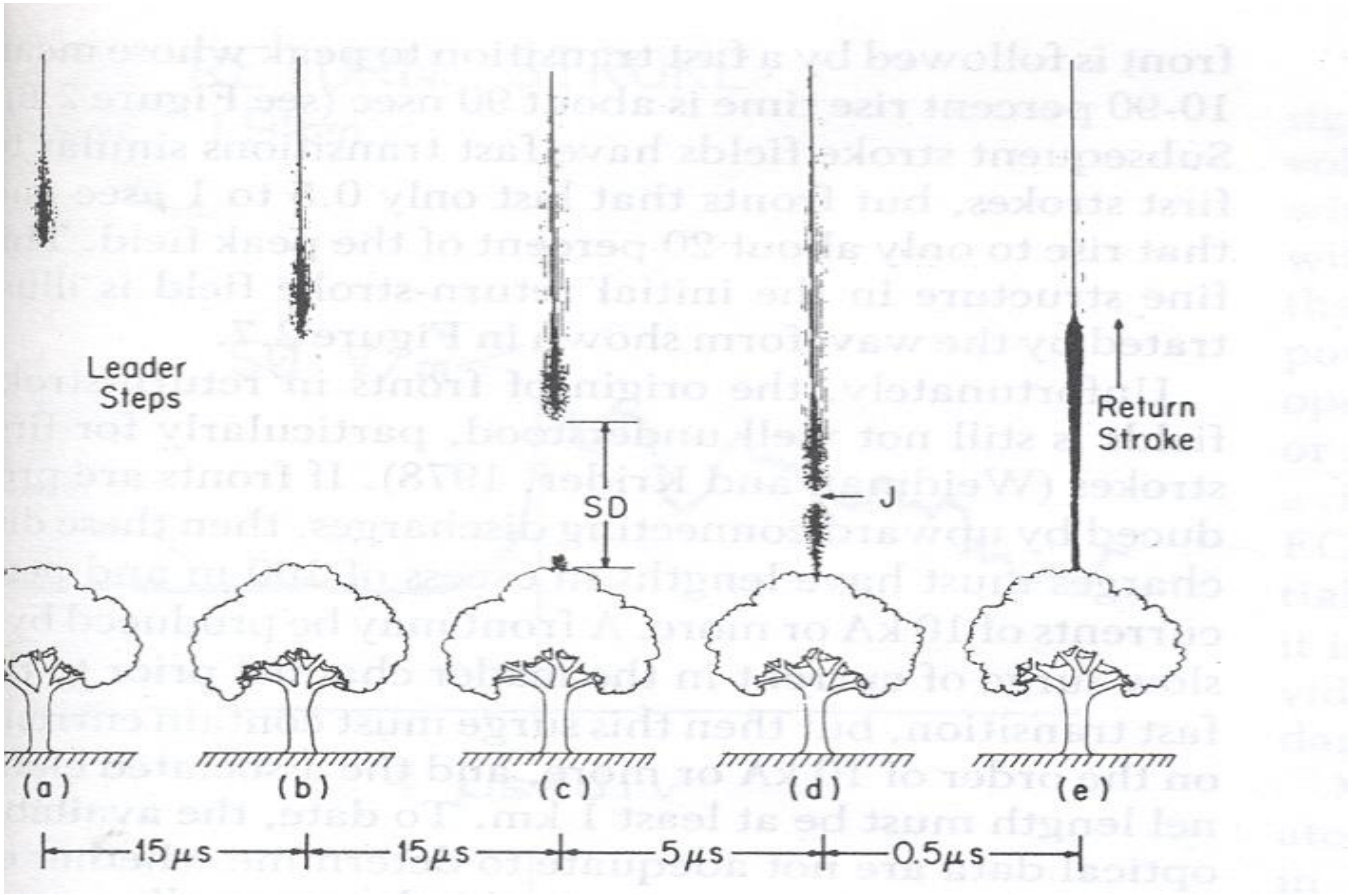
(c)

Diagram showing the luminosity of a three-stroke ground flash and the corresponding current at the channel base: (a) still-camera image, (b) streak-camera image, and (c) channel-base current.

