

Lightning Meteorology I: An Introductory Course on Forecasting with Lightning Data

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1. INTRODUCTION

The Virtual Institute for Satellite Integration Training (VISIT) provides forecasters with meteorological training on a number of remote sensing topics using distance education techniques (Zajac et al. 2002). VISIT has developed a two-part course on forecasting with cloud-to-ground (CG) lightning data. The first course, "Lightning Meteorology I: Electrification and Lightning Activity by Storm Scale" describes thunderstorm electrification and CG lightning activity in most isolated storms and mesoscale convective systems (MCSs). The second course, "Lightning Meteorology II: Anomalous Lightning Activity and Advanced Electrification" examines the unusual CG lightning activity found in some severe storms and many winter storms. This article provides an overview of Lightning Meteorology I.

2. COURSE OBJECTIVES

The broad objective of Lightning Meteorology I is to teach forecasters how to utilize CG lightning data in nowcasting and short-range forecasting. This objective is met by 1) introducing theoretical concepts on the thunderstorm lifecycle, electrification and CG lightning production and 2) presenting four AWIPS¹ case studies that show consistency between theory and observation. The theoretical concepts introduced in Lightning Meteorology I are the simplest concepts needed to explain the CG lightning activity observed in 80–90% of the isolated storms and MCSs that occur during the warm season. The specific course objectives are:

- to gain a basic understanding of the ice-ice collisional mechanism
- to identify thresholds in radar reflectivity and satellite cloud top temperature associated with CG lightning
- to know the charge distributions in thunderstorms and their effect on the timing, location and frequency of –CGs and +CGs.
- to infer storm lifecycle and precipitation type (convective vs. stratiform), location and intensity using –CGs and +CGs.
- to integrate CG lightning data with sounding, satellite and radar data

Lightning Meteorology I is organized into five sections, which are summarized here in Secs. 3–7.

3. THUNDERSTORM LIFECYCLE

The lifecycle of a typical isolated thunderstorm is reviewed in terms of storm dynamics and microphysics. The formation of graupel at mid-levels is emphasized because numerous studies have found correlation between initial electrification and the formation of graupel (e.g., Dye et al. 1986). The thunderstorm lifecycle is separated into four stages: shallow cumulus, towering cumulus, mature cumulonimbus and dissipating cumulonimbus (Fig. 1a–d). This four-stage model is an extension of the three-stage model developed by Byers and Braham (1949). A fourth stage is added to capture the growth of ice crystals into graupel by deposition (i.e., growth from the vapor phase) and riming (i.e., the collection of supercooled water droplets).

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4. ELECTRIFICATION AND THRESHOLDS

Research over the past century has identified the gross charge distribution within a typical isolated thunderstorm and the main mechanism that produces this charge distribution. The normal dipole, with positive charge overlying negative charge (Fig. 1c), is a manifestation of the ice-ice collisional charging mechanism. This mechanism describes the exchange of charge during collisions between ice particles in the presence of supercooled liquid water (Figs. 2a–b). In the high cloud liquid water (CLW) environment of the convective updraft, the normal dipole forms when graupel and ice crystals collide and become oppositely charged, then gravitate to different regions of the storm due to their large fall speed differential (Saunders 1993; Figs. 2a and 1c). Negatively-charged graupel particles are suspended at mid-levels or fall out as convective precipitation, while positively-charged ice crystals are lofted to upper-levels. The ice-ice collisional charging mechanism is considered the main charging mechanism in thunderstorms since it is most consistent with observations (Saunders 1993).

Figure 1 shows how the normal dipole evolves during the thunderstorm lifecycle. Electrification begins with the formation of graupel in the towering cumulus stage (Fig. 1b). The normal dipole is established in the mature cumulonimbus stage as charge is both generated and advected (Fig. 1c). The normal dipole evolves into a tilted dipole as the storm ages and the anvil is advected downshear (Fig. 1d).

The first AWIPS case study examines four storms that passed over Fort Collins, Colorado on 28 July 1997. All four storms produced heavy rain but only the second two storms, slightly deeper than the first two, produced CG lightning. An analysis revealed the following thresholds for CG lightning.

