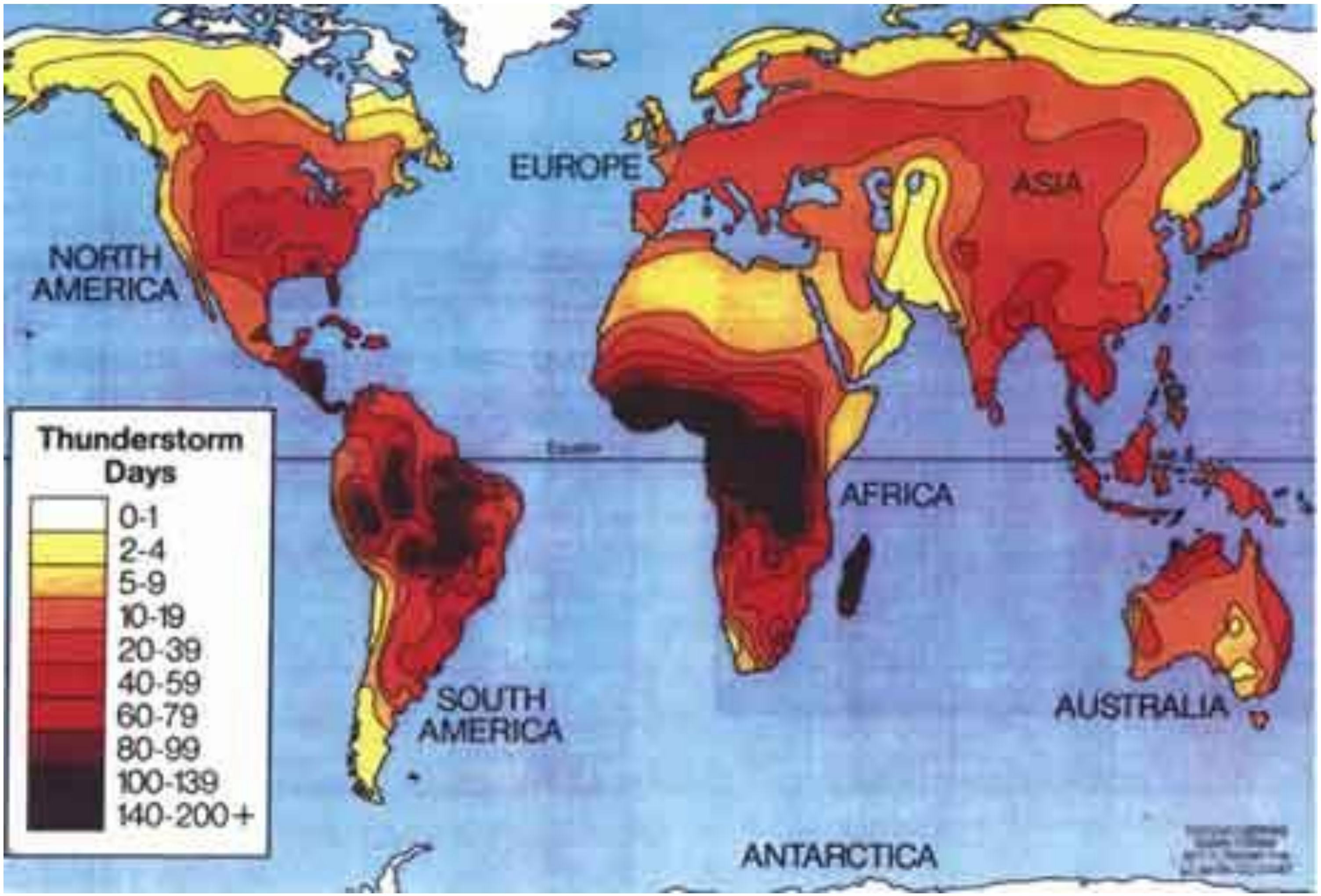
THUNDERSTORMS

- Convective heavy rain accompanied by lightning and thunder

Ahrens

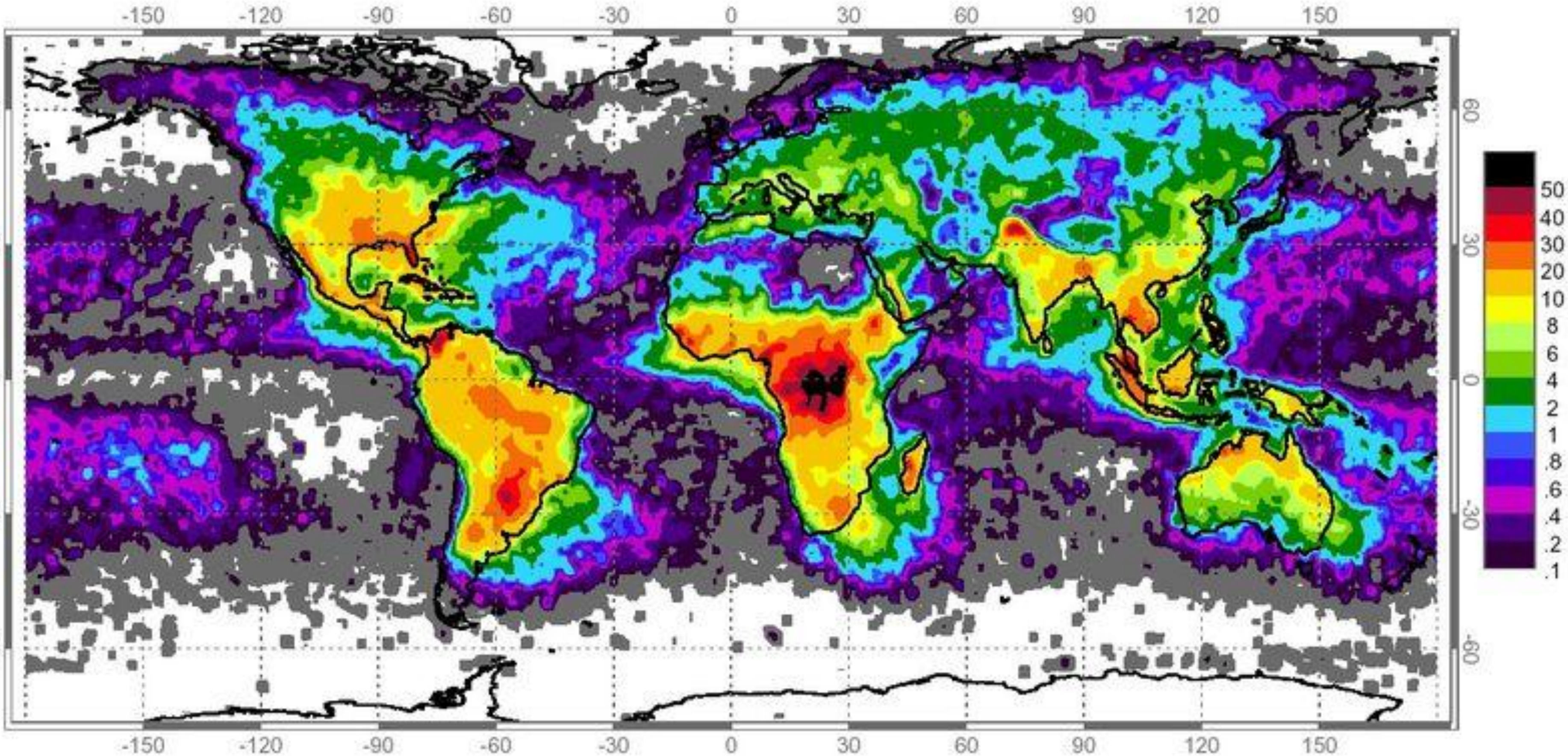
Thunderstorms

About 1,800 T-storms occur around the world at any instant
Where do they occur the most?



