

Thunderstorm Initial Setting

- Warm moist air at surface
- Lots of sunshine to further heat surface
- Unstable or Conditionally Unstable air overhead
- Other lifting mechanism
 - sloping terrain
 - cold front or dry line
 - convergence zone (e.g. Central Florida)

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com

Development of Thunderstorm

- Updraft from surface heating makes Cu
- Strong updrafts continue & suppress others
- Warm air drawn in from surrounding area
- Cloud continues to grow (~15 min) & reaches above freezing level
- Snow forms. falls, melts, rain reaches surface
- Falling rain drags down air & evaporative cooling causes it to drop
- This causes upward movement to cease
- With no new moisture, thunderstorm dies

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com

Thunderstorm Description

- Lasts less than an hour
- Vertical velocities may reach 70 mph
- Thunderstorm top reaches 30-60 kft
- Ahead of storm, strong wind during downdraft stage
- Under storm: heavy showers, gusty winds, fall in temperature, sudden rise in pressure

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com

Squall Line

- Line of thunderstorms ahead of front
- New cells develop from downdraft from old cells (since air can't move sideways, gust front must move ahead where it meets other air and pushes it up)
- May persist for hours
- Tends to move toward NE

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com

Dry Line

- Both mT and cT are hot, but cT is dry and thus denser than mT
- Thus cT advancing on mT acts like a cold front causing thunderstorms

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com

Severe Thunderstorm

- Large enough to have simultaneous up and down drafts so down drafts don't stop updrafts
- Weak inversion aloft (1-2 km) keeps Cu from forming until late afternoon when air is very warm so energy builds up and makes larger storm
- Since up and downdrafts at same time, hail can occur
- May also get tornadoes

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com

Distribution of Thunderstorms

- Most in tropical regions
- Maximum in Kampala Uganda 242 da/yr
- Maximum in US in Florida ~ 100da/yr
- Oswego ~ 30da/yr
- Can happen any time, but maximum in late afternoon or early evening when ground has heated the most
- Can get lightning from lake-effect snow bands

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com

Type	Appearance	Vertical Wind Shear	Chance of Severe Weather
Air mass/ordinary single-cell	"Popcorn" in visible satellite image	Small	Unlikely
Multicell	MCC: state-sized circular cloud in infrared satellite image Squall line: line of thunderstorms in radar or satellite images	Small Moderate	Likely (nontornadoic high winds) Likely (20% of tornadoes from nonsupercell storms)
Supercell	Hook echo in radar reflectivity image	Large	Very likely (80% of tornadoes from supercells)

*Severe thunderstorms have winds of at least 58 mph, hail with 1 inch or greater diameters, or a tornado.

Figure T02: The three thunderstorm types

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com



Figure 09: Photo of ordinary thunderstorm

Courtesy of Tim Webster

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com

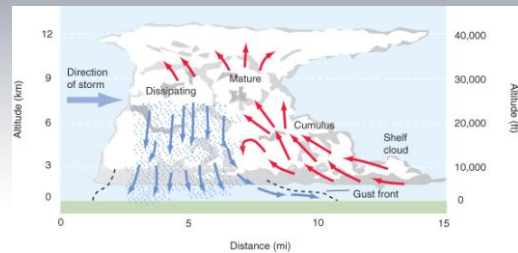
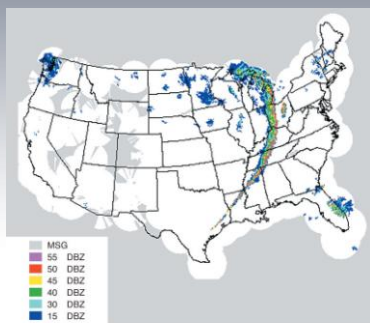


Figure 10: Schematic of a multicell thunderstorm

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com



(a)