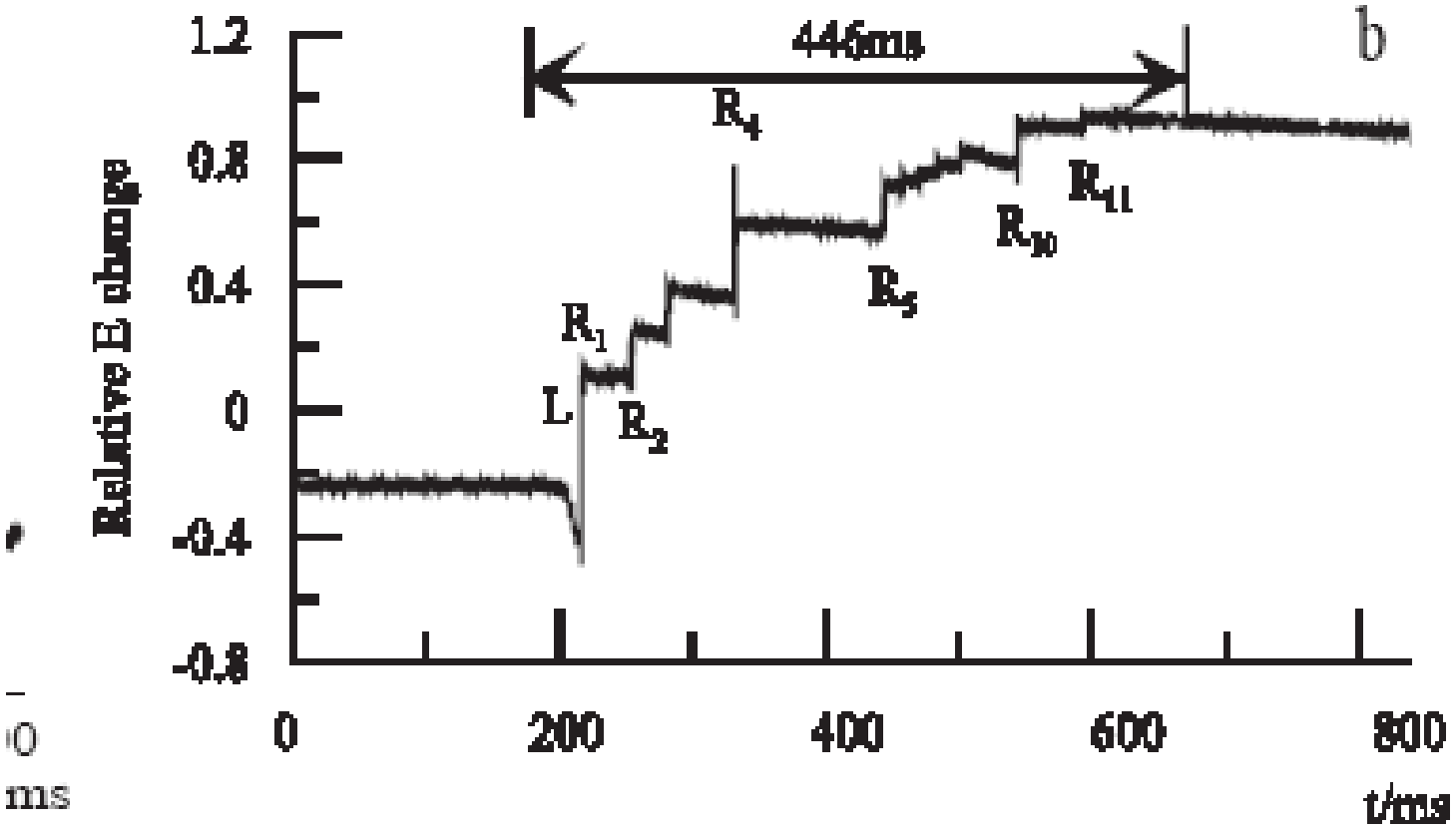


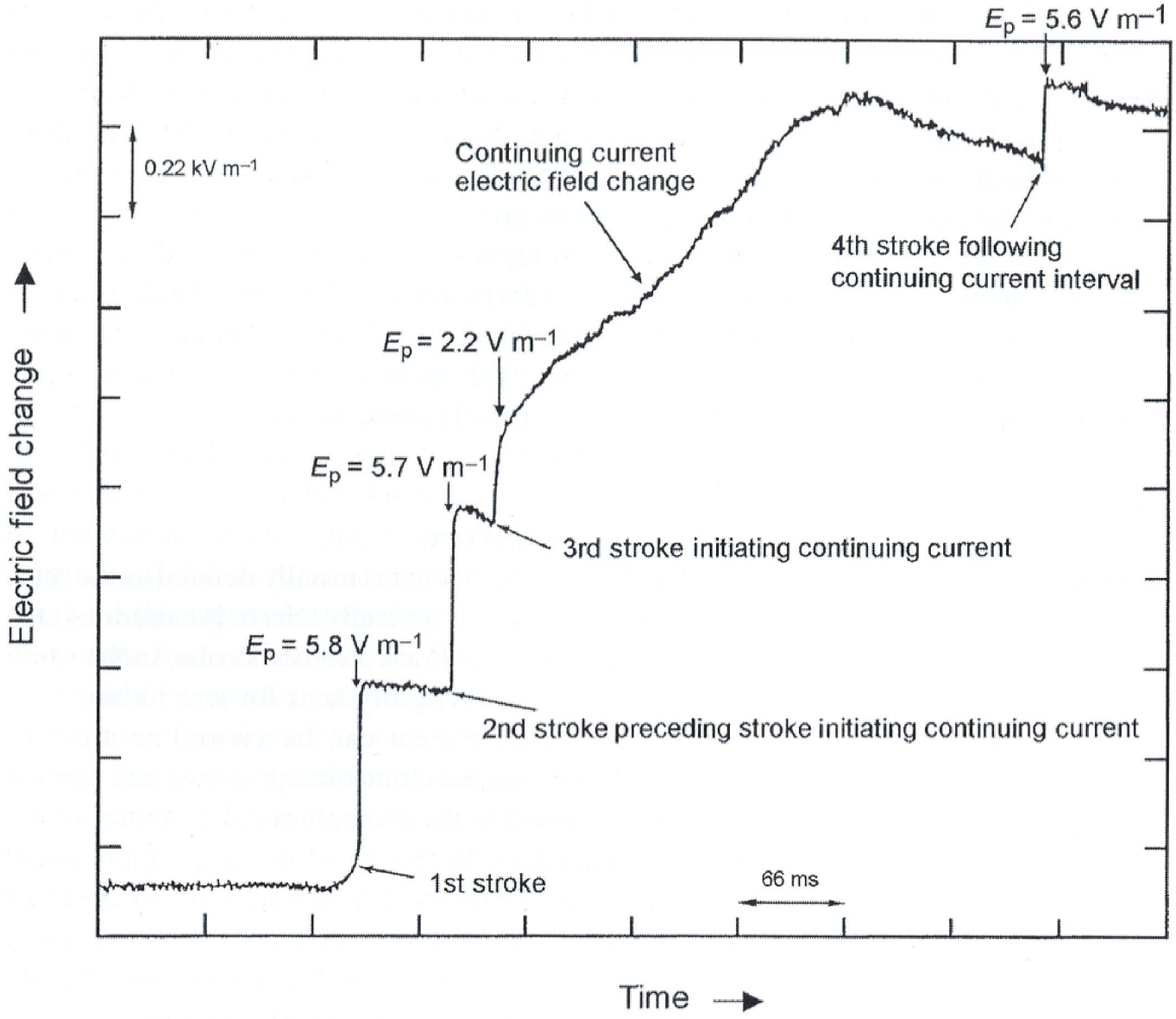
Lightning stroke to chimney pot showing meeting point between downward leader and upward streamer.