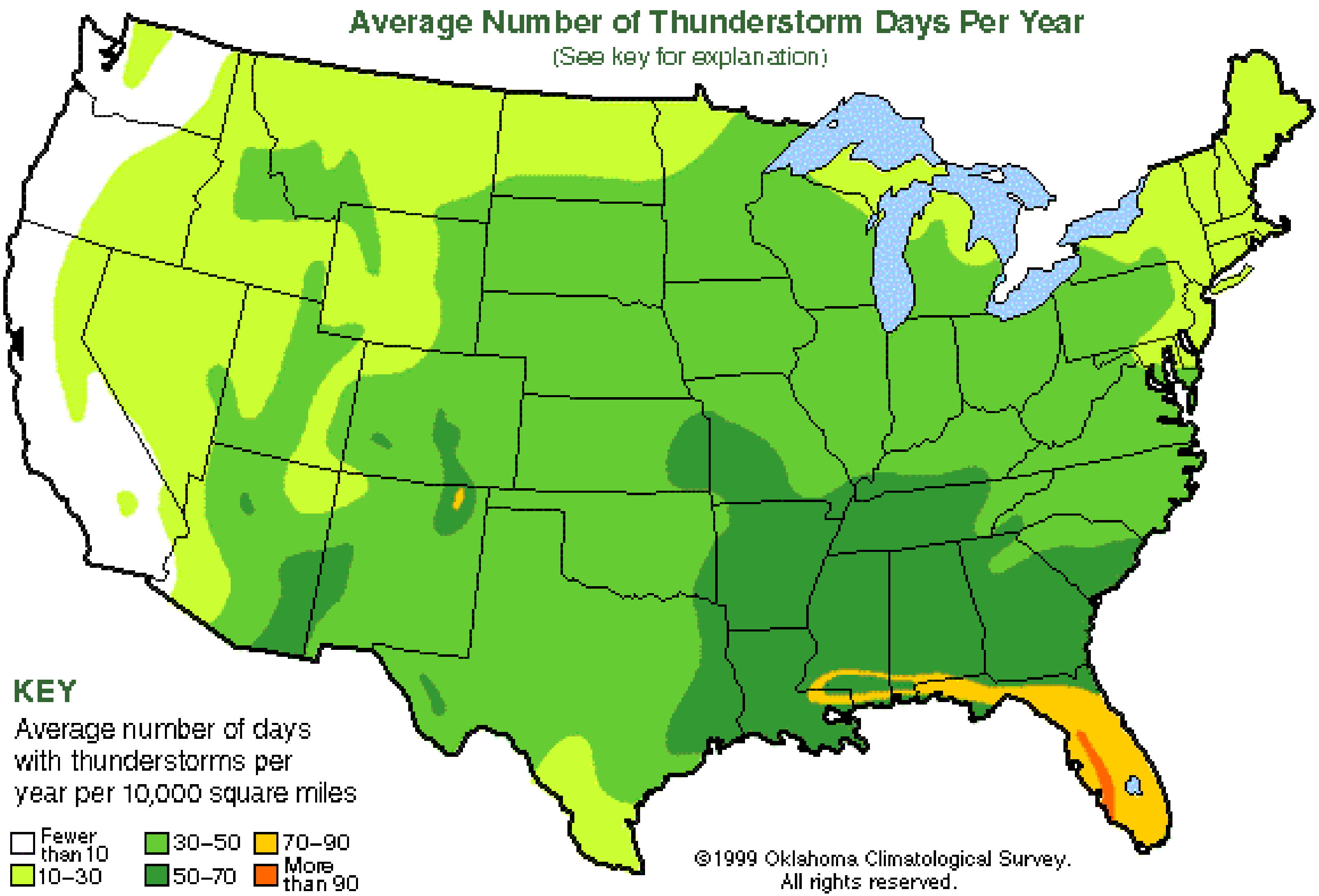
National Lightning Safety Institute

Satellite lightning frequency: flashes per km^2 per year

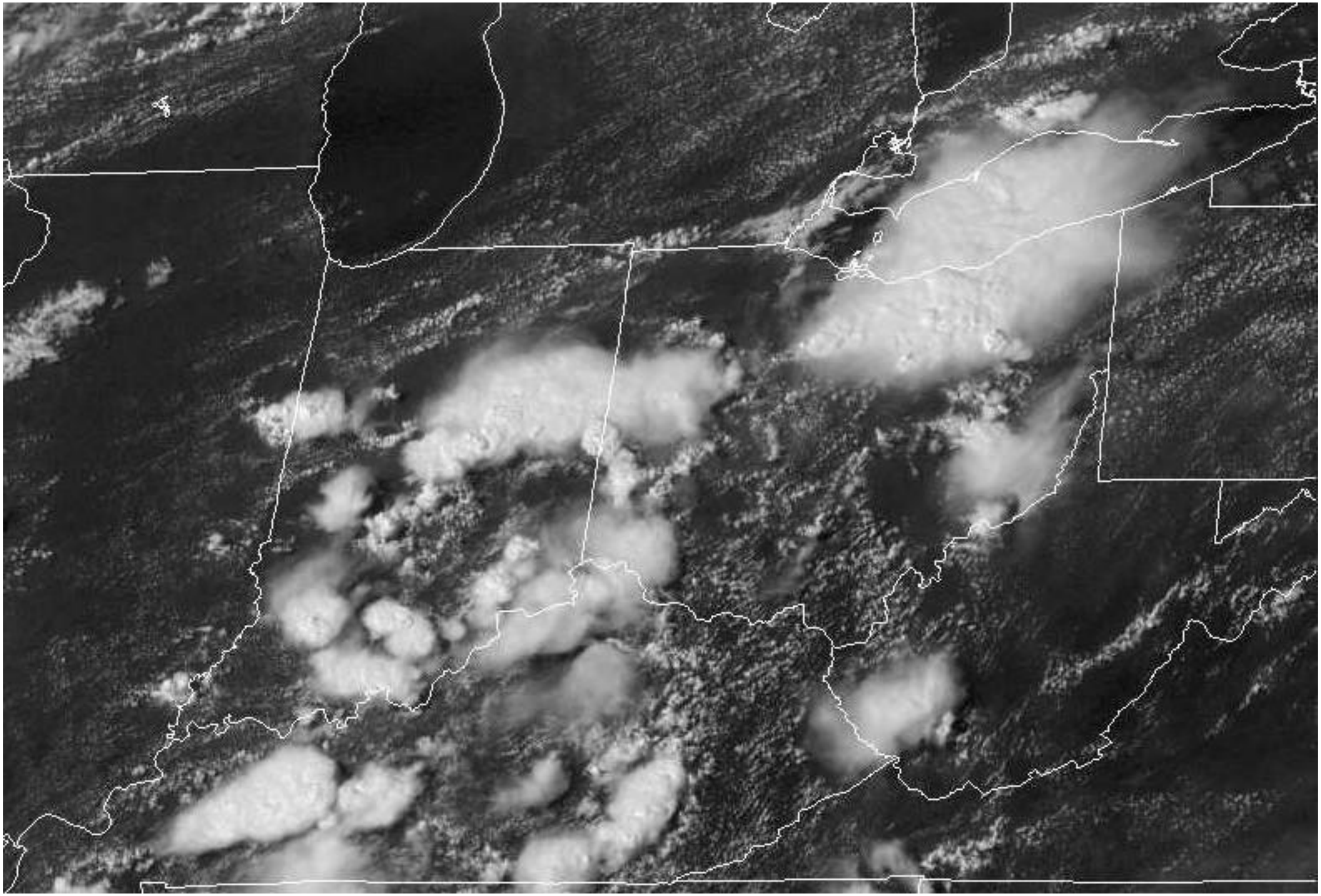


National Lightning Safety Institute

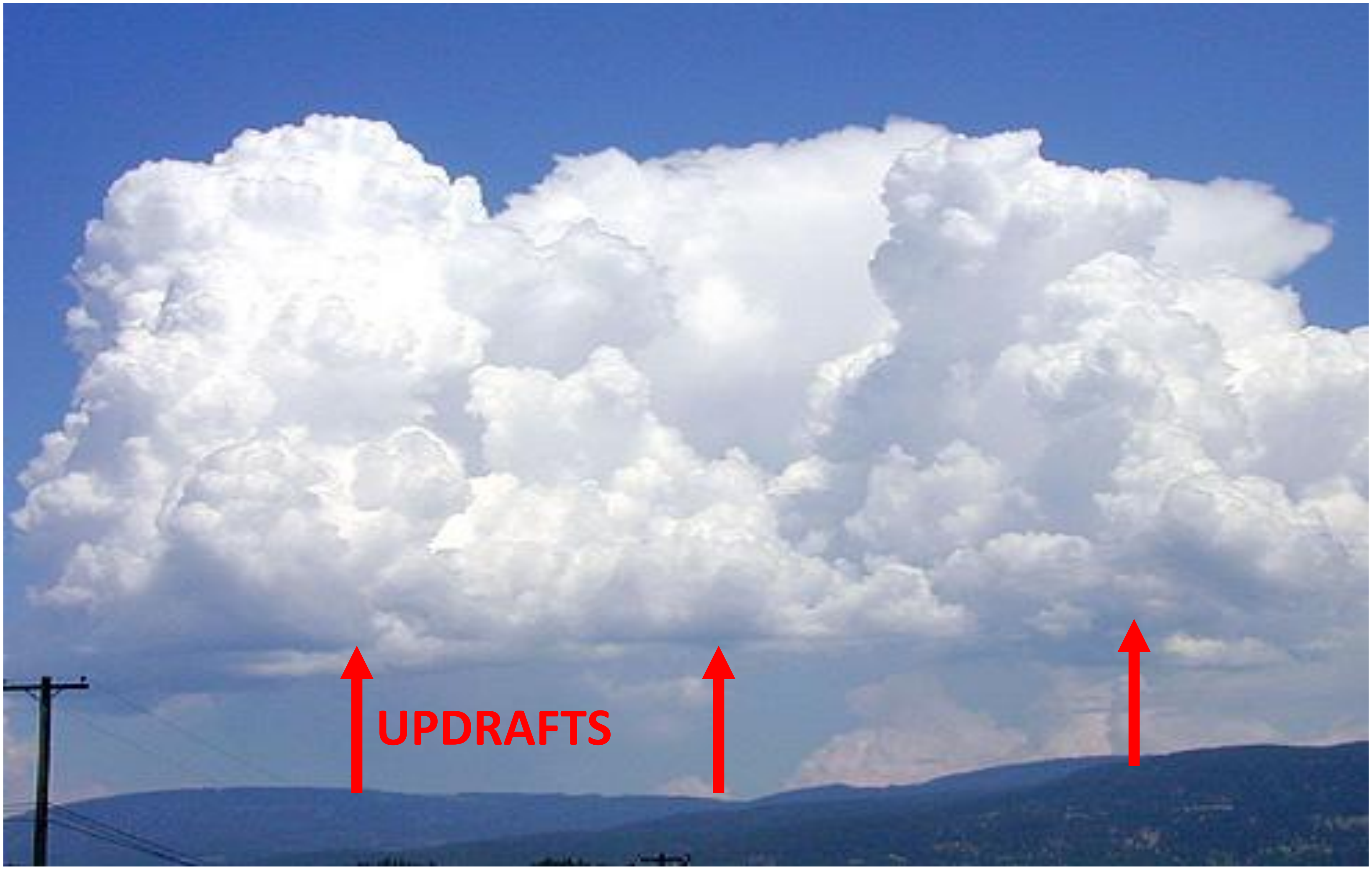
Where do Thunderstorms occur the most often?



Supercell thunderstorms on a visible satellite image



An "Air Mass" Thunderstorm, caused by heated surface parcels



CUMULUS STAGE

Dr. M. Pidwirny, Dep. of Geography, Okanagan University College

Glaciated anvil top of a mature air-mass thunderstorm

MATURE STAGE

Dr. M. Pidwirny, Dep. of Geography, Okanagan University College

Microburst in the region of cold, precipitation laden downdrafts

DISSIPATING STAGE (DOWNDRAFTS)

Microbursts and aviation dangers

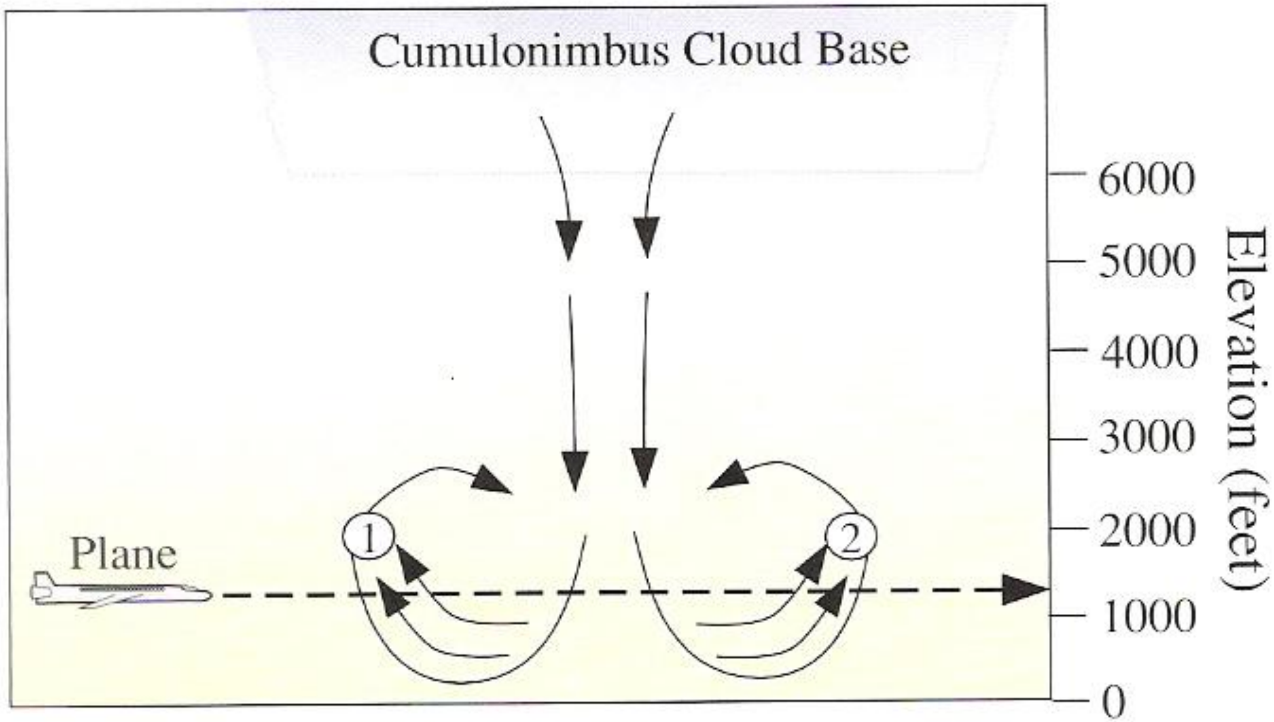
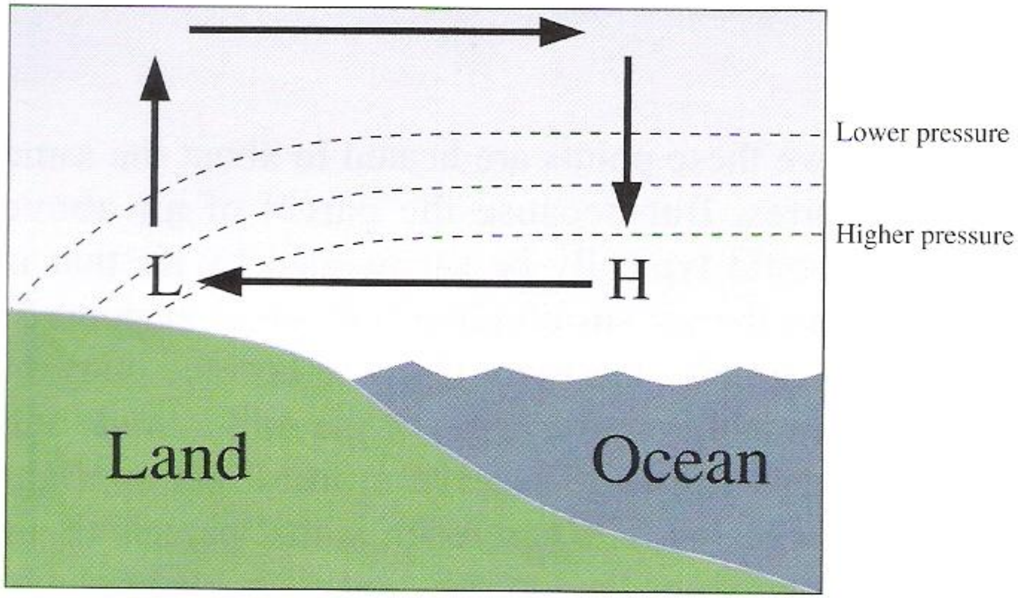


FIGURE 9.47 The microburst's threat to aviation. At point 1, the aircraft encounters a strong headwind. Soon afterward, at point 2, the aircraft encounters a strong tailwind. The relative motion of the tailwind to the aircraft can lead to loss of lift and an aircraft crash (plane not to scale).

Development of the sea breeze and formation of convection



Sea breeze

FIGURE 9.18 During the day, the unequal heating of the land and adjacent water leads to the formation of a sea breeze.