- *minimum radar reflectivity at –10°C* = 35 to 45 dBZ
- *minimum cloud top temperature* = –25 to –30°C

The radar threshold indicates that high concentrations of millimeter-sized graupel are needed to support electrification. The satellite threshold indicates that a deep cloud is needed for oppositely charged graupel and ice crystals to separate.

5. ISOLATED THUNDERSTORMS

This section comprises an exercise on induced charge and the second AWIPS case study. The exercise asks forecasters to consider how the surface of the earth—a conductor—responds to a thunderstorm overhead. Using basic physics principles, forecasters determine the location, amount and polarity of induced charge as is shown in Figs. 1a–d.

The combination of charge in the cloud and induced charge on the earth's surface produces strong electric fields and CG lightning. More specifically, charges in the cloud and on the earth's surface control the timing, location and frequency of –CGs and +CGs². The following characteristics are common to most warm season isolated thunderstorms:

¹ The Advanced Weather Interactive Processing System (AWIPS) is the main tool used by National Weather Service forecasters. AWIPS merges weather observations and numerical model output into a common computer framework.

² Negative CGs are defined as strikes that neutralize negative charge within the cloud. Positive CGs neutralize positive charge within the cloud.

Fig. 1. Four-stage lifecycle of a typical isolated thunderstorm.

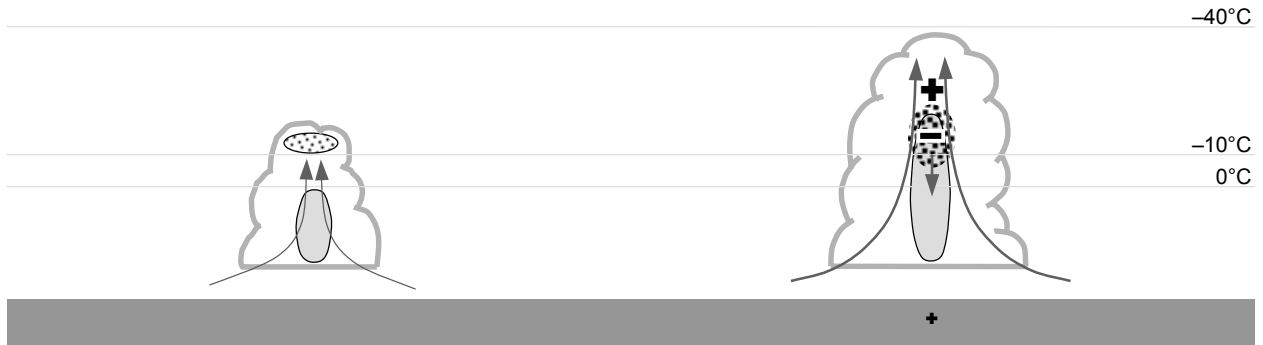


Fig. 1a – Shallow Cumulus

Dynamics

- weak updraft, no downdraft

Microphysics

- max water supersaturation in updraft
- max cloud liquid water content (CLWC) in updraft
- supercooled CLW above freezing level
- ice nucleation above -10°C
- ice growth by deposition \rightarrow ice crystals

Electricity

- no graupel, no charging

Fig. 1b – Towering Cumulus

Dynamics

- strong updraft, initial downdraft at mid-levels

Microphysics

- max CLWC in updraft (supercooled above 0°C)
- small ice crystals ascend; large ice crystals descend
- large ice collects supercooled CLW \rightarrow graupel

Electricity

- charge generation at mid-levels
- negative charge on graupel, positive on ice crystals
- positive charge induced on surface beneath storm