Cloud-to-Ground lightning discharge



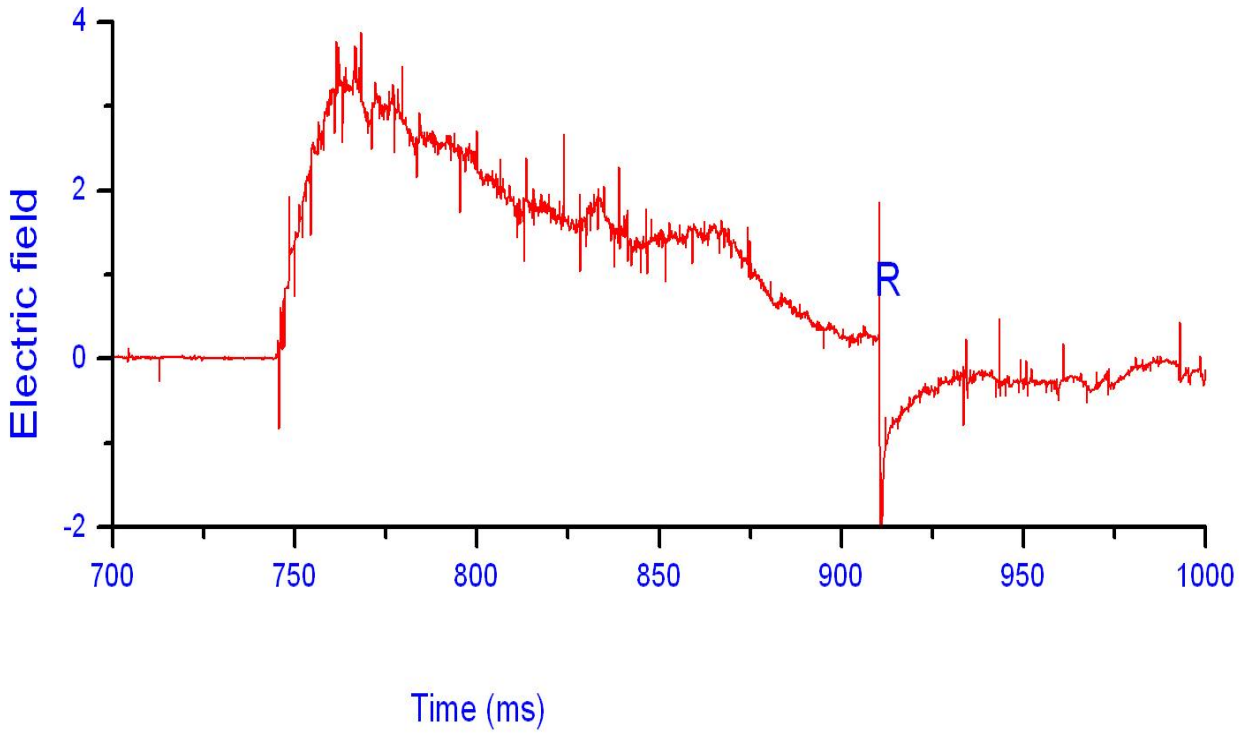
Electric field change produced by Negative CG





Overall electric field change for a four-stroke flash with a long continuing current following the third stroke. The flash occurred in Florida on 27 July 1979 at 2240:14 UT and at a distance of 6.5 km. Microsecond-scale initial electric field peaks are not resolved in this figure, but their