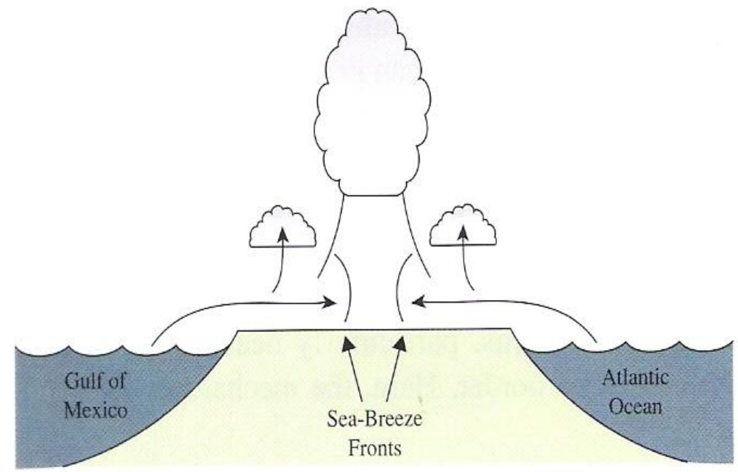
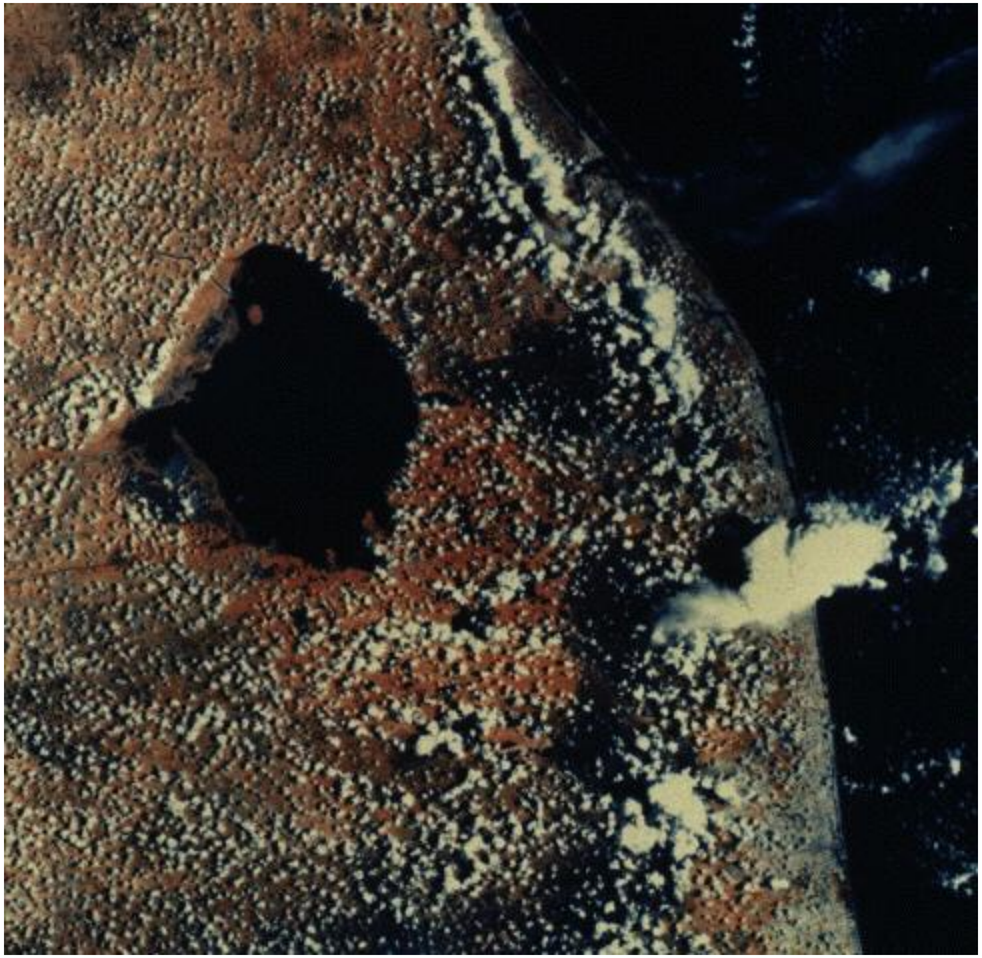
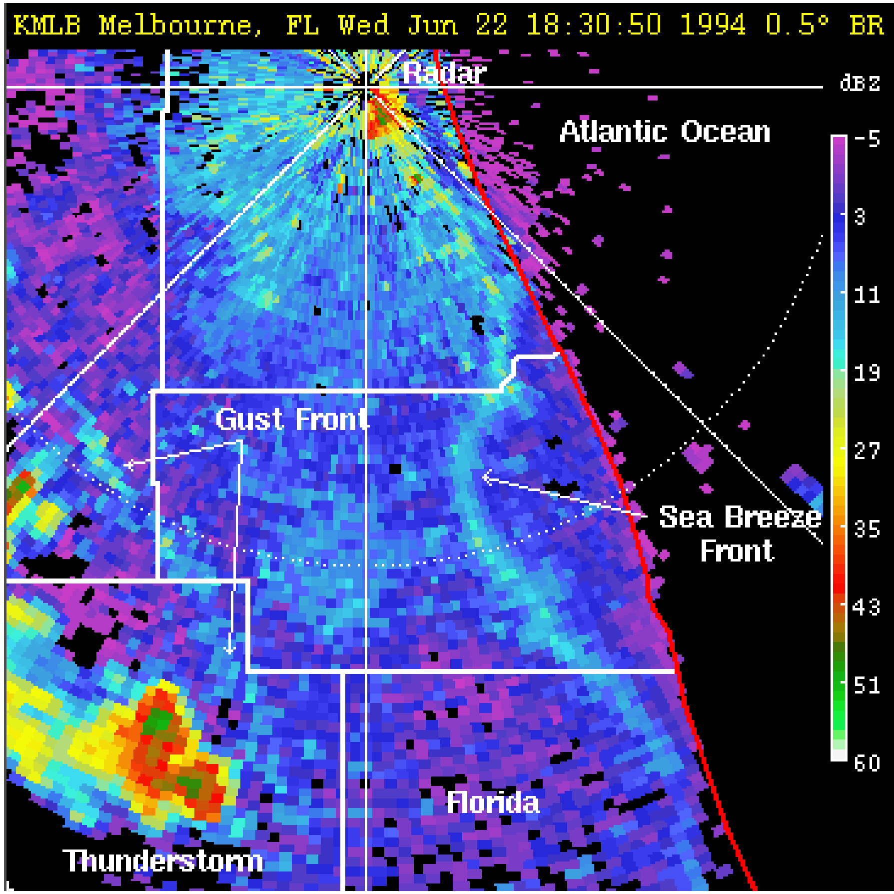


FIGURE 9.21 Converging sea-breeze fronts from the Atlantic and Gulf of Mexico over central Florida during summer can create huge uplift and powerful thunderstorms.

Satellite and Radar images of the Florida Sea Breeze Front





How can the front be “seen” by radar?

Lightning facts:

- Breakdown potential: 3 MV/meter
- For a 1000 m strike, how much Voltage needed?
- Can carry 30-40 kA
- The channel can reach 30000 degrees C
- The channel can be seen for over 100 mi.
- Thunder results from shockwave of exploding hot air channel
- Sound travels at ~330 m/s in air
- …one thousand one, one thousand two, one thousand three:
- Cloud to cloud, Intracloud, Cloud to ground (10%)
- Sprites and Jets
- Positive (10%) or negative charge (90%)
- Process leading to charge separation is complex
- People still don't really understand how lightning rods work

Lightning

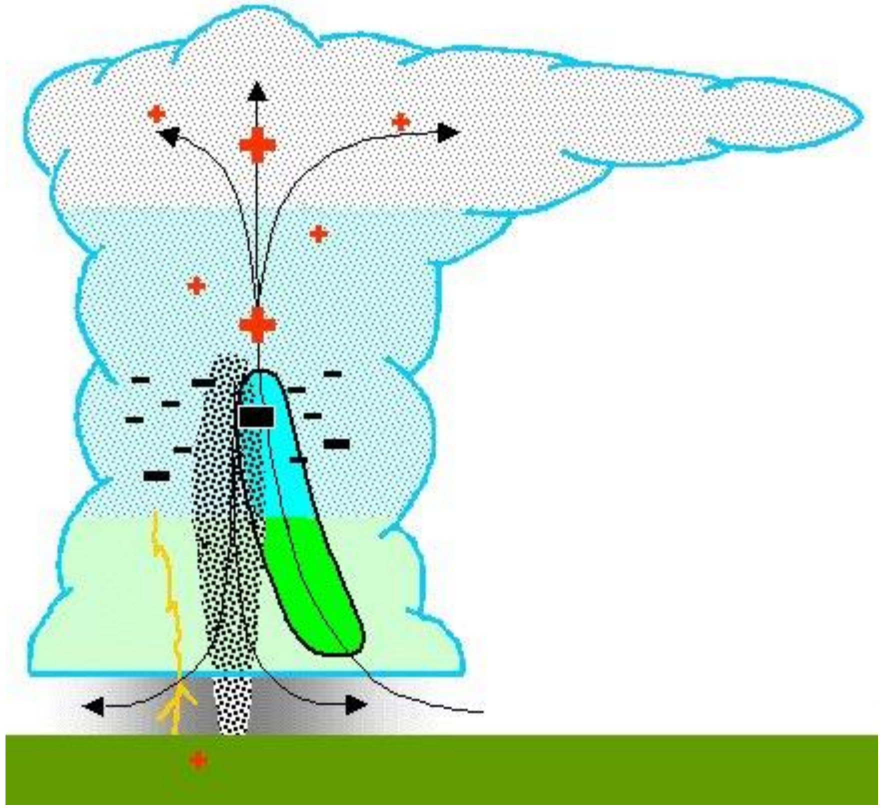
Charge separation:

•Charges reside on the ice-crystal surfaces

•During collision between particles, charges get transferred

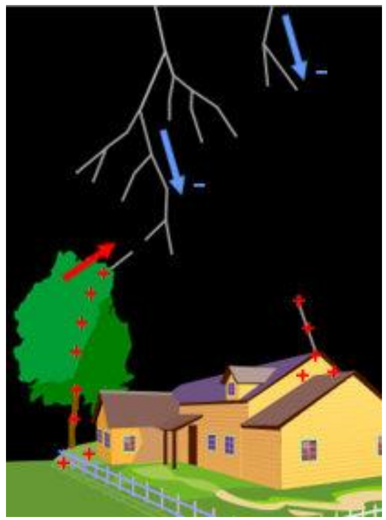
•Small ice crystals tend to acquire net positive charge and then get carried toward the cloud top

•Typical distribution of charges shown, but it can be much more complex

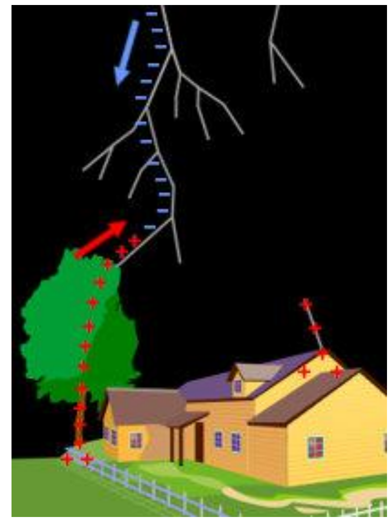


The lightning process

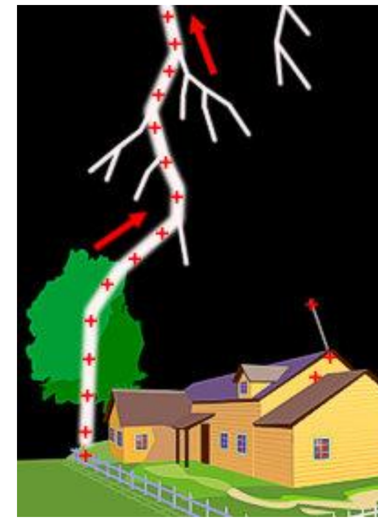
1: Stepped Leader
A series of steps about 50 meters (160 ft) in length and 1 microsecond (0.000001 seconds) in duration.
Studies of individual strikes have as many as10,000 steps!



2: Upward streamer
Induction causes positive charges to trace an upward path from high, sharp points until channels meet



3: Connection
Ionized path allows easy-flow of charge downward from cloud to surface



4: Return stroke
Positive charge from the ground flows back upward along the path. This is where most of the current is: 30000 Amps produces heat, glow, and thunder

Lightning and the rumbling thunder: an issue of path distance

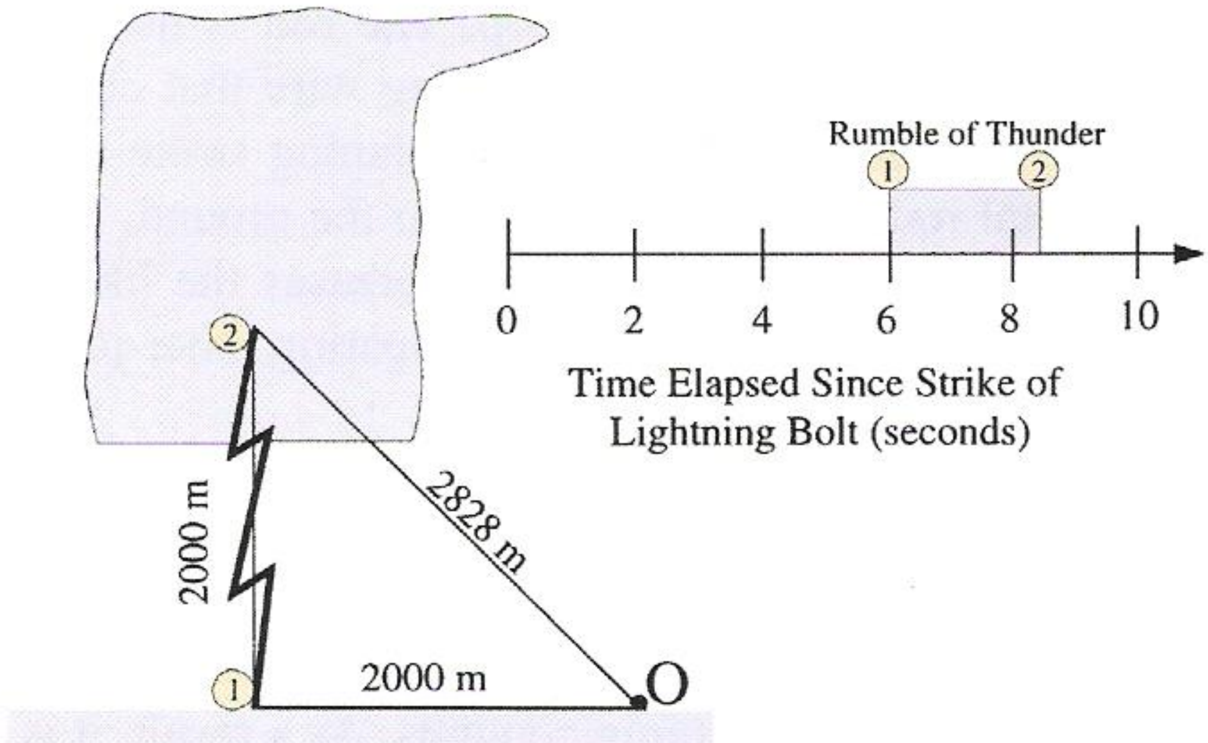


FIGURE 9.10 The distance between an observer (at point O) and a lightning bolt can be estimated by determining the length of time between seeing the bolt and hearing the thunder (the length of the hypotenuse of the right triangle is computed using the Pythagorean theorem—if the legs of a right triangle have lengths *a* and *b*, and the hypotenuse has length *h*, then $a^2 + b^2 = h^2$). In this example, the hypotenuse (the line from point O to point 2) is 2828 m long

Red Sprites discharging from the top of a thunderstorm

HAIL

Figure 11.31

Hailstones grow inside of thunderstorms, with clear and white rings developing as the stone cycles through the tall, moist cumulonimbus cloud. Hailstones fall out of the cloud when the updraft no longer can support the stone's weight. This hailstone is baseball-sized. However, the largest hailstone on record was found in Coffeyville, Kansas, in September 1970. It weighed over 0.7 kilograms (1.5 pounds) and had a diameter of 14 centimeters (5.5 inches).