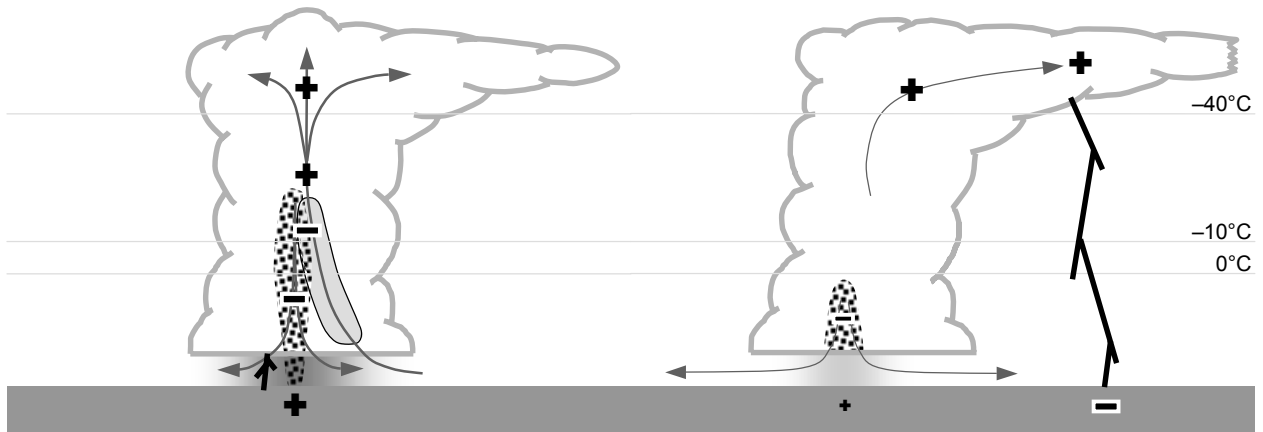


Fig. 1c – Mature Cumulonimbus

Dynamics

- strong updraft, strong downdraft with outflows at sfc

Microphysics

- max CLWC in updraft (supercooled above 0°C)
- large ice collects supercooled CLW \rightarrow graupel
- melting/evaporation of graupel enhances downdraft

Electricity

- charge generation and advection \rightarrow normal dipole
- normal dipole: positive charge above negative
- enhanced positive charge on sfc \rightarrow -CG strike

Fig. 1d – Dissipating Cumulonimbus

Dynamics

- weak updraft, weak downdraft

Microphysics

- weak updraft cannot support water supersaturation
- no supercooled CLW, no graupel production
- residual graupel falls out of storm

Electricity

- no charge generation; charge advection continues
- tilted dipole: positive charge downshear of negative
- enhanced negative charge on sfc \rightarrow +CG strike

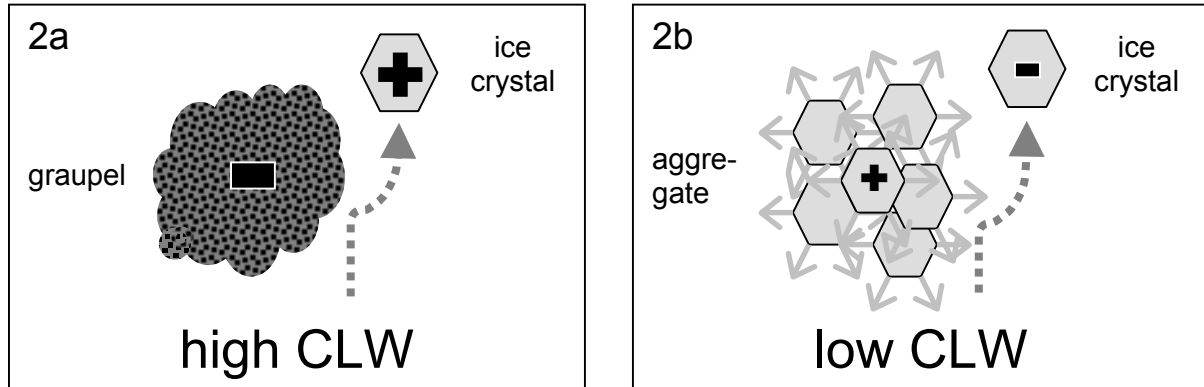


Fig. 2. Conceptual model of the ice-ice collisional charging mechanism as a function of cloud liquid water (CLW). (a) Charging in a high CLW environment representative of convective updrafts. The dotted gray line indicates the ascent of the ice crystal with respect to the stationary graupel particle. (b) As in (a), except for a low CLW environment representative of stratiform updrafts. Less charge is transferred in low CLW collisions than in high CLW collisions.