values E_p (normalized to 100 km) are given. A positive electric field change (atmospheric electricity sign convention, subsection 1.4.2) deflects upward. Adapted from Rakov and Uman (1990a).

Electric field change produced by positive CG



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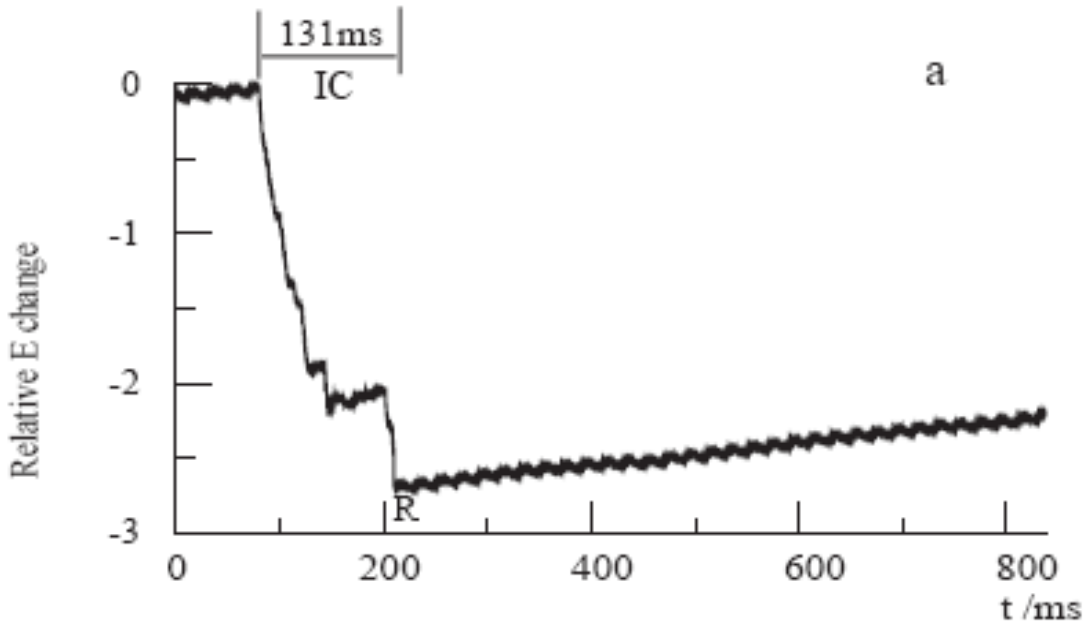
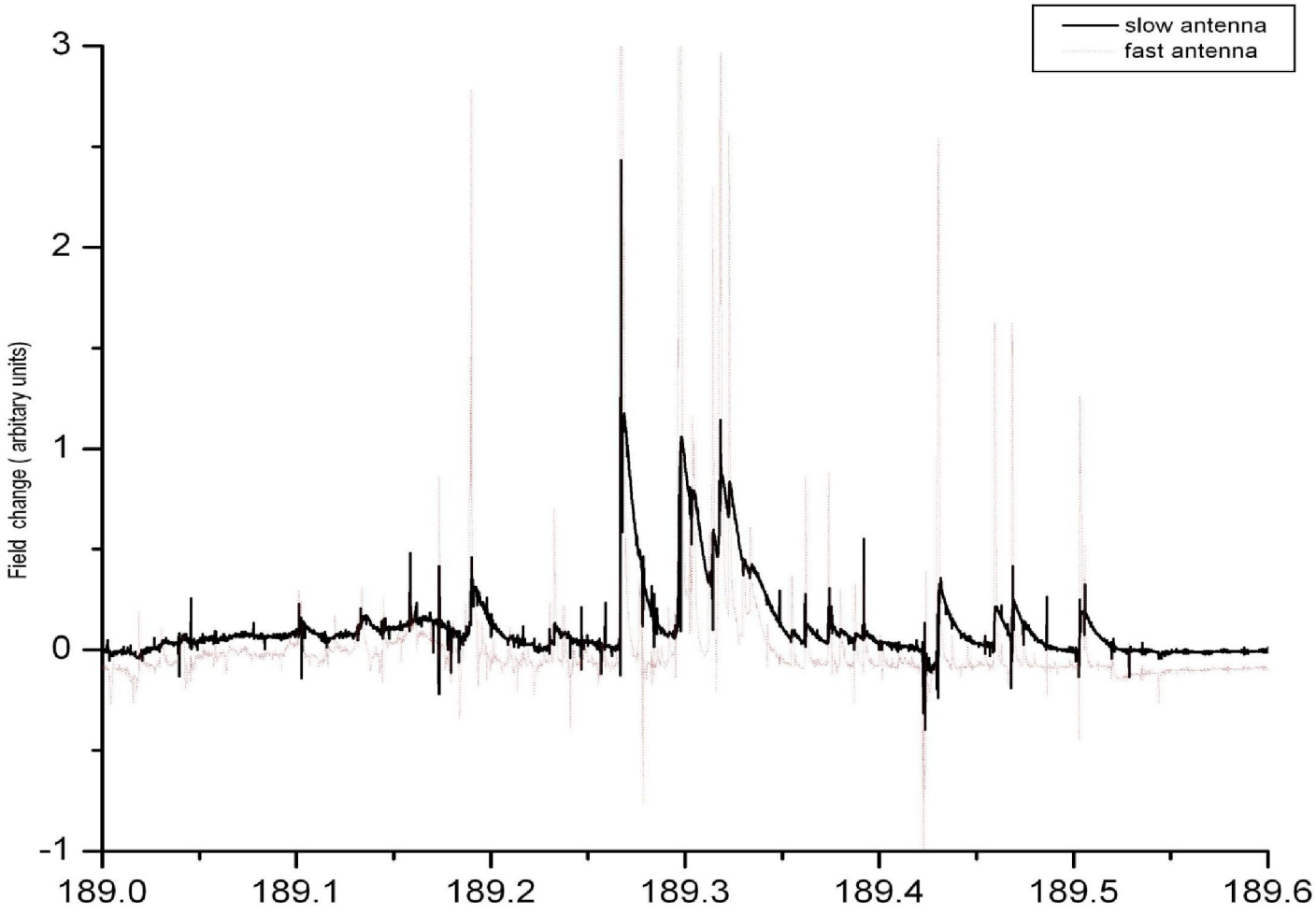
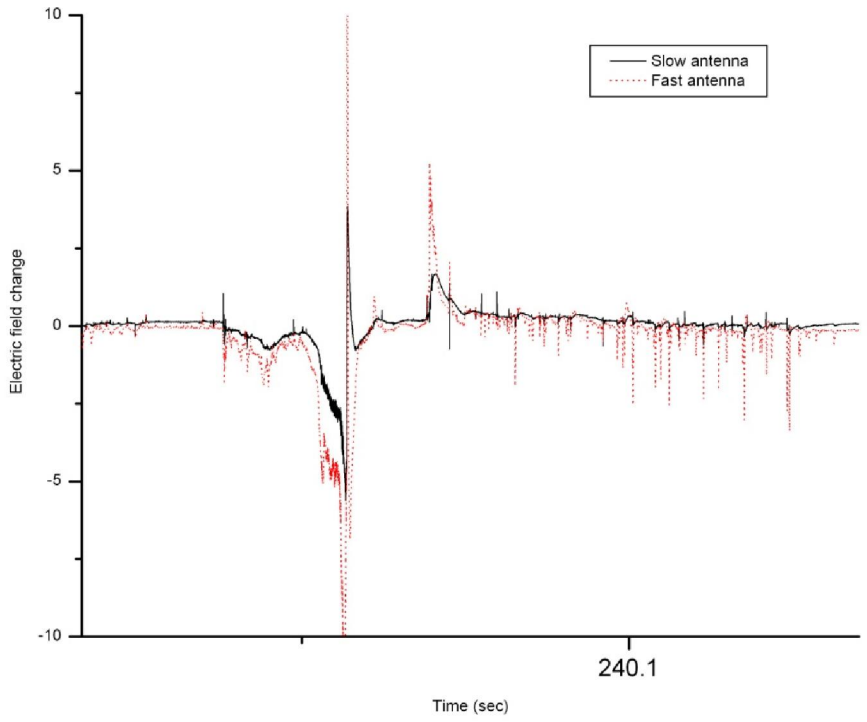