(Points 2 and
can fall into
freezing and
the storm to
cally cycles t
4) of differen
through the
Small su
The rapid fr
multiple sca
spreading ov
supercooled
structure of
The proc
dant supply
large hailstor

1970 Coffeyville KA hailstone

Thunderstorms

HAIL DAMAGE

Thunderstorms

HAIL DAMAGE

NWS definition of a severe thunderstorm

- Hail 3/4" or larger, or basically the size of any coin or larger
(a dime is 11/16" which the NWS accepts as 3/4")

- Fallen tree limbs with a minimum diameter of an average adult's wrist

- Living trees uprooted or blown down

- Any part of a permanent, well-built structure damaged or destroyed

- Measured wind gust from a calibrated anemometer of 58 MPH (50 knots) or greater

SEVERE THUNDERSTORMS

THREE MAIN TYPES:

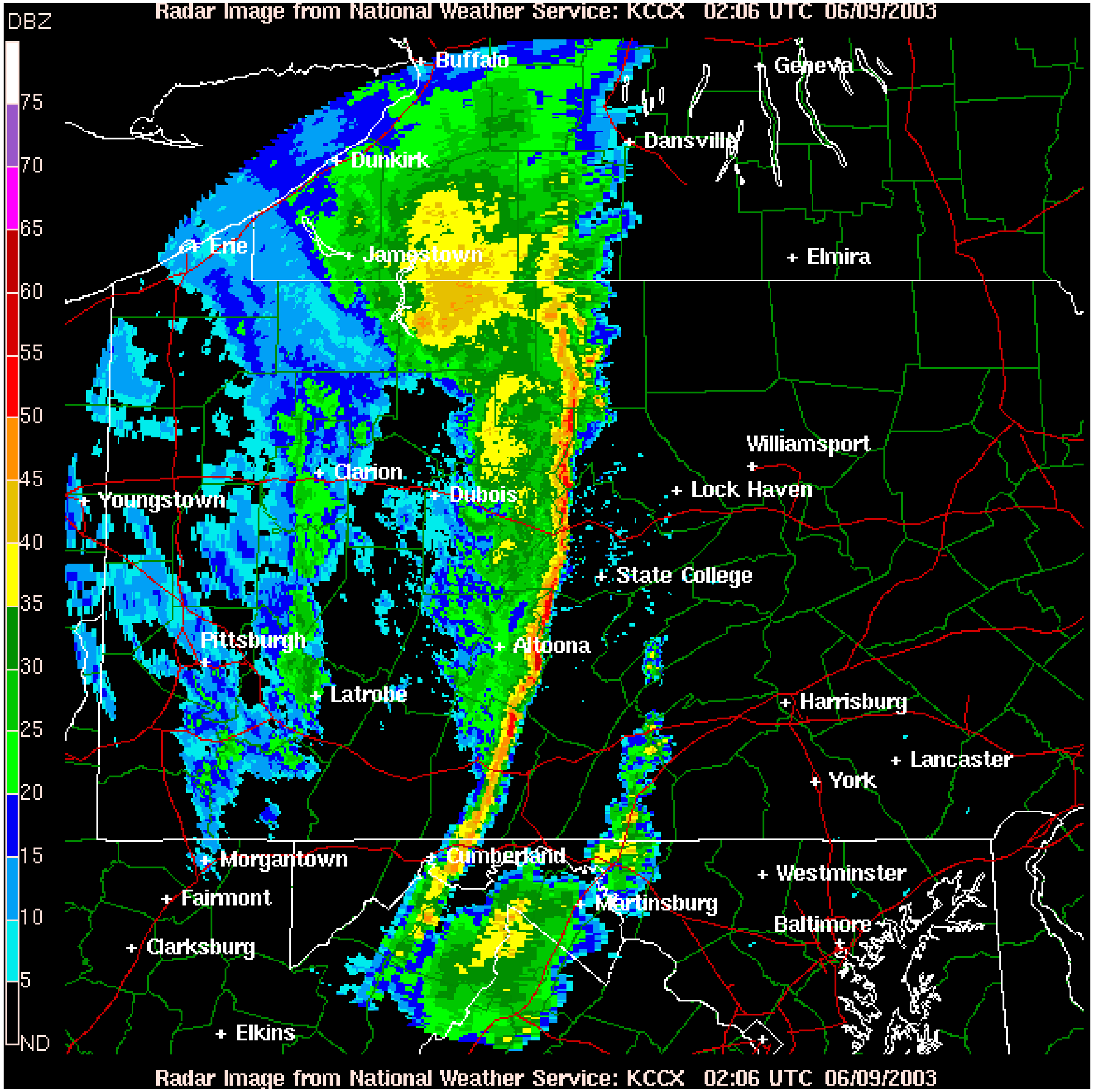
1) **SQUALL LINE THUNDERSTORMS**

2) **MESOSCALE CONVECTIVE COMPLEX (MCC)**

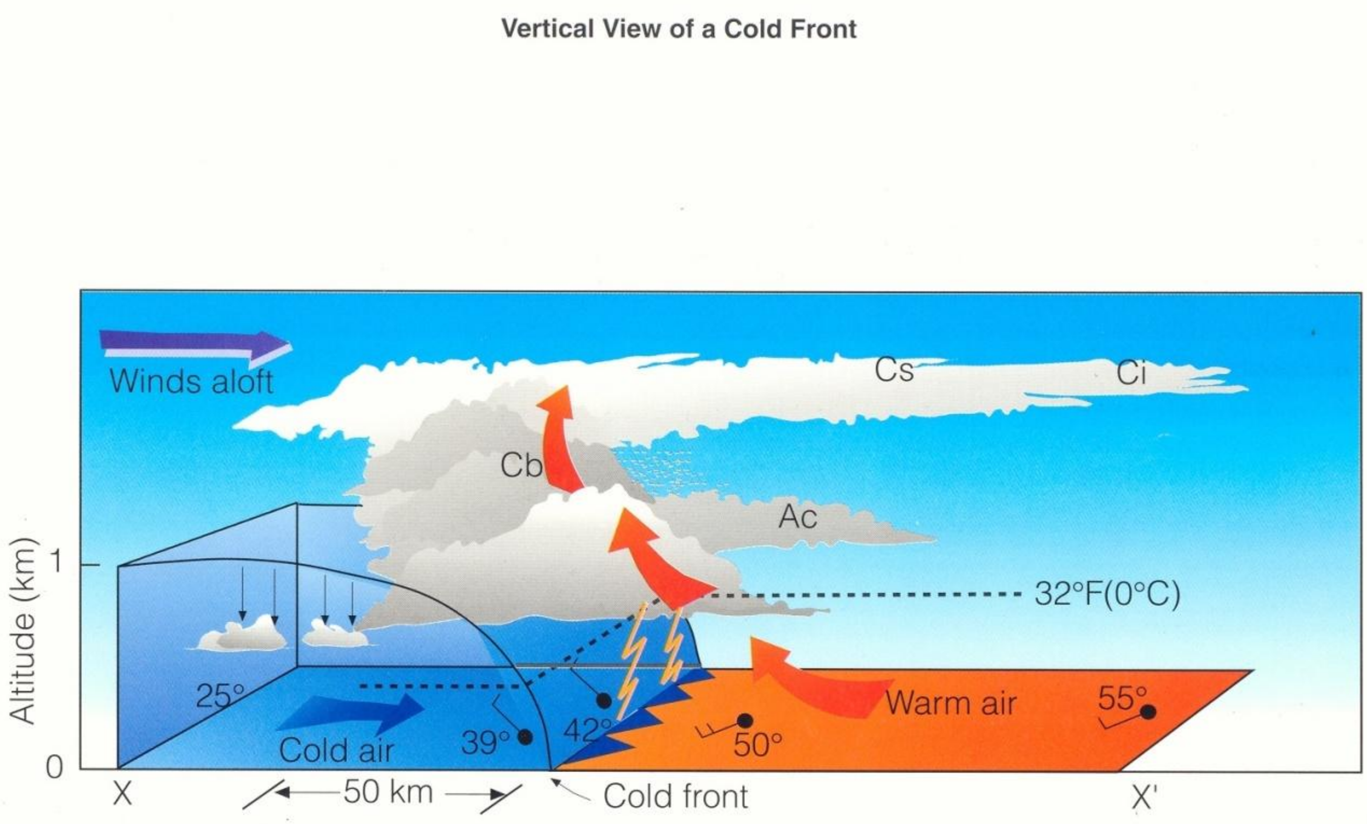
3) **SUPERCELL THUNDERSTORMS**

All three types last much longer than ordinary thunderstorms.
All three types need warm air and other factors in order to form.