- -CGs are associated with the fallout of convective precipitation
- +CGs are associated with upper-levels and often with the anvil
- -CGs greatly outnumber +CGs

These statements are supported by the second AWIPS case study as well as other studies (e.g., Lopez et al. 1990). Figure 3 shows that the onset of -CGs was roughly coincident and collocated with the onset of heavy precipitation at the surface. As the storm evolved, -CGs continued to be associated with heavy precipitation until the storm began to dissipate around 20:00 UTC.

Two +CGs were produced, the first near the storm core at 19:39 UTC and the second downshear of the storm core at 19:50 UTC. The second +CG was produced by the anvil, seen as an area of light precipitation in subsequent radar scans.

Negative CGs outnumbered positive CGs 30-to-2.

6. MESOSCALE CONVECTIVE SYSTEMS

MCSs are best divided into convective and stratiform regions due to significant differences in charge distributions and CG lightning activity. The charge distribution and CG lightning activity in MCS convective regions are similar to those found in isolated thunderstorms (Figs. 4 and 1, respectively).

The charge distribution in MCS stratiform regions is complex due to 1) the advection of positive charge at upper-levels from convective regions and 2) the generation of an inverted dipole at mid-levels in the low CLW environment of the stratiform updraft (Figs. 2b and 4). +CGs are favored in stratiform regions due to the excess of positive charge and the closer proximity of positive charge to the earth's surface.

The third AWIPS case study shows that precipitating MCS stratiform regions produce +CGs (Fig. 5). Other studies show similar results (e.g., Rutledge and MacGorman 1988).

7. WARNING SCENARIO CASE

The final AWIPS case study tests the forecaster's ability to utilize satellite and CG lightning data following a radar failure at 19:00 UTC. The satellite-lightning overlay shown in Fig. 6 can be used to monitor the lifecycle of this severe MCS including 1) the merger of isolated convective elements into a squall line, 2) the evolution of the squall line into a bow echo, 3) the formation of a large precipitating stratiform region on the northern side of the system and 4) the development of new convection on the western side.

8. CONCLUSIONS

Lightning Meteorology I demonstrates the utility of CG lightning data in nowcasting and short-range forecasting, including warning environments. -CGs provide information about convective precipitation, while +CGs provide information about vertical wind shear and stratiform precipitation.