Figure 11A: Radar image of squall line

Courtesy of NWSNOAA

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com



Figure 12: Photo of shelf cloud

© Peter Wollinga/Dreamstime.com

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com

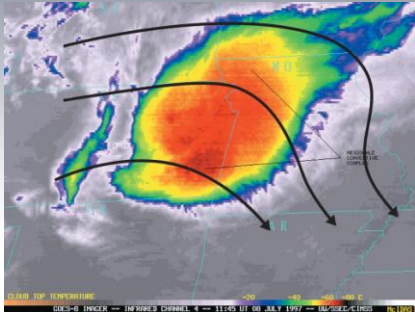


Figure 13: Satellite image of MCC

Courtesy of SSEC and CIMSS, University of Wisconsin-Madison

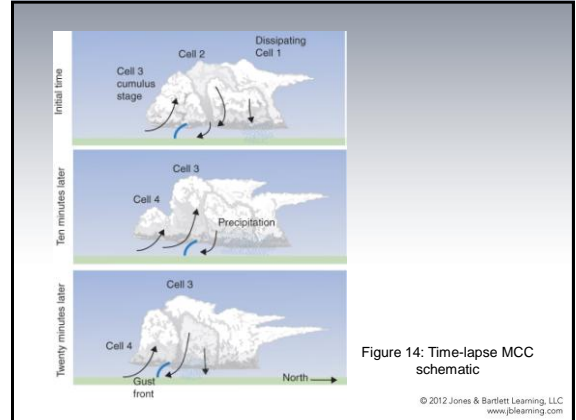
© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com

Figure 14: Time-lapse MCC schematic

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com

Tornado Initial Setting

- Need Severe Thunderstorm
- Jet stream, dry line, weak inversion help
- Need convergence and rotation from strong wind shear
- Rotation tilted up by updraft
- As convergence draws rotation in, it speeds up
- (e.g. 1km x 40 mph = 200m x 200 mph)

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com

Appearance of Tornado

- Expansion due to lifting cools air & causes condensation making tornado visible
- Dust drawn makes it darker
- Tornado appears to drop from cloud, move along ground at speed of cloud then rise up into cloud again
- May have rotation within rotation so speeds can add giving maximum damage to small areas that are curved in shape
- Find wind speeds from extent of damage