SQUALL LINE ON RADAR

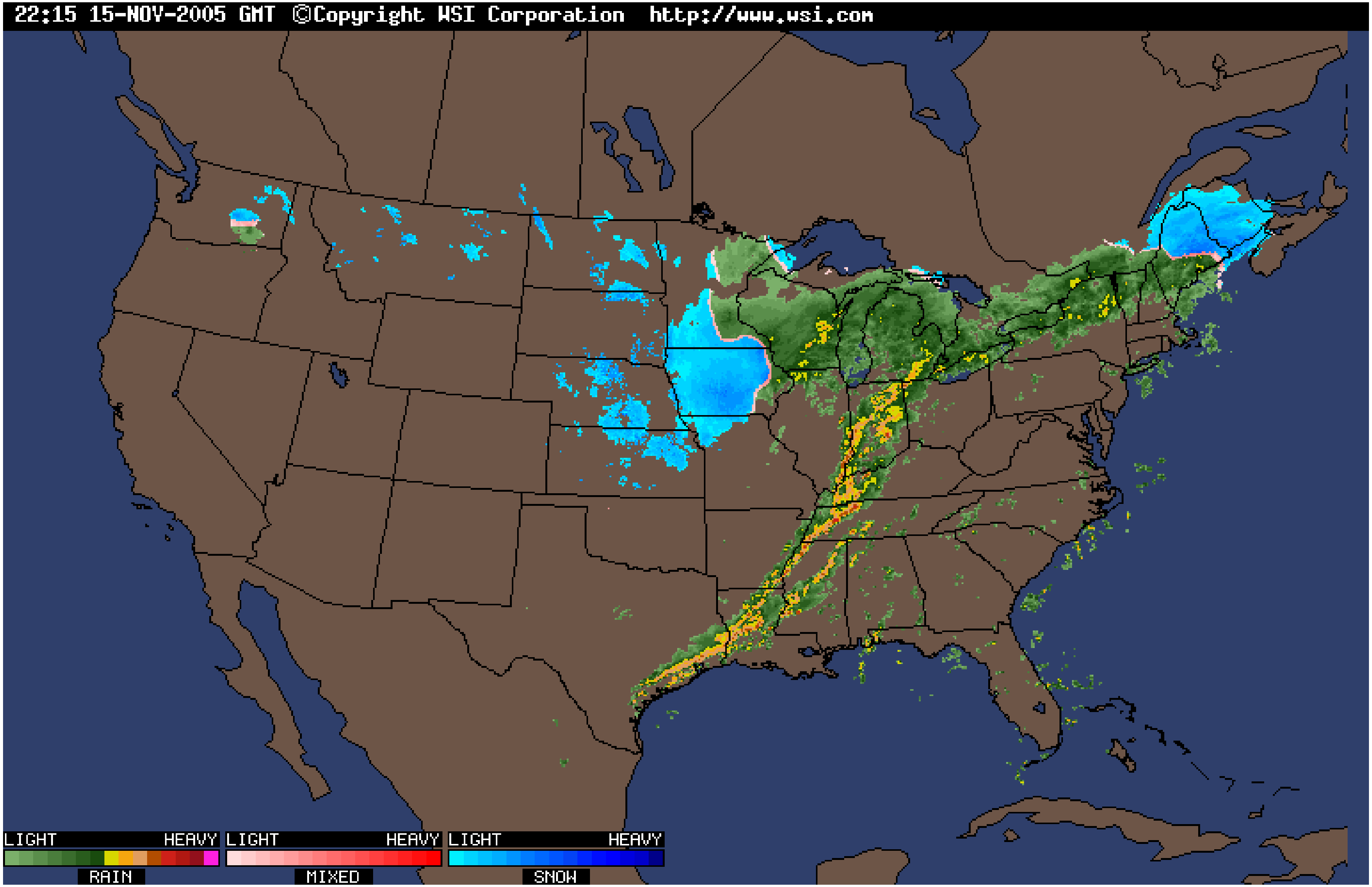


SQUALL LINE THUNDERSTORMS

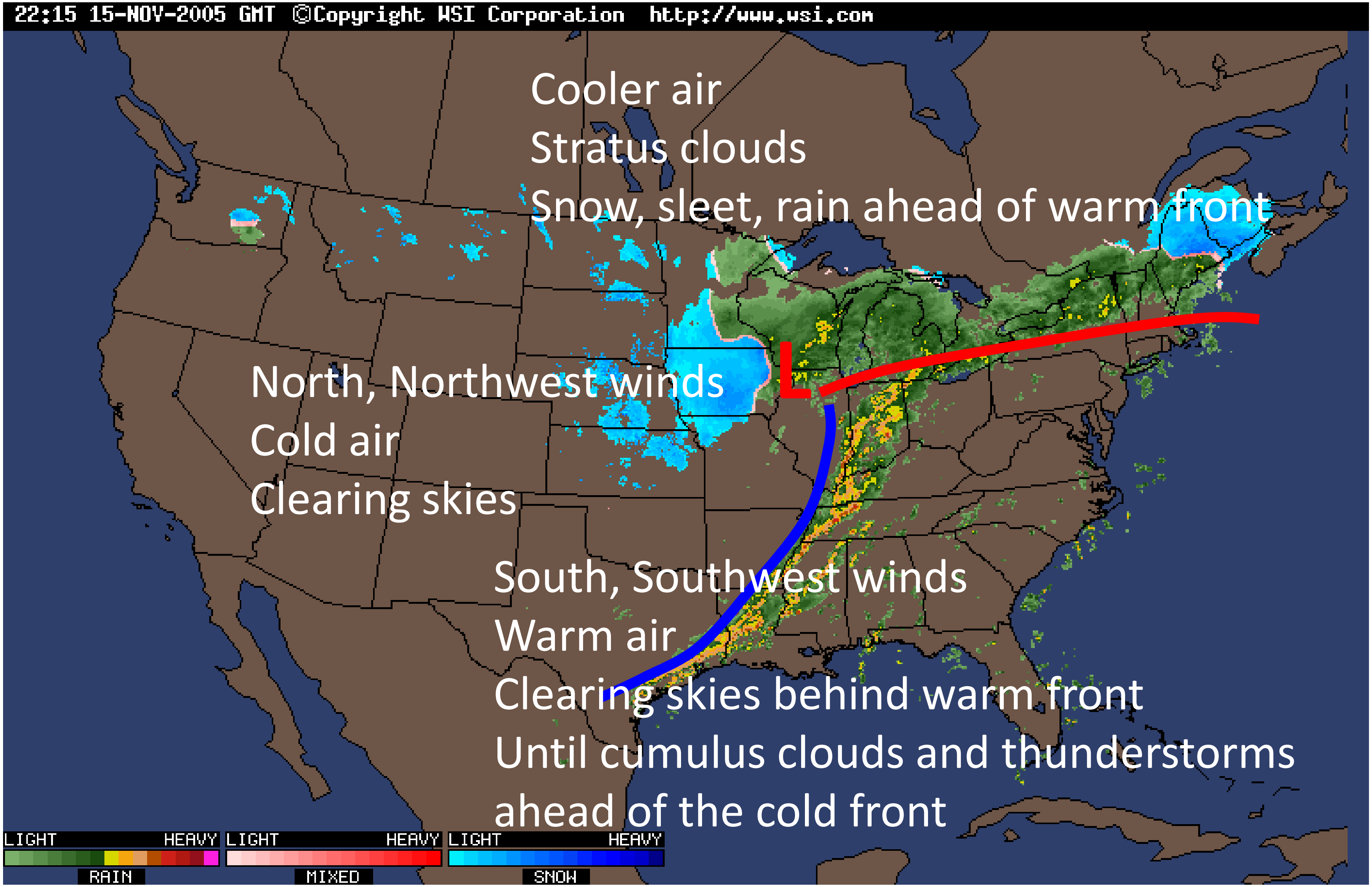


*Develop ahead of cold fronts
*Multi-cell storms
*Often produce wind damage (DOWNBURSTS)

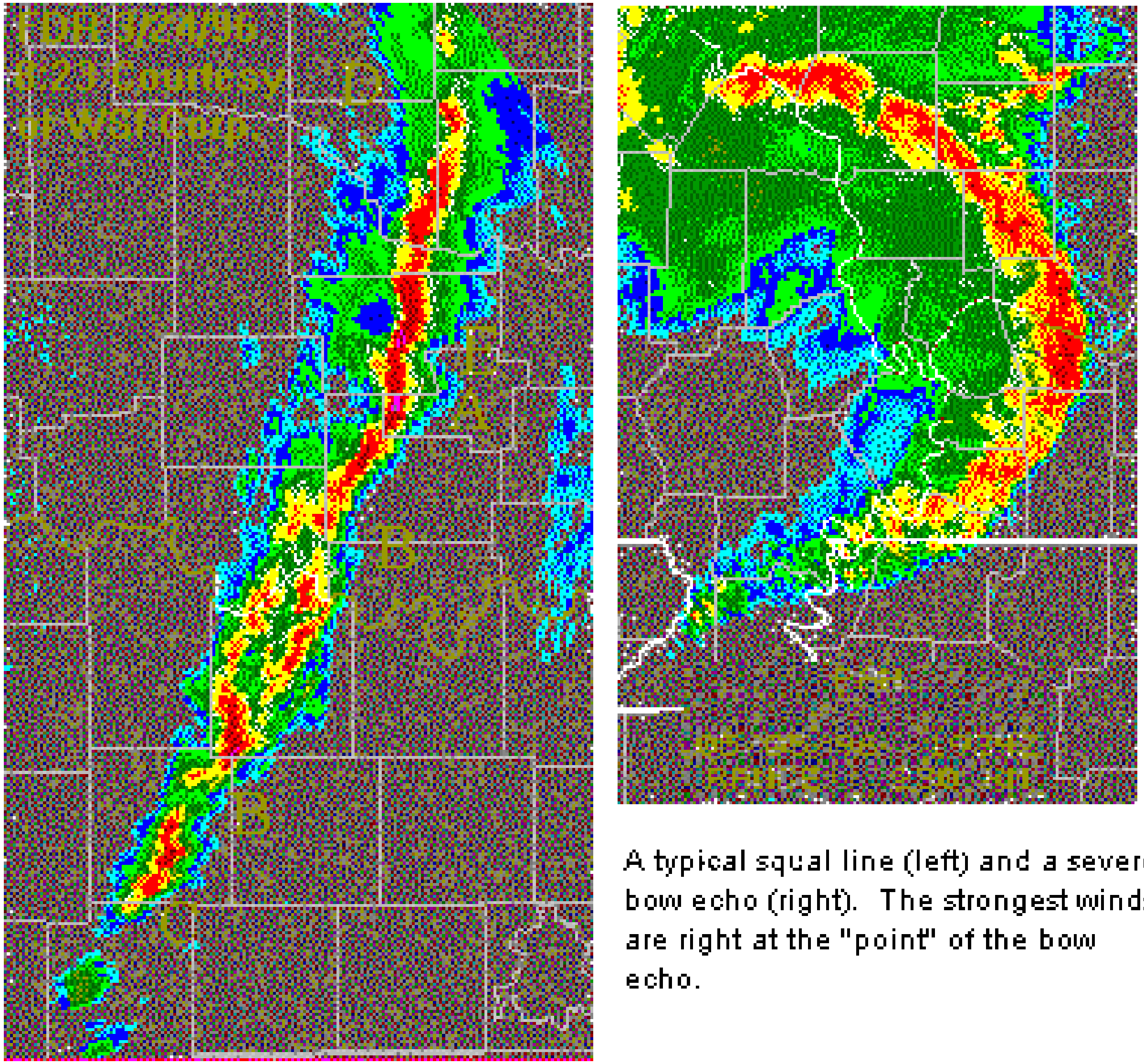
Squall Line Thunderstorms



Squall Line Thunderstorms

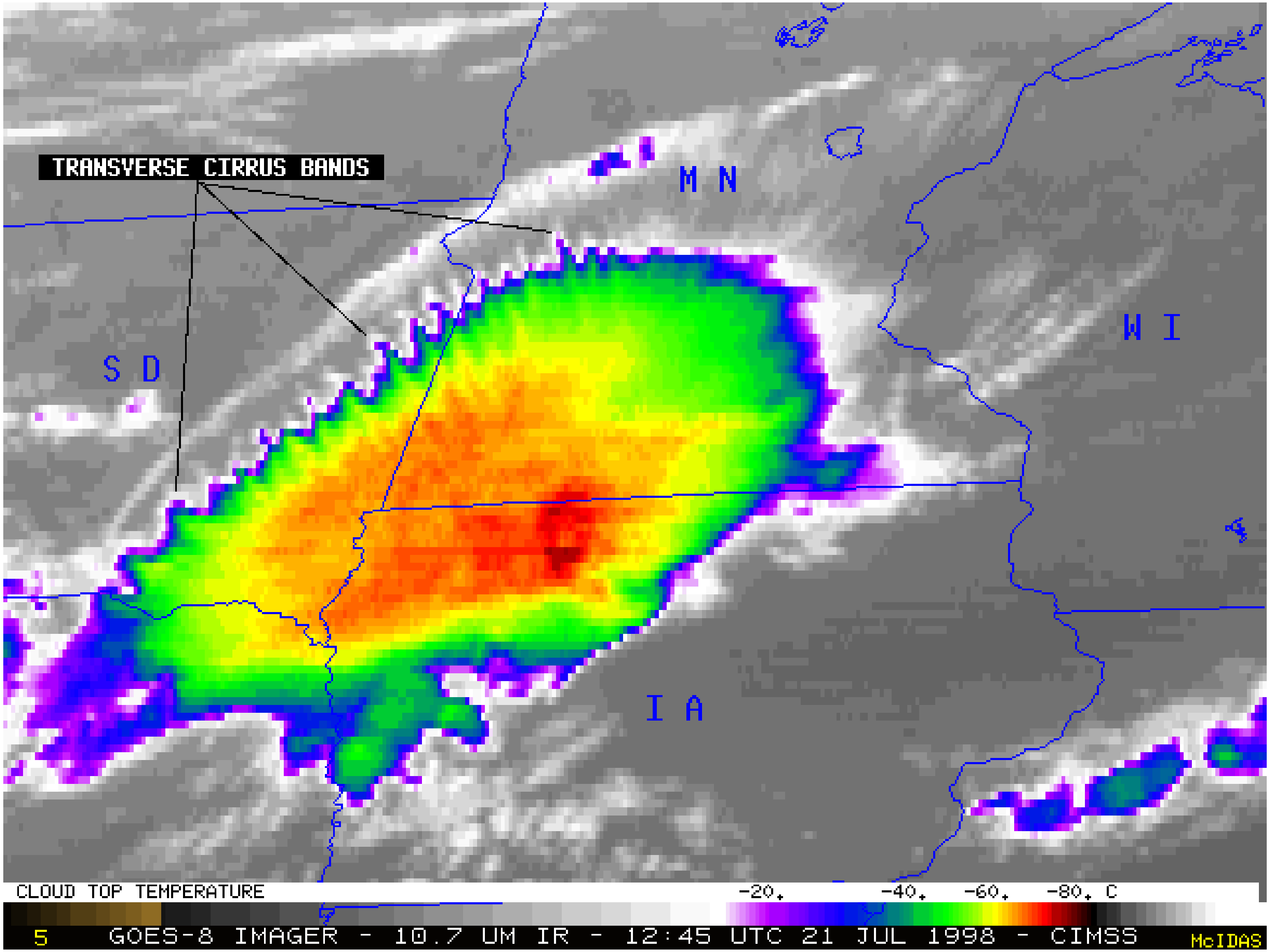


Squall Line Thundestorms



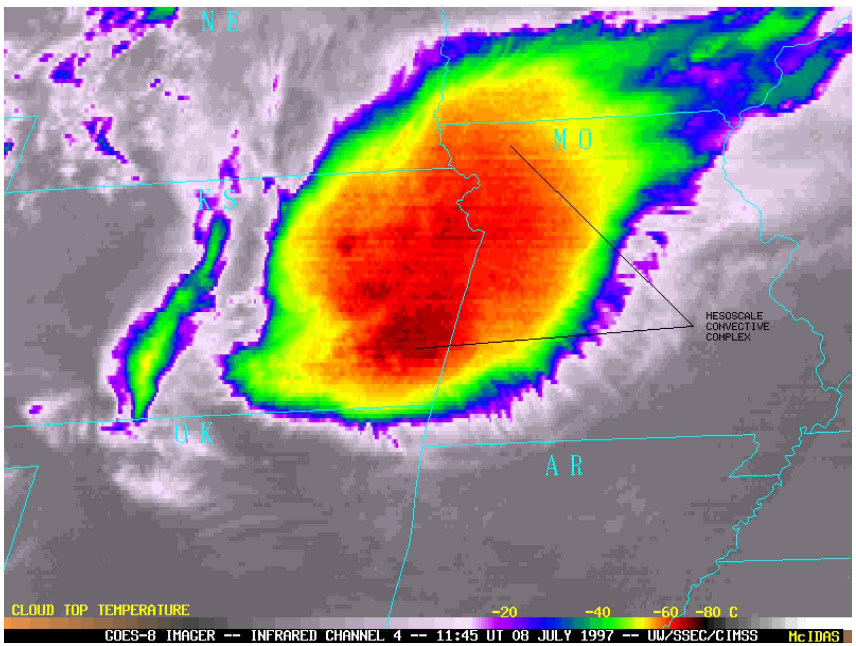
A typical squal line (left) and a severe bow echo (right). The strongest winds are right at the "point" of the bow echo.