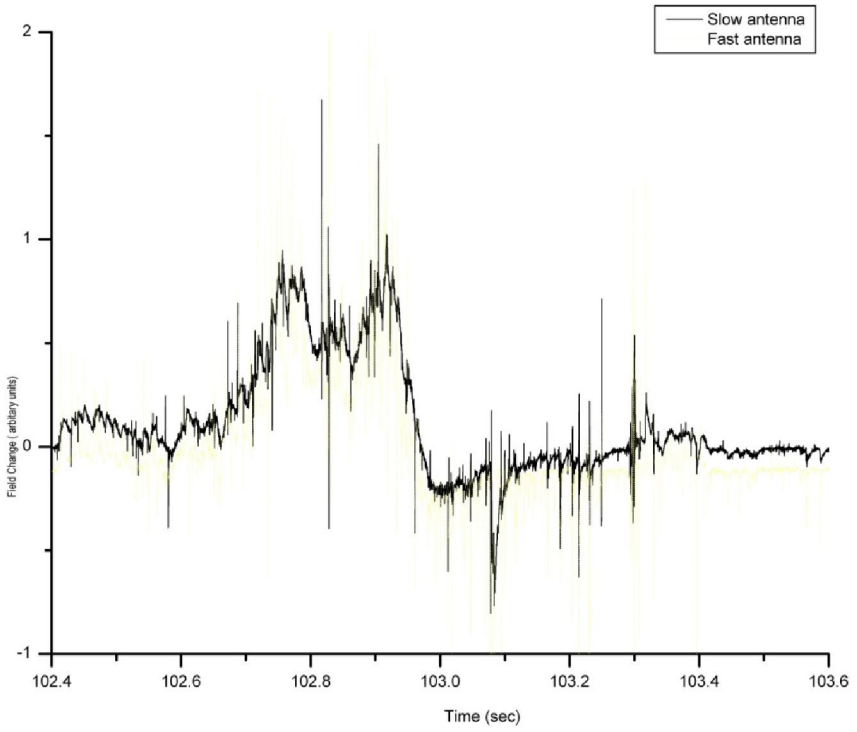
Electric Field change

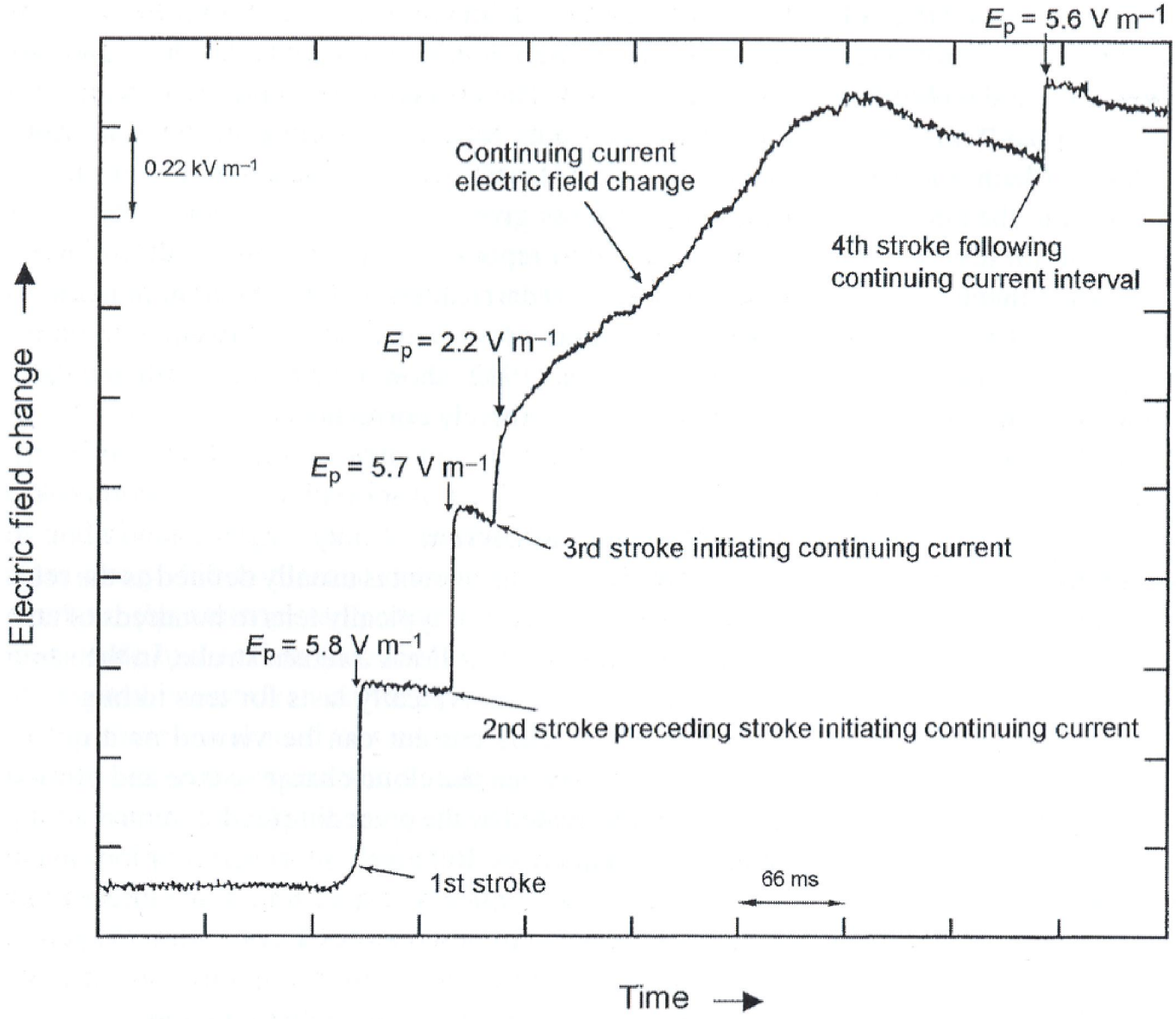


CG Discharge



IC Discharge





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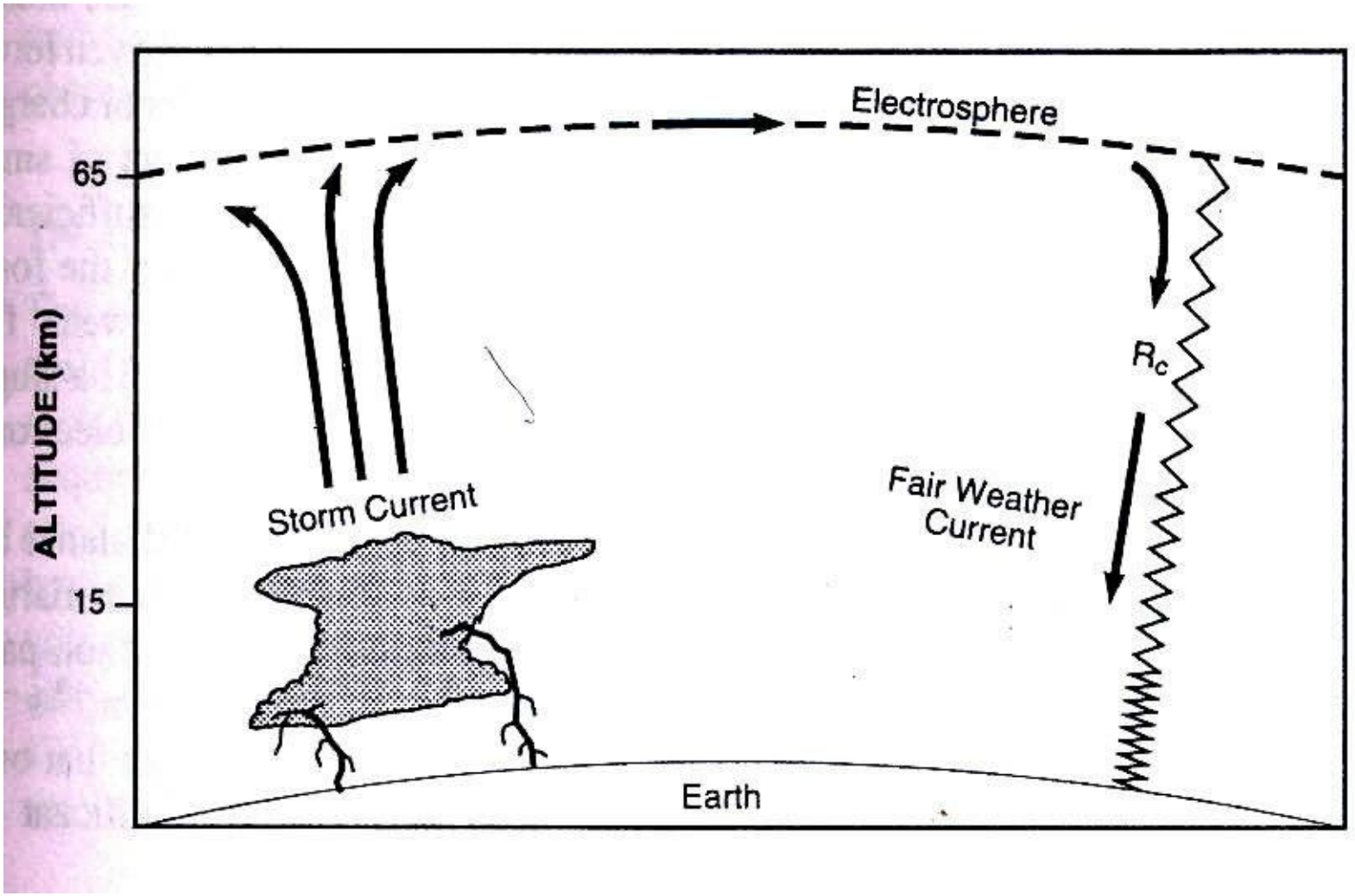
Gross features of discharges