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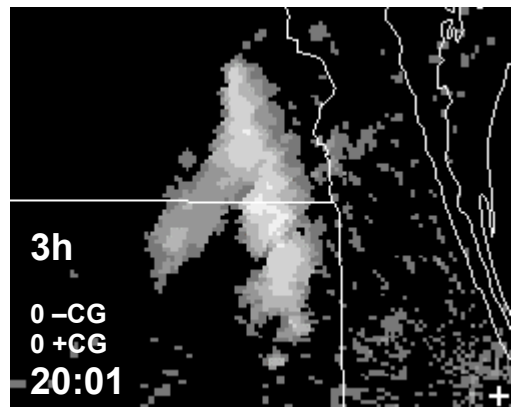
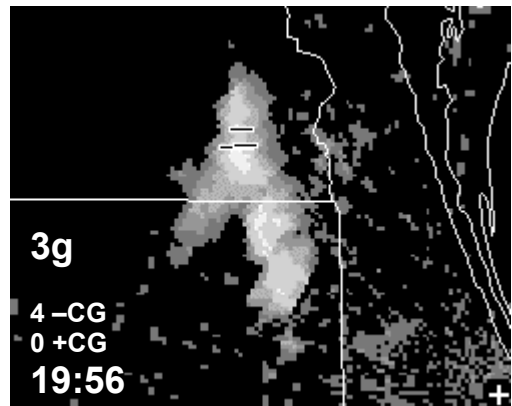
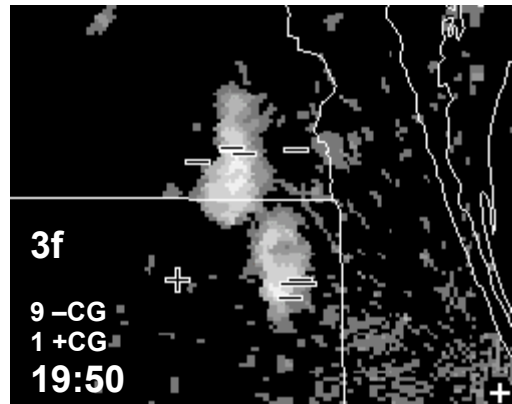
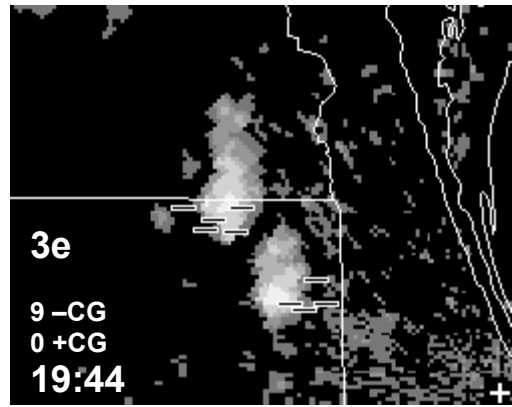
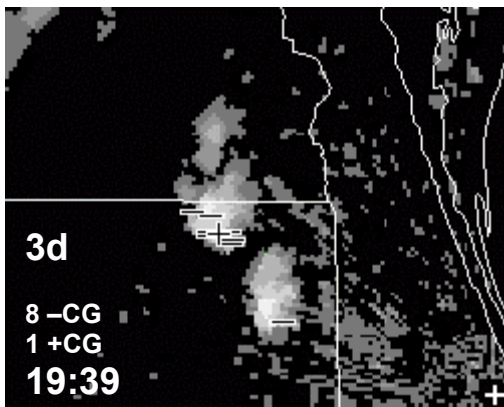
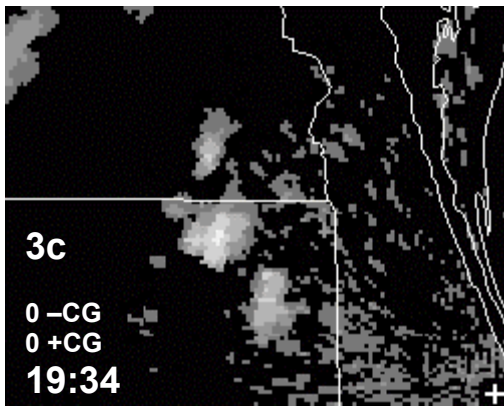
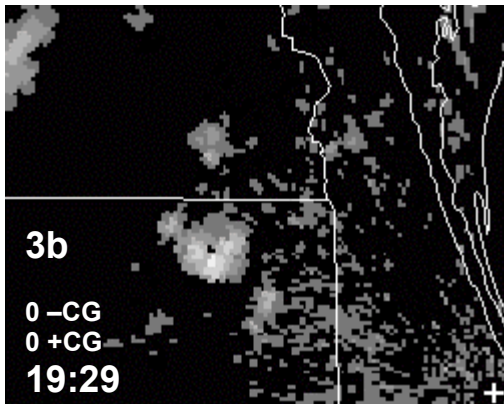
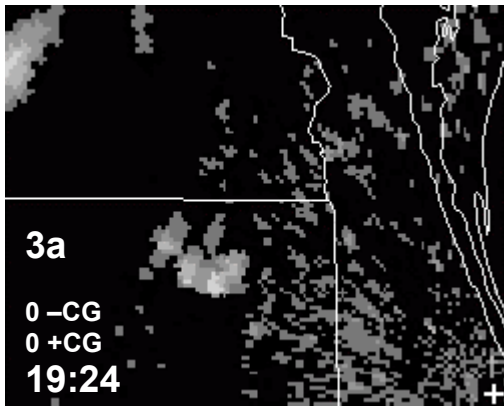


Fig. 3. Previous page. Radar and lightning data from 19:24–20:01 UTC on 28 June 2000 over Melbourne, Florida. Radar reflectivity data from the 0.5° scan of the WSR-88D in Melbourne (radar location shown by the “+” in the lower right corner) and 5-minute CG lightning data. Reflectivity data is displayed in 10 dBZ bins (10–20, 20–30, 30–40, 40–50, and 50–60). The radar sampled volumes roughly 1,500’ above ground level at the location of the storms shown. Radar scan times and –CG and +CG counts are listed in the lower left corner. County boundaries are shown.