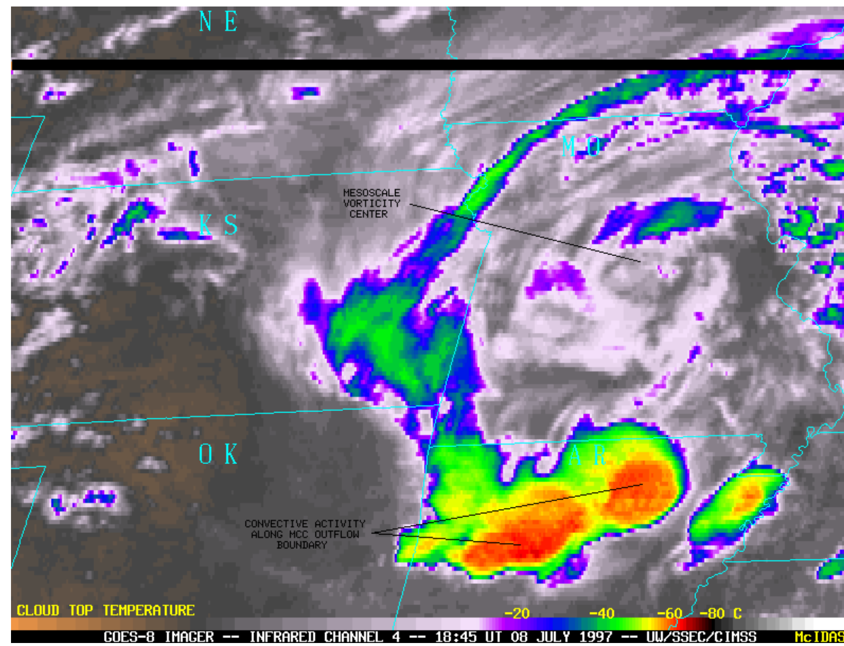
Mesoscale Convective Complex



MCC

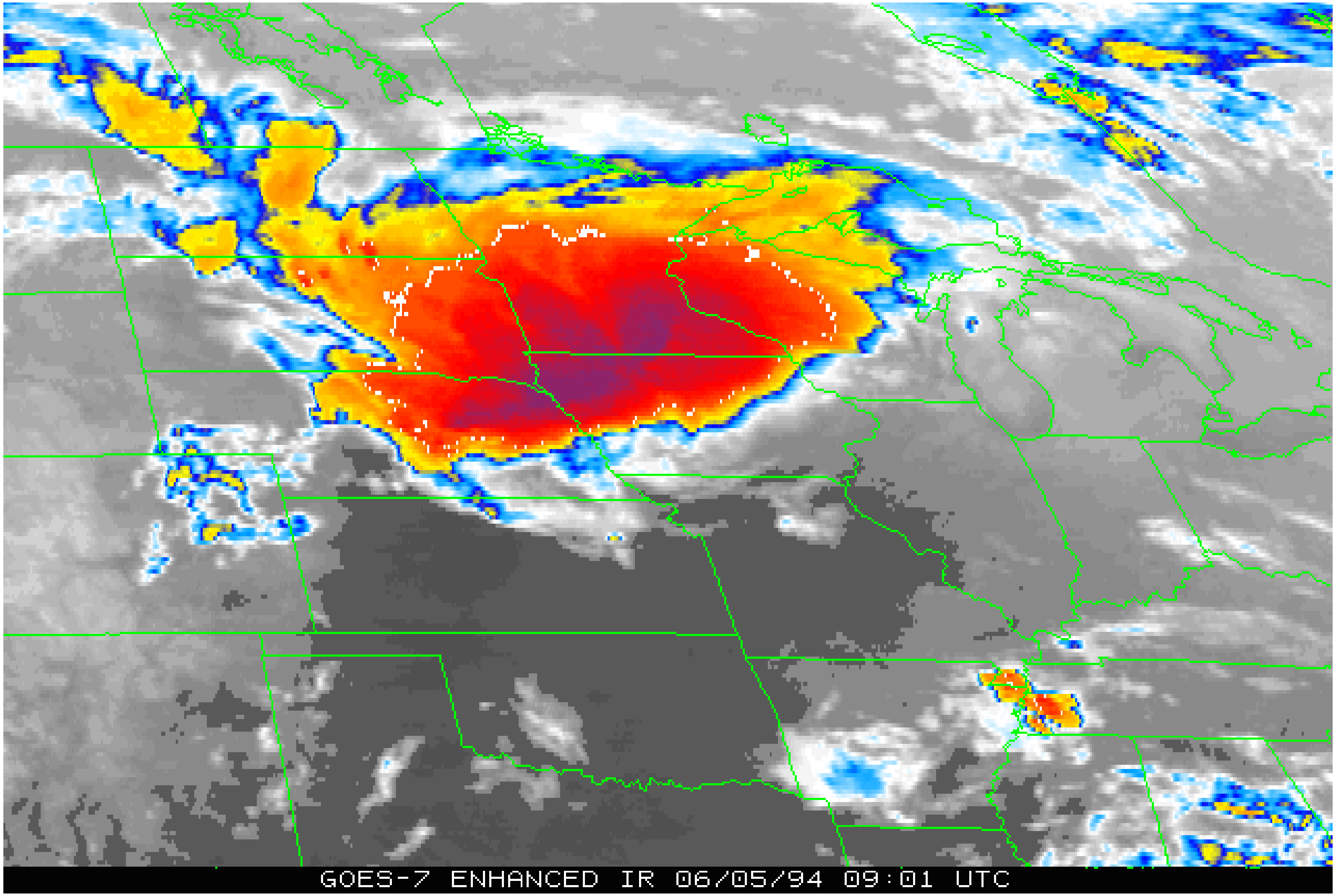
*MCC must live more than 6 hrs
*MCC high cloud cover must be larger than 18,000 square miles (size of CT, RI, MA)
*MCC high cloud cover must be circular in shape





Nebraska MCC moving Southeast, July 1997 – 7 hour difference between satellite images
CIMMS, WISC U