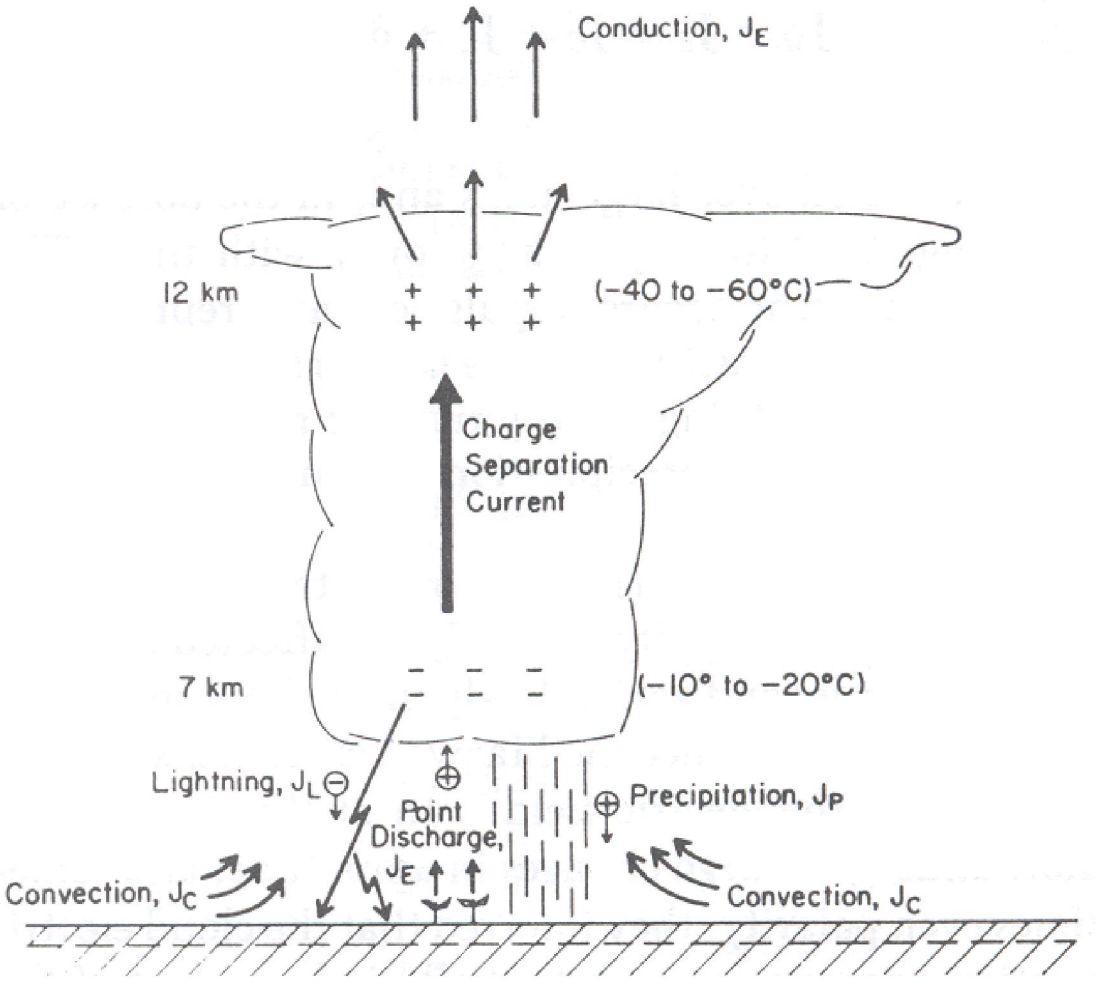
- Currents flowing in a discharge 20,000 to 200,000 amp.
- Charge destroyed in a single discharge ~ 20 C.
- Electrical moment destroyed in a single discharge ~ 100 C km.
- Energy of a flash - 10^9 – 10^{10} J.

Protection can help -

- Lightning cannot be prevented; it can only be intercepted or diverted to a path that will, if well designed and constructed, not result in damage. While there is no single technology hat can completely eliminate the risk of a direct strike and/or over voltage transients, a holistic approach to total facility protection can help safeguard almost any facility, equipment or person.