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com

Pressure in Tornado

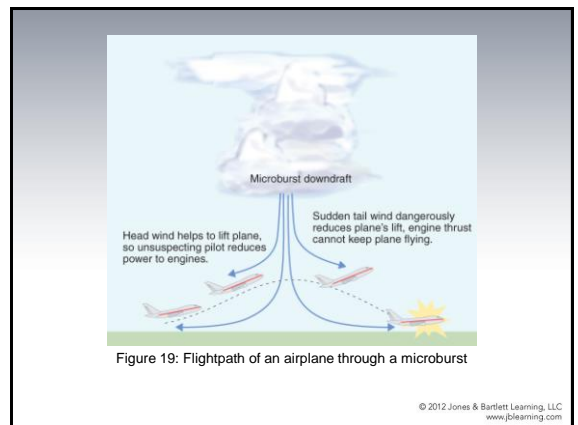
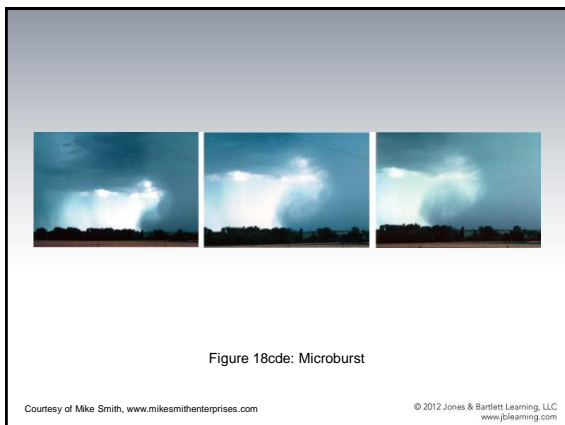
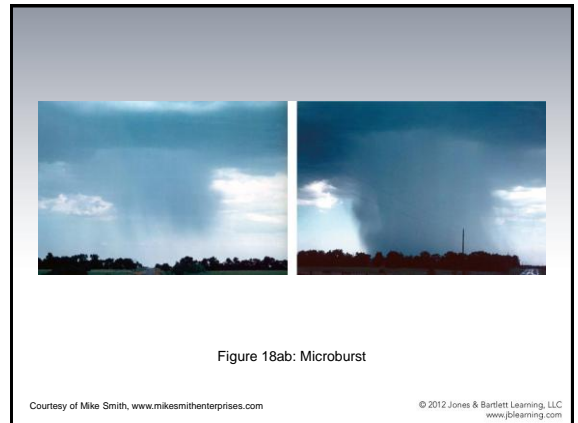
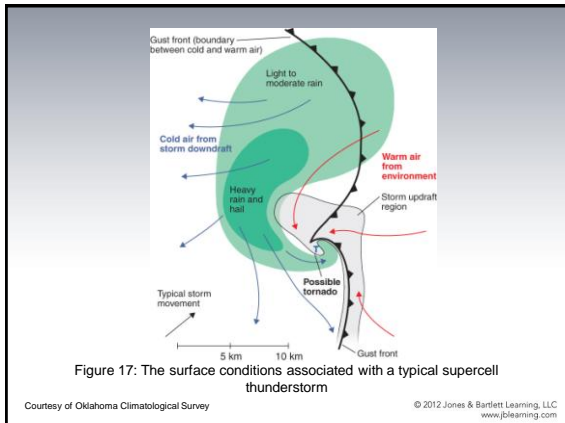
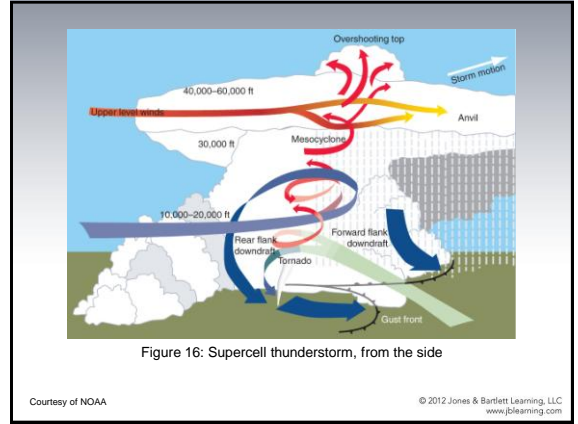
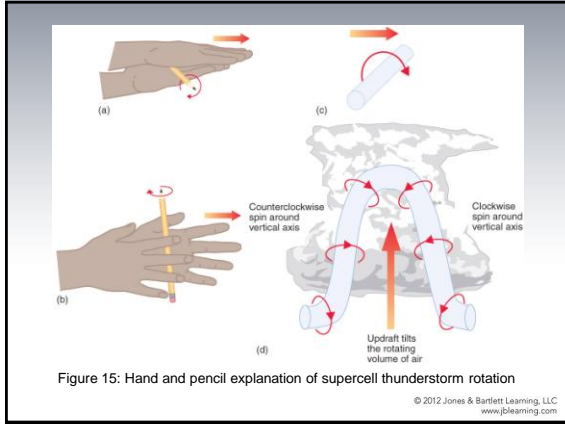
- High Centrifugal force must match pressure gradient so there must be a large pressure drop within a Tornado
- Typically 25-200 mb
- E.g. 100 mb ~ 1.5 lb/in² = 8½ tons on 8x10 ft wall