MCC



Minnesota MCC moving Southeast, June 1994
NCDC

MCC
The Great USA Flood of 1993

1993 Mississippi River, Grafton IL Flooding, USGS – the “500-year” flood

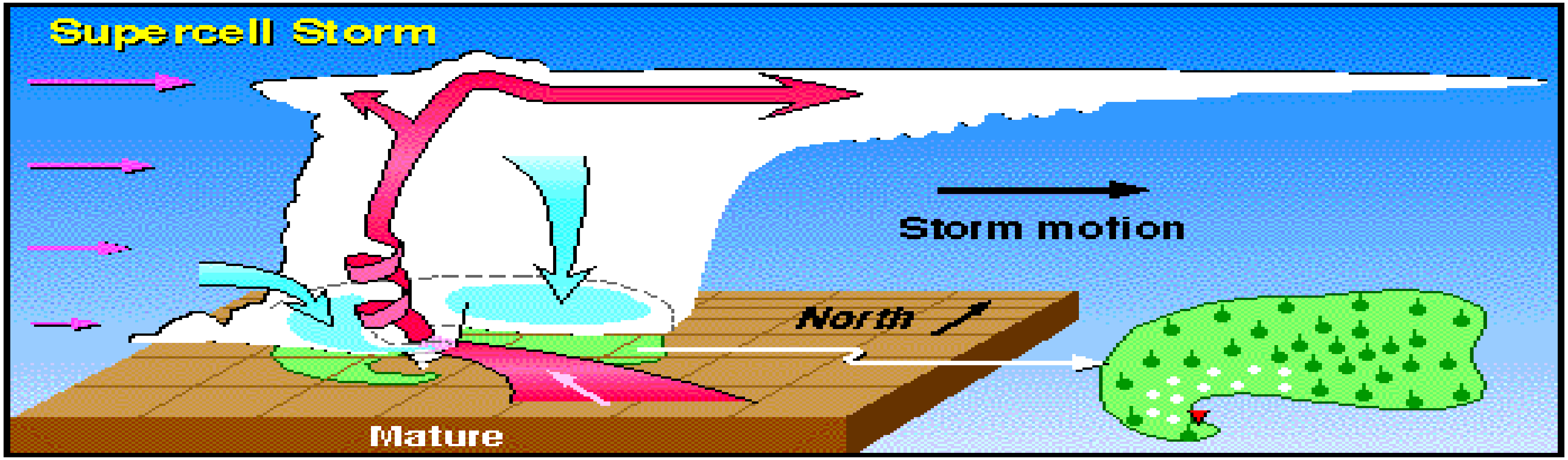
SUPERCELL THUNDERSTORMS

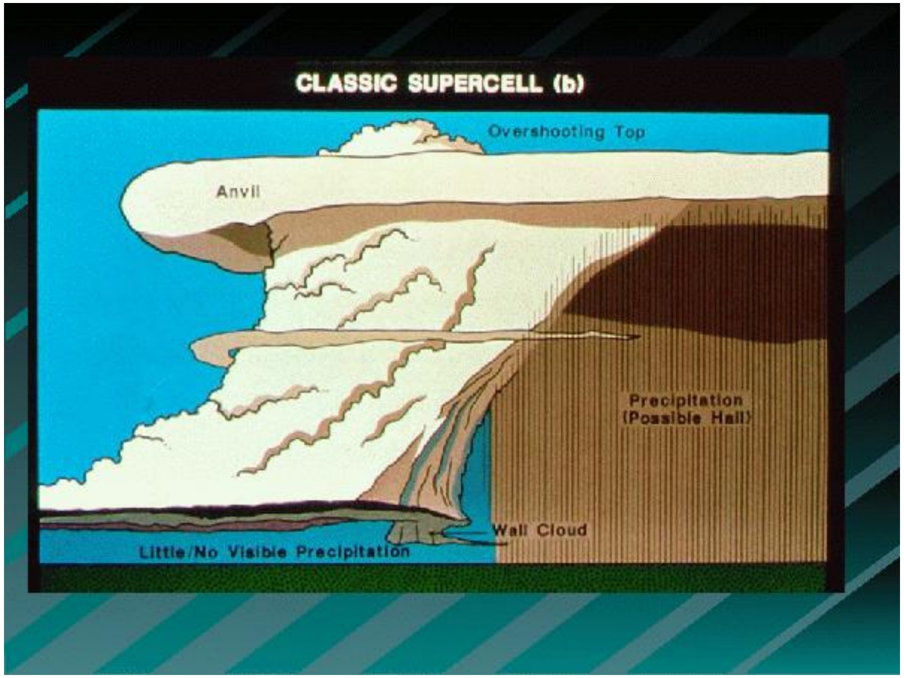
SUPERCELL THUNDERSTORMS

SUPERCELL THUNDERSTORMS

SUPERCELL THUNDERSTORMS

SUPERCELL THUNDERSTORMS





*Vertical Wind Shear

*Two Downdrafts

SUPERCELL THUNDERSTORMS

Chaseday.com

Supercell Thunderstorms

Robert Slattery

Figure 11.19

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

Tornados

Tornados

A rotating column of air

Tornados

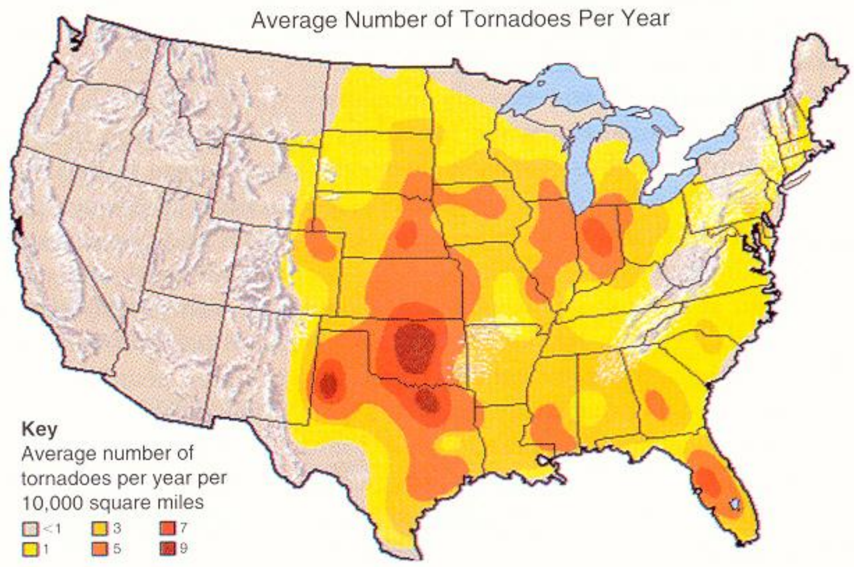
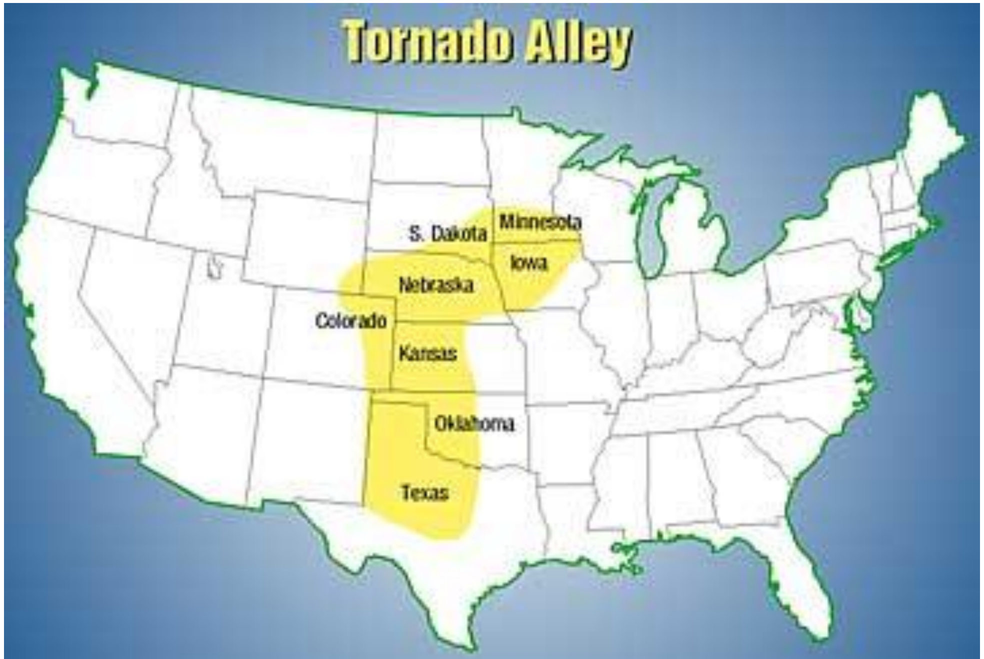
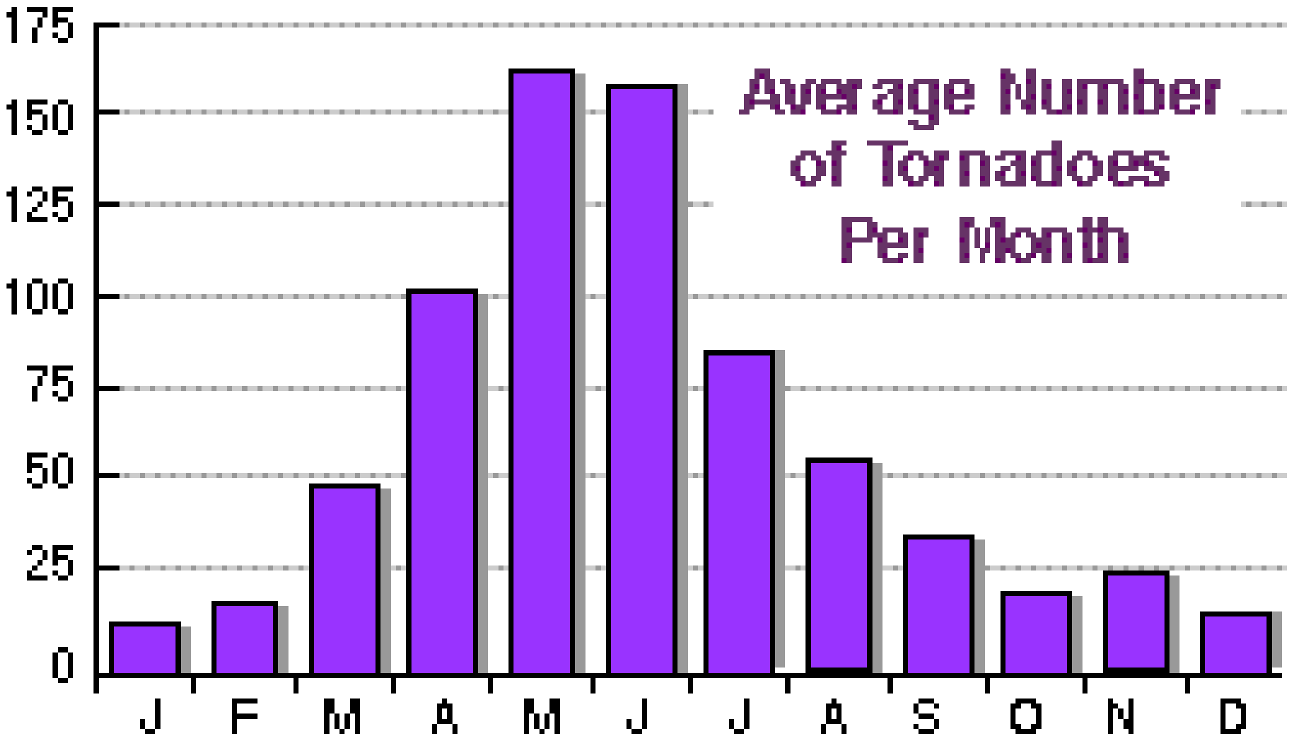


Figure 11.24

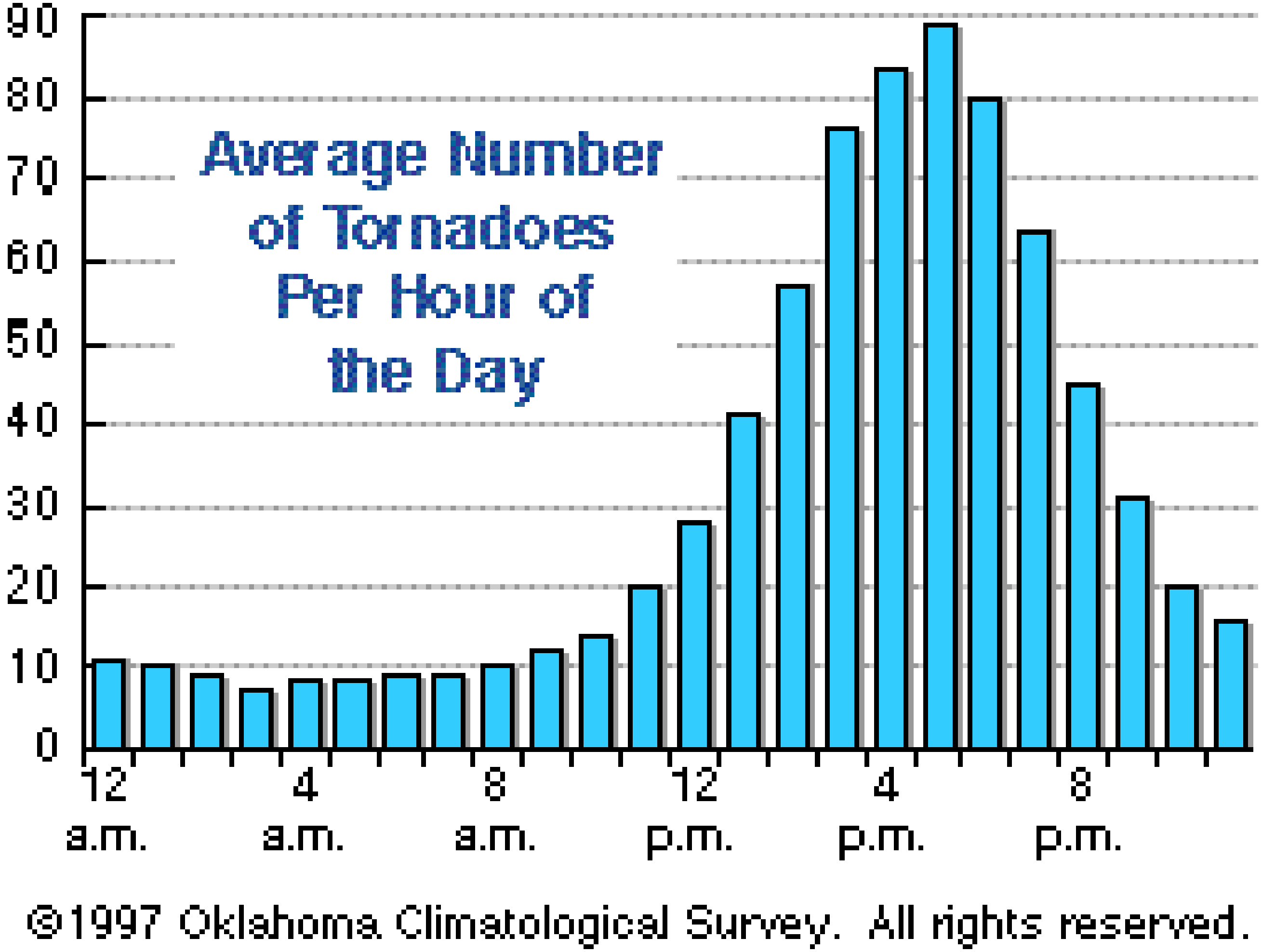
Average yearly number of tornadoes per 10,000 square miles across the lower 48 United States. The traditional "tornado alley" from Texas to Kansas stands out as the region of highest tornado occurrence. (Source: http://k12ocs.ou.edu/teachers/graphic/TornadoFreq.gif.)



Tornados


175
150
125
100
75
50
25
0
Average Number of Tornadoes Per Month
J
F
M
A
M
J
J
A
S
O
N
D

Tornados



90
80
70
60
50
40
30
20
10
0
Average Number of Tornadoes Per Hour of the Day
12 a.m.
4 a.m.
8 a.m.
12 p.m.
4 p.m.
8 p.m.
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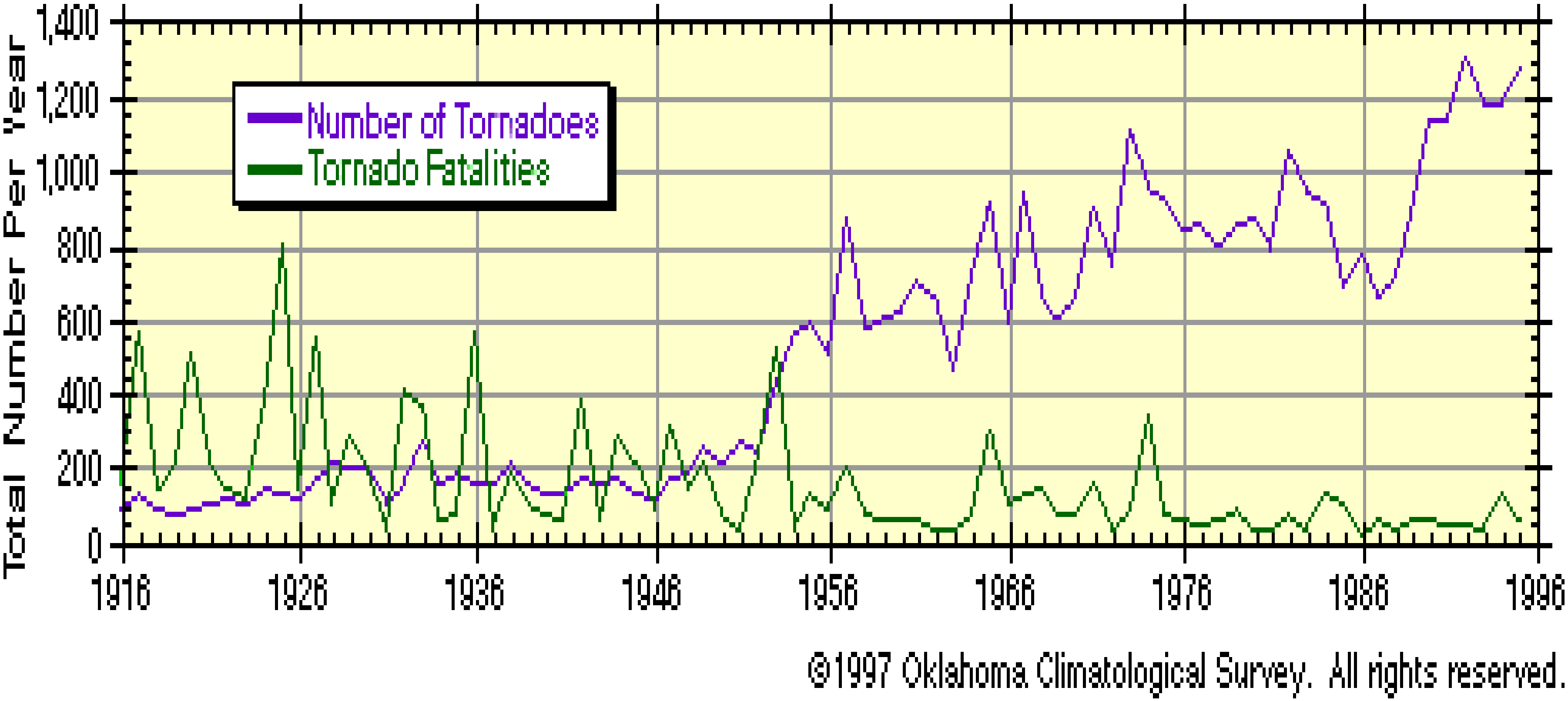
Tornados


Number of Tornadoes
Tornado Fatalities
Total Number Per Year
1,400
1,200
1,000
800
600
400
200
0
1916
1926
1936
1946
1956
1966
1976
1986
1996
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Development of Spin in a thunderstorm: Divergence and Wind Shear

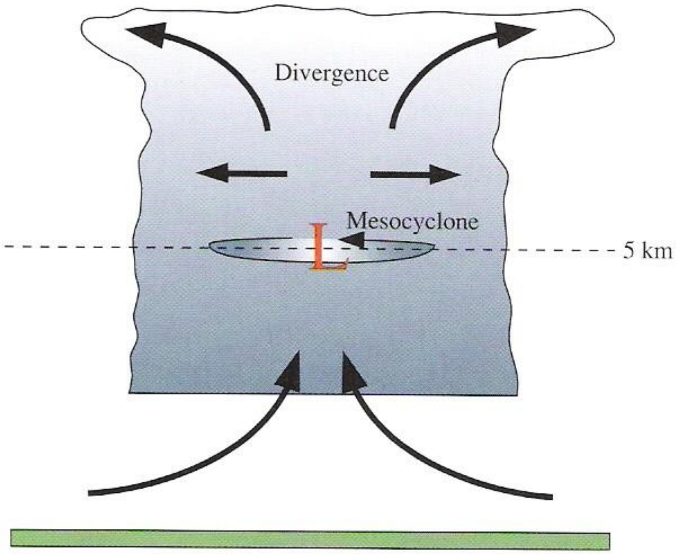


FIGURE 15.11 A small-scale low-pressure system called a mesocyclone can first appear at altitudes near 5 or 6 km (3 or 4 mi) within a supercell.