Global Electric Circuit


Electrosphere
65
ALTITUDE (km)
15
Storm Current
Fair Weather
Current
R_c
Earth

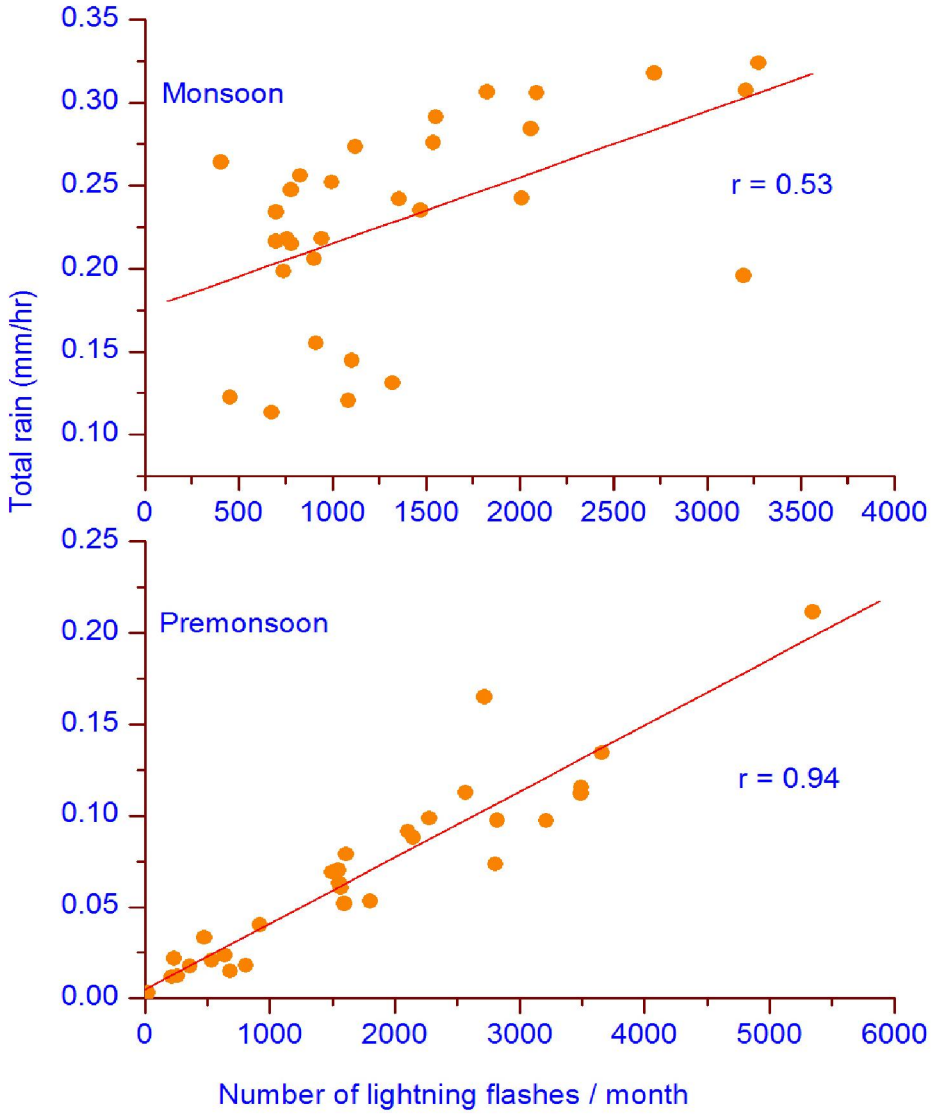


$$\vec{J}_M = \vec{J}_E + \vec{J}_C + \vec{J}_L + \vec{J}_P + \frac{\partial \vec{D}}{\partial t} \quad \text{Below T.S.}$$

$$\vec{J}_M = \vec{J}_E + \frac{\partial \vec{D}}{\partial t} \quad \text{Above T.S.}$$

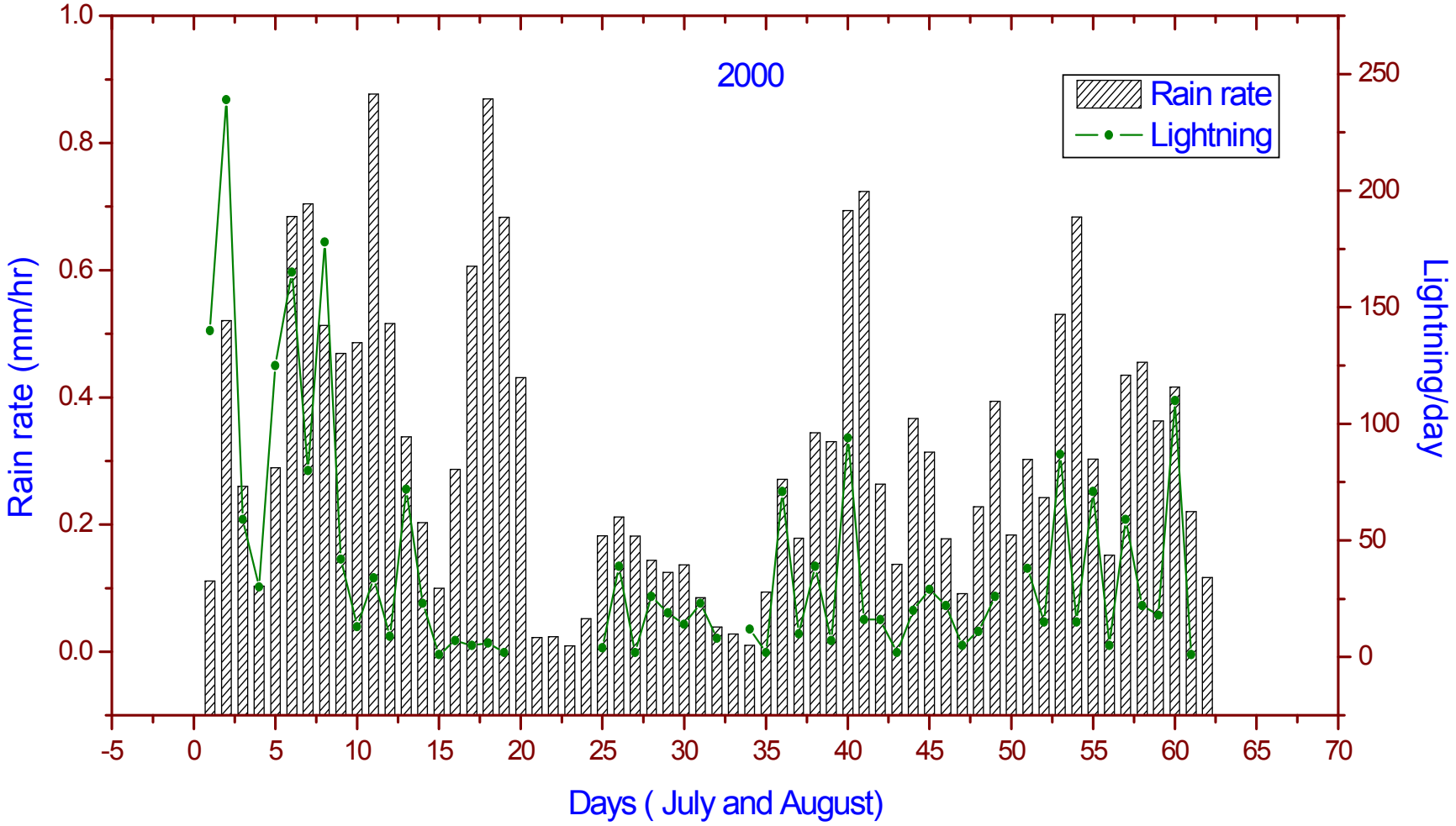
Schematic illustrating the various currents that flow within and in the vicinity of thunderstorms: J_E is the conduction current, J_c is a convection current, J_L is the lightning current, J_p is the precipitation current, $\partial D/\partial t$ is the displacement current, and J_M is the total Maxwell current.