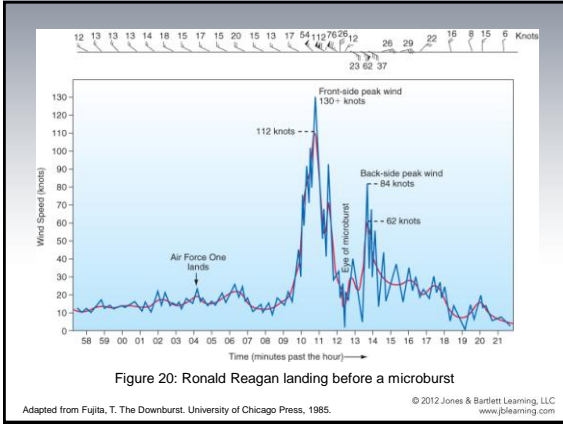
© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com

Location of Tornadoes

- From hurricanes, but less intense
- Most common in US (warm moist air from the Gulf of Mexico, cool dry air from over Rockies, only such combination in world)
- US averages around 1000/yr
- Australia second with ~15/yr
- Max per mi² in Oklahoma, 2nd in Kansas
- Most in May, least in December
- In SE US, Max is late winter & early spring
- Most 1:00-4:00 pm

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com





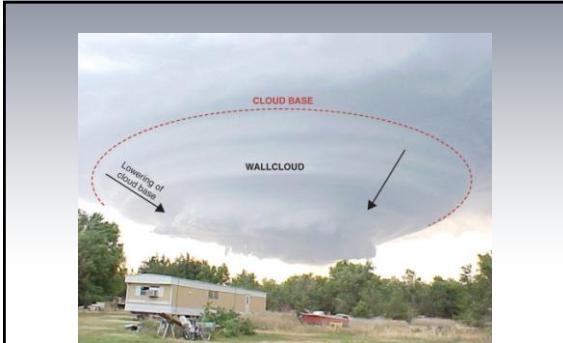


Figure 22: The ominous approach of a rotating wall cloud is a sign that a tornado may develop at any moment.

Courtesy of Nolan T. Atkins

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com

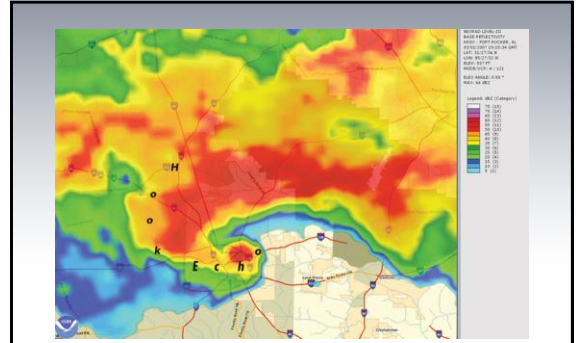


Figure 24A: Radar reflectivity image of Enterprise, AL tornado

Courtesy of NCCDC/NOAA

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com

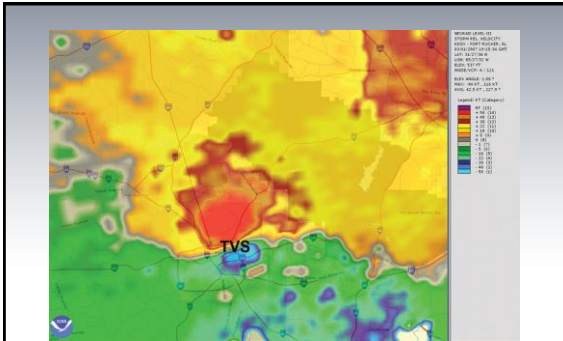


Figure 24B: Radar velocity image of Enterprise, AL tornado

Courtesy of NCCDC/NOAA

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com

Three-Second Wind Gust		
EF Scale	MPH	km/hr
EF0 (Weak)	65-85	105-137
EF1	86-110	138-177
EF2 (Strong)	111-135	178-217
EF3	136-165	218-266
EF4 (Violent)	166-200	267-322
EF5	> 200	> 322