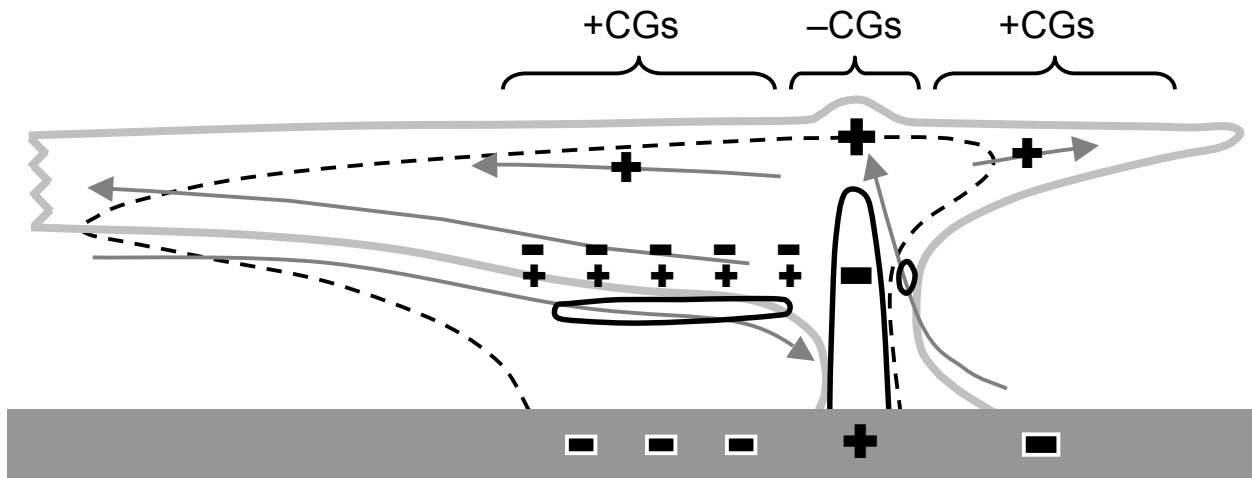


Fig. 4. Conceptual model of a mesoscale convective system organized into a squall line with trailing stratiform precipitation (adapted from Houze et al. 1989) with charge distributions overlaid. The MCS is viewed in a vertical cross section, oriented perpendicular to the squall line and parallel to its motion. Solid light gray line shows the cloud boundary; dashed (solid) black line shows radar echo boundary > 5 dBZ (> 30 dBZ); dark gray lines with arrows show parcel trajectories. Charges within the cloud are based on the convective and stratiform modes of the ice-ice collisional charging mechanism (Figs. 2a-b). Charges on the earth’s surface are based on induction. The dominant CG lightning polarity associated with anvil, convective and stratiform regions is indicated.