Lightning –Precipitation Relationship

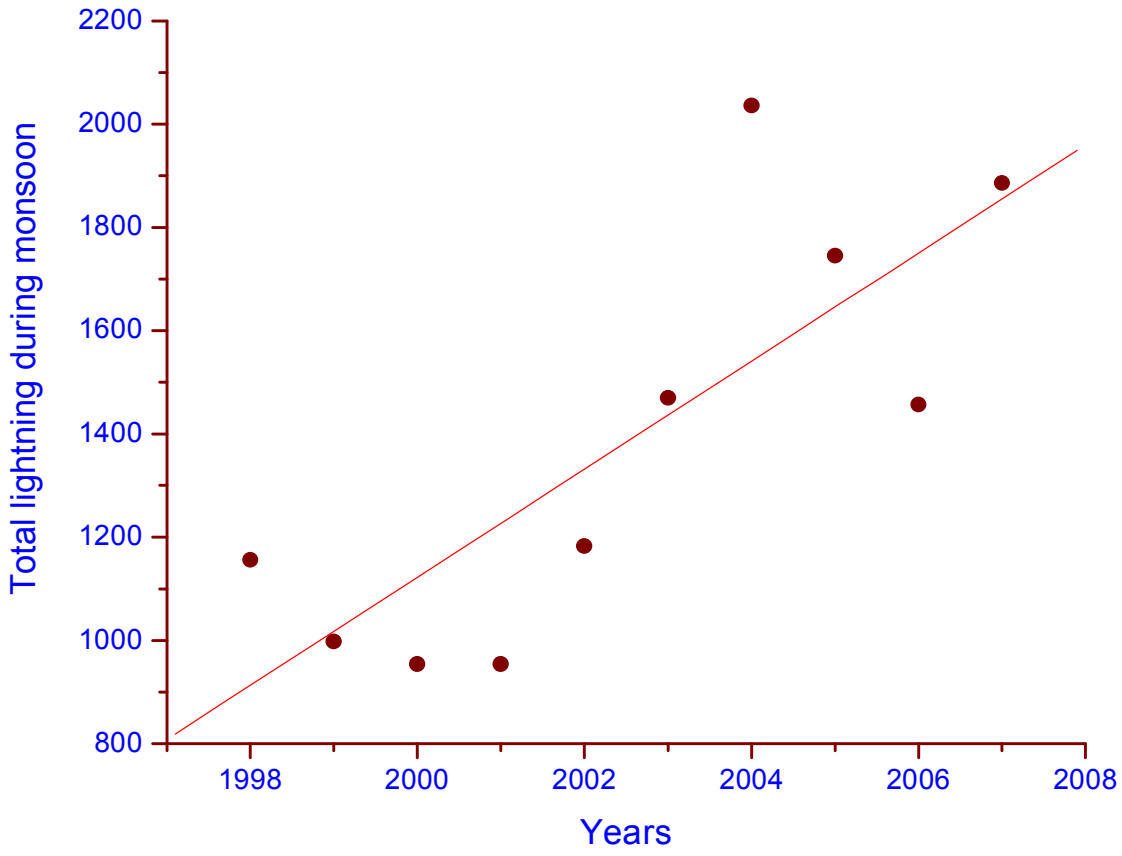


Atmospheric Research 2009

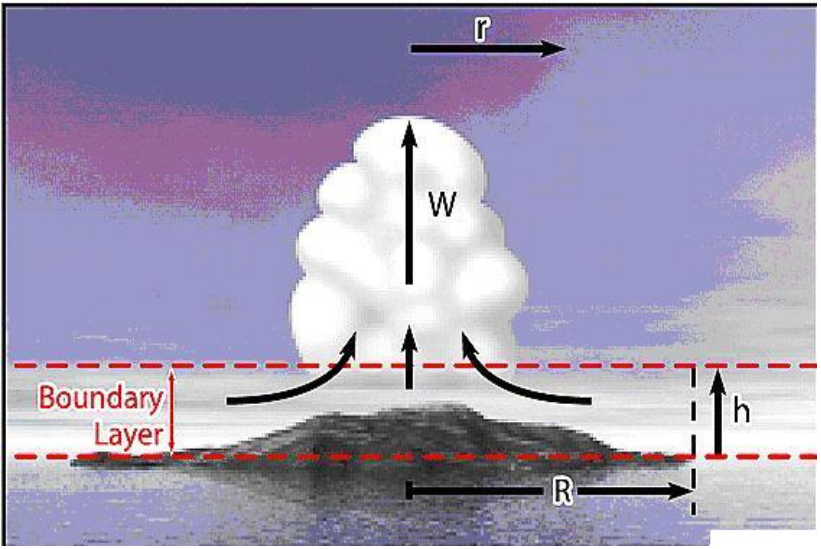
Rainfall-Lightning relationship during monsoon



Lightning during monsoon

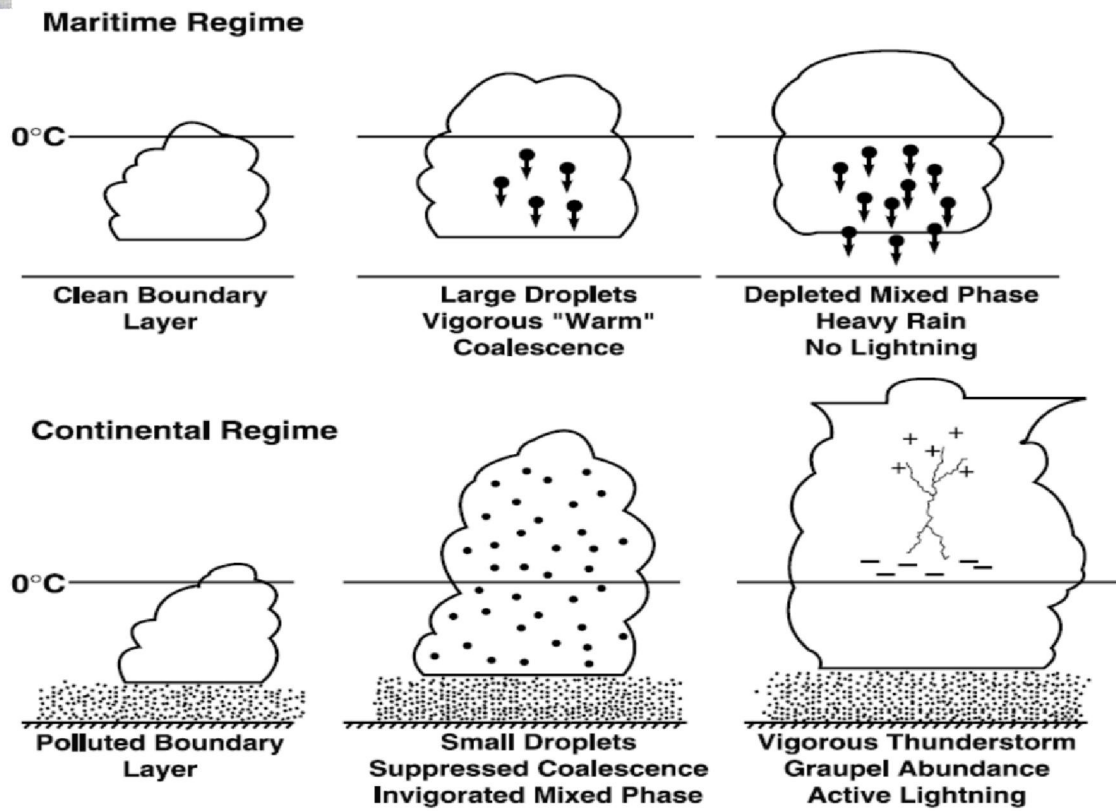


Effect of urbanization on local weather



•Thermal Hypothesis

Aerosol Hypothesis



Thank You