Figure T03: The Enhanced Fujita Scale for Tornadoes

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com

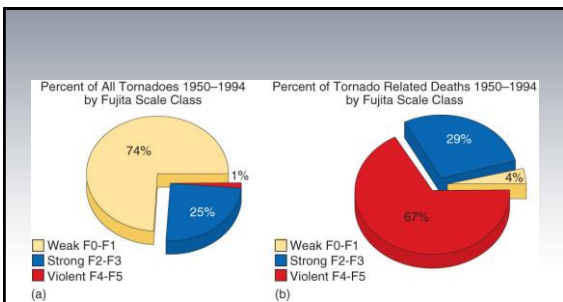


Figure 25: Fujita scale pie charts

Courtesy of Tom Grazulis, tornadoprospect.com

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com

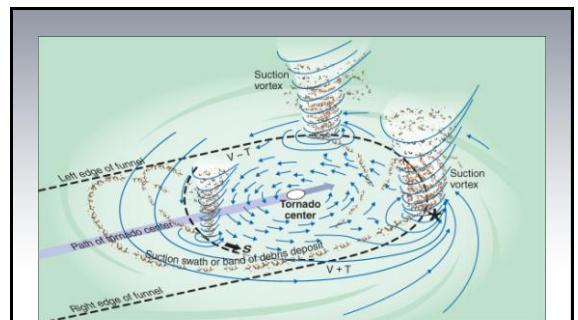


Figure 26: Multiple-vortex tornado

Modified from Tom Grazulis, The Tornado: Nature's Ultimate Windstorm, Oklahoma University Press, 2000, p. 111.

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com

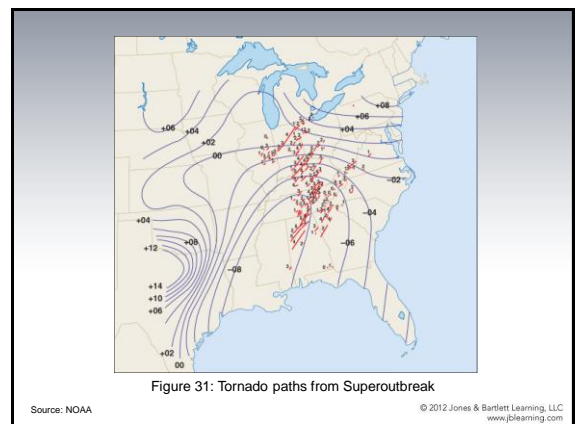
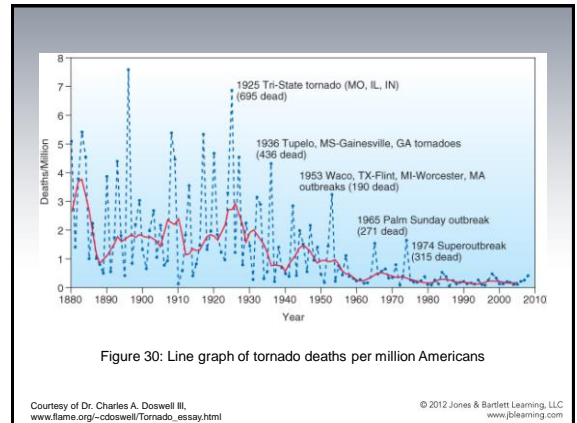
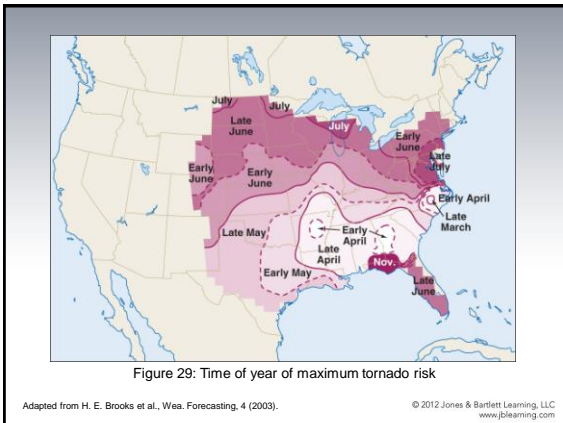
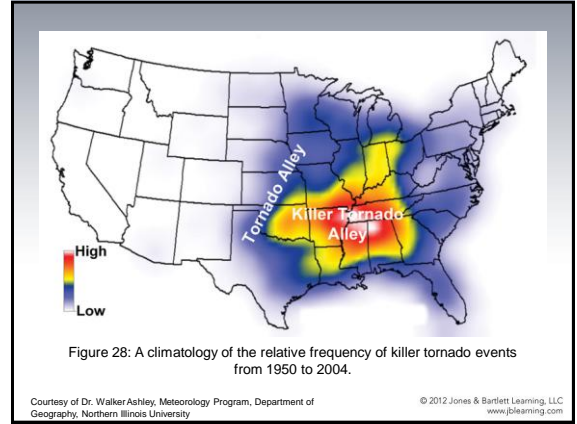
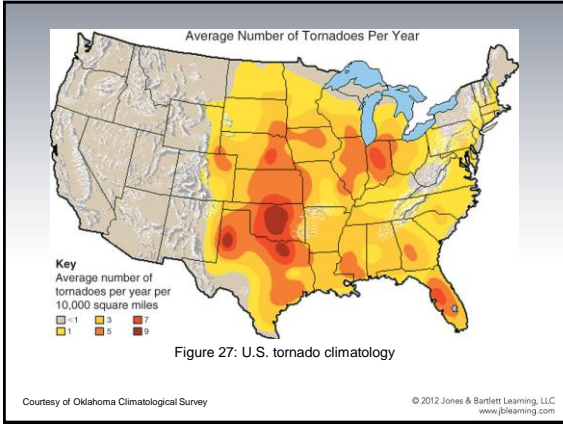