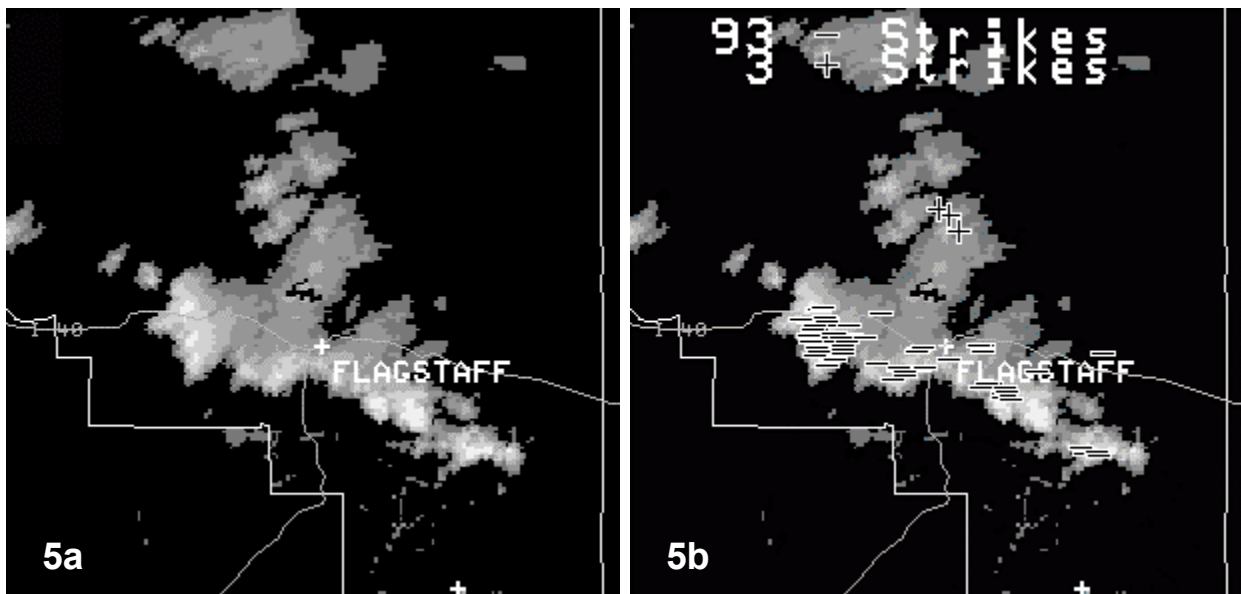


Fig. 5. (a) Radar data from 20:00 UTC on 28 June 2000 over Flagstaff, Arizona. Radar reflectivity data from the 0.5° scan of the WSR-88D in Flagstaff (radar location shown by the “+” in the lower right corner). Reflectivity data is displayed in the following dBZ bins: 10–20, 20–30, 30–40, 40–50, and 50–65. (b) As in (a), except for the overlay of 15-minute CG lightning data. Counts of –CGs and +CGs are listed. Flagstaff, county boundaries and interstate highways are shown in both figures.