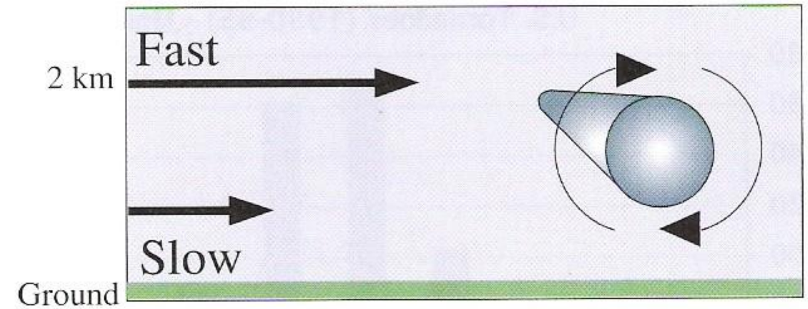


FIGURE 15.9 When winds at altitudes near 2 or 3 km (6500 to 9800 ft) blow appreciably faster than winds near the ground, enough speed vertical wind shear exists for tubes of air to rotate about a horizontal axis, forming a "horizontal roll."

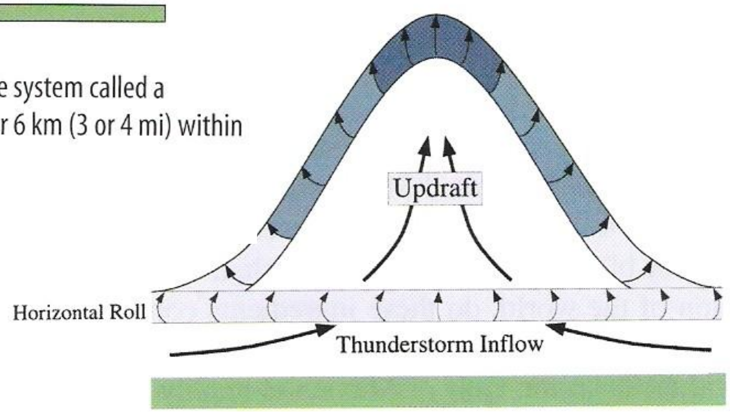
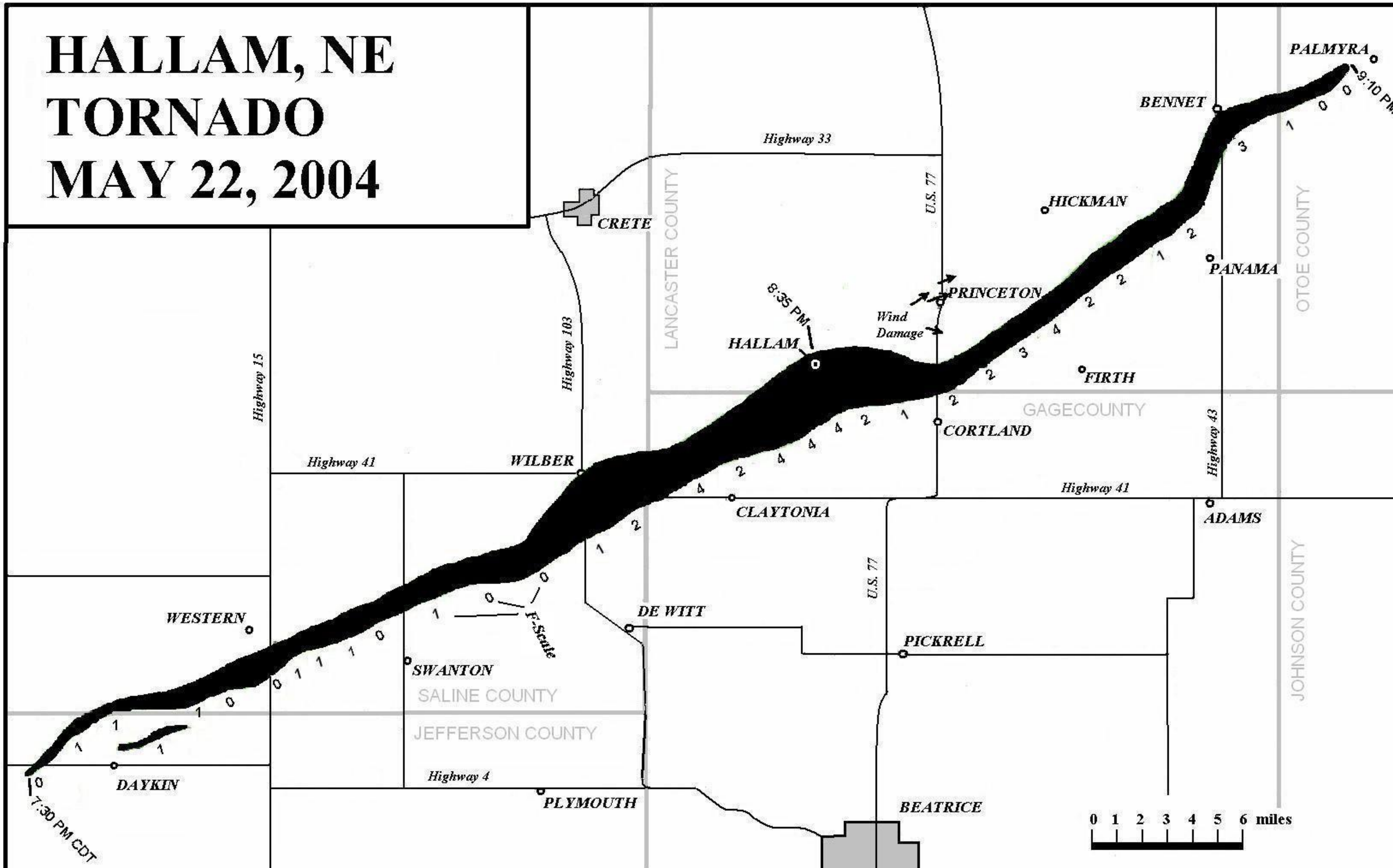


FIGURE 15.10 Once a "horizontal roll" forms in response to speed vertical wind shear in the lowest 2 or 3 km (6500 to 9800 ft), the updraft of a developing supercell tilts the horizontal roll vertically. Though distorted, the roll acquires some rotation about a vertical axis, an important first step in the process of making a tornado.

http://esminfo.prenhall.com/science/geoanimations/animations/Tornadoes.html

Tornado Tracks: Width, length, and intensity vary widely



BASED ON STORM SURVEYS BY NWS OMAHA/VALLEY AND EMERGENCY MANAGEMENT

The New Fujita Scale

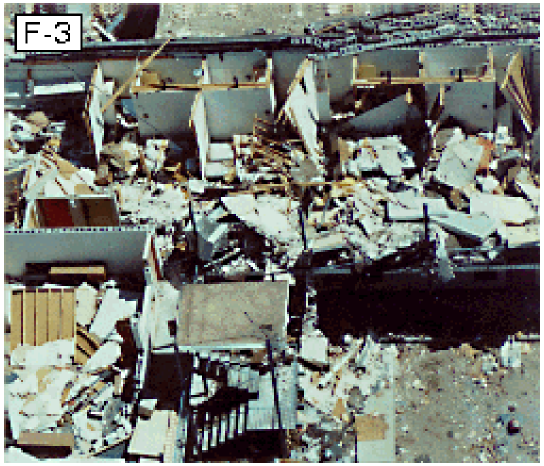
ORIGINAL FUJITA SCALE		ENHANCED FUJITA SCALE	
F5	261-318 mph	EF5	+200 mph
F4	207-260 mph	EF4	166-200 mph
F3	158-206 mph	EF3	136-165 mph
F2	113-157 mph	EF2	111-135 mph
F1	73-112 mph	EF1	86-110 mph
F0	<73 mph	EF0	65-85 mph

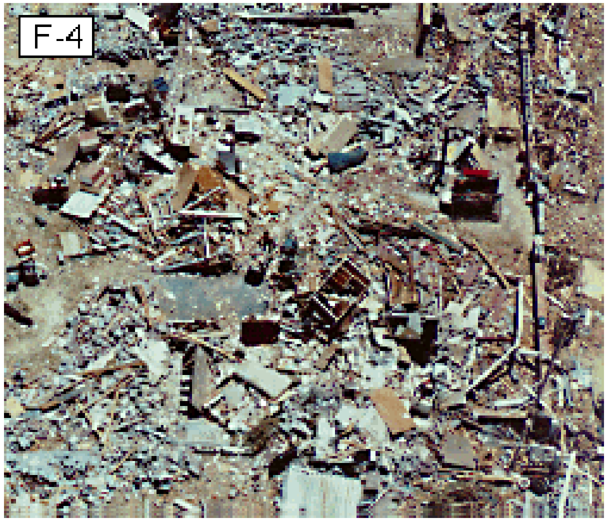
http://www.spc.noaa.gov/faq/tornado/ef-scale.html

http://whyfiles.org/013tornado/3.html

http://www.pbs.org/wgbh/nova/tornado/damage.html

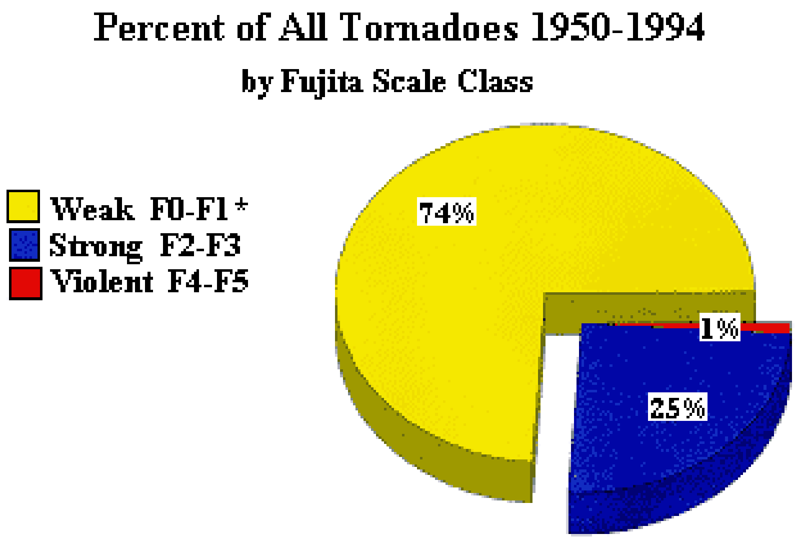
Tornado Damage

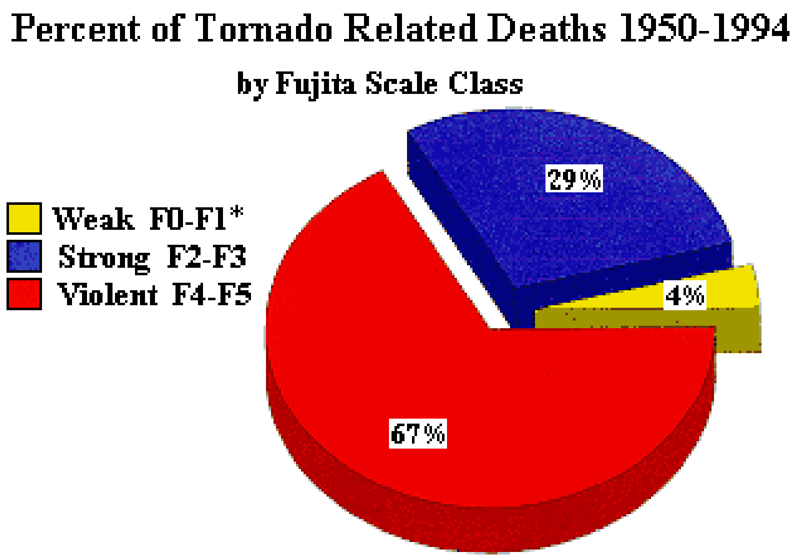




NSSL

Tornado Facts





Tornadoproject.com

Area most likely to find favorable conditions for tornados