Figure 32: Greensburg, KS devastation

Courtesy of Greg Henshall/FEMA

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com



Figure 33: Path of Atlanta tornado in EF scale

Courtesy of National Weather Service Forecast Office, Peachtree City, GA/NOAA

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com



Figure 34: Atlanta skyscraper post-tornado

Courtesy of Bruce Bracey www.flickr.com/photos/brooc2/2358025514

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com



Figure 35: Waterspout

Courtesy of Dr. Joseph Golden/NOAA

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com

Waterspouts

- Similar to tornadoes, but less intense
- Not need thunderstorms, only some convection
- Small ones visible over Lake Ontario near Oswego in the fall

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com

Waterspout near Oswego #1

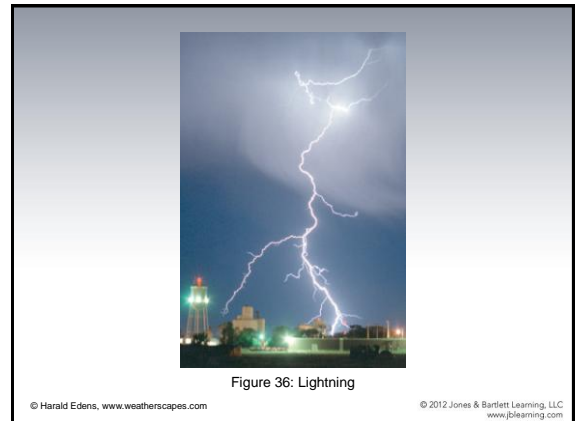




Dust Devils

- No clouds needed, only convection
- ~1 m in diameter
- 10 mph winds
- 1 - 5 min
- Occasionally larger with stronger winds and last longer

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com



© Harald Edens, www.weatherscapes.com

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com

Electric Field

- Earth normally negative relative to upper air (ionosphere 80-90 km) ~100 V/m
- Small ice collides with large groupel
- Ice loses (-) to graupel
- Lighter ice moves to top of Cb
- Under thunderstorm ~30,000 V/m
- Net (-) at bottom induces (+) at surface
- Lightning neutralizes this by moving (-) down
- This leaves net (-) at surface & (+) on top Cb