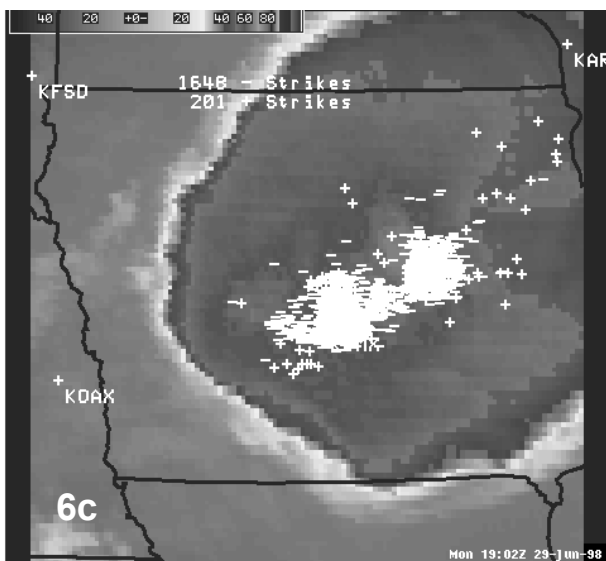
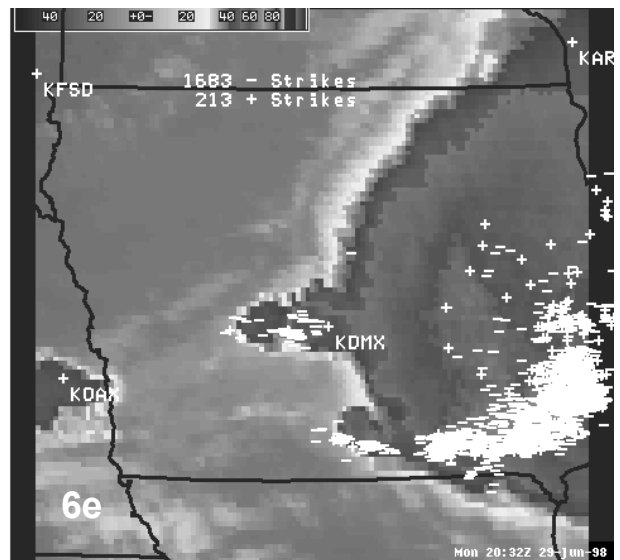
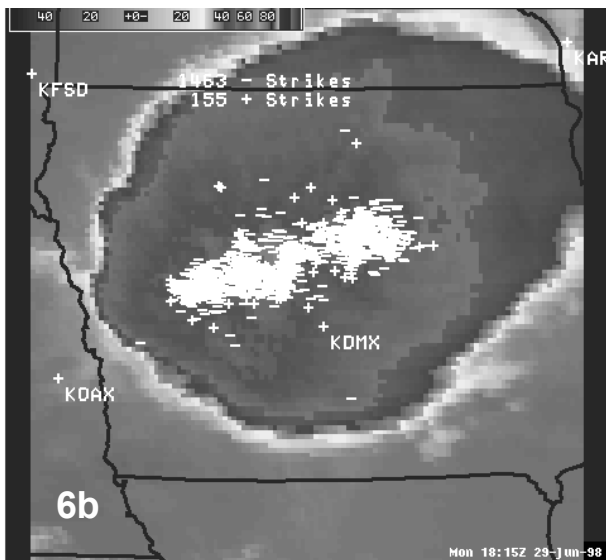
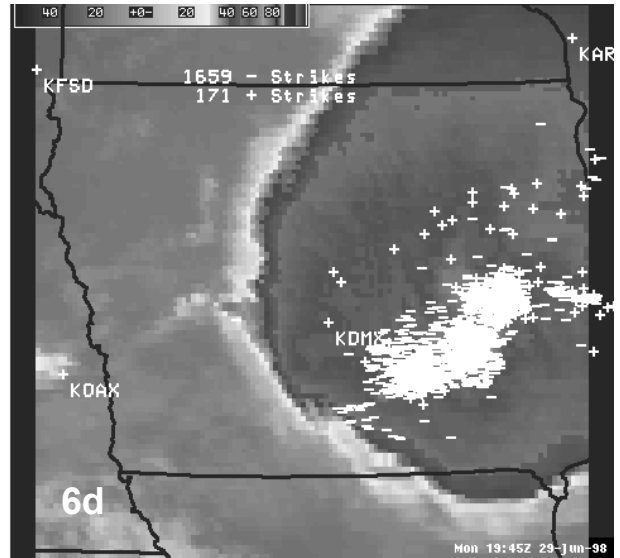
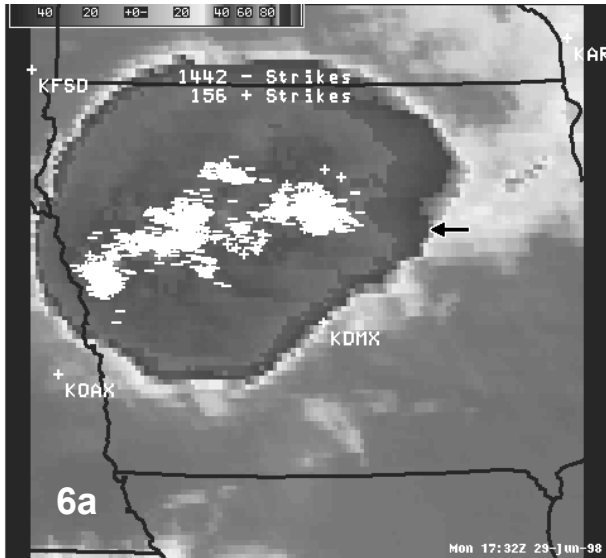


Fig. 6. Satellite and lightning data from 17:32–20:32 UTC on 29 June 1998 over Des Moines, Iowa. Infrared satellite imagery from GOES-8 (Ch. 4; 10.7 μm) and 15-minute CG lightning data. Satellite imagery is displayed as infrared blackbody temperature. The arrow in the Fig. 6a provides reference to the -40°C contour. Satellite scan time is listed in the lower right corner. Counts of $-$ CGs and $+$ CGs are listed. State boundaries and locations of WSR-88D radar are shown.