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com

Lightning Stroke

- Step leader (-) moves down from cloud and reaches surface
- Return stroke drains (-) from path and near contact point with cloud
- Other (-) move toward this point in cloud and move down this path (dart leader)
- 2nd return stroke when this meets ground
- This can repeat many times

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com

Charge

- Estimate the amount of charge transferred by an average thunderstorm
- Estimate total charge to maintain charge difference in atmosphere
- Conclude that this requires 40,000 thunderstorms per day over the earth

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com



Figure 37A: Charges collect in the base of the cloud

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com



Figure 37B: Negative charges build up near the base of the cloud, the ground repels negative charges and changes from its usual negative to a positive charge.

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com

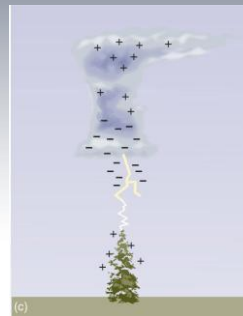


Figure 37C: The stepped leader connects the cloud to the ground

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com

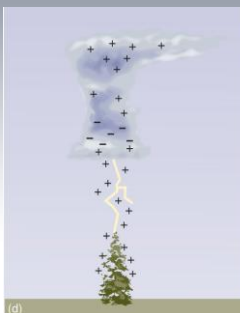


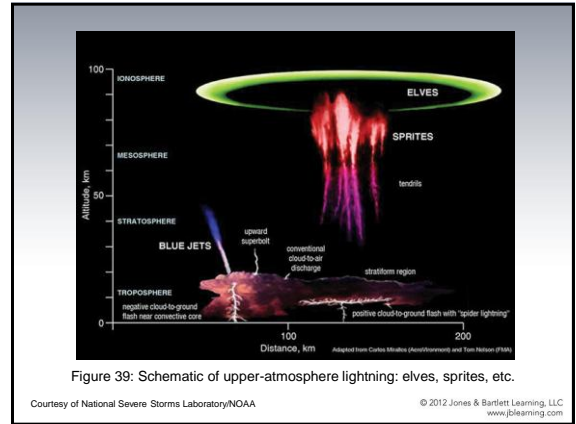
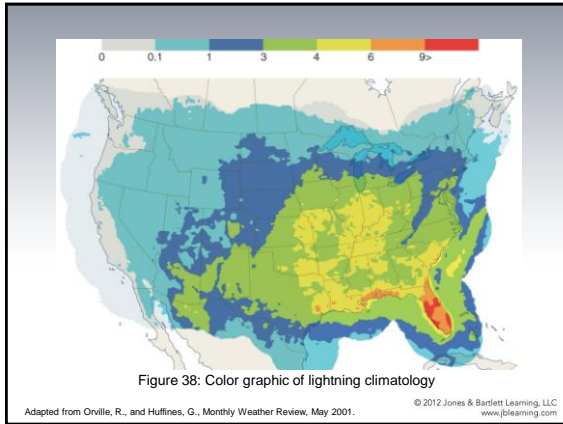
Figure 37D: The bright return stroke surges upward

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com

Thunder

- Lightning heats air causing rapid expansion
- Shock wave like sonic boom created
- Distance of lightning 1mi/5s lag between lightning and thunder
- Rumble due to top of stroke being farther away than bottom plus echos

© 2012 Jones & Bartlett Learning, LLC
www.jblearning.com



Heat Lightning

- Lightning a long distance away so can't hear thunder (> 15 mi)
- Clear overhead but see flashes or glow in the distance
- This is ordinary lightning
- Usually warm and at night so it was called heat lightning

© 2012 Jones & Bartlett Learning, LLC www.jblearning.com

Warning

- Crouch low but only feet must touch ground
- Keep away from trees & other high objects
- OK inside of metal car
- If inside, keep away from TV cable, plumbing (bathtub, shower), ground line phone, electrical outlets

© 2012 Jones & Bartlett Learning, LLC www.jblearning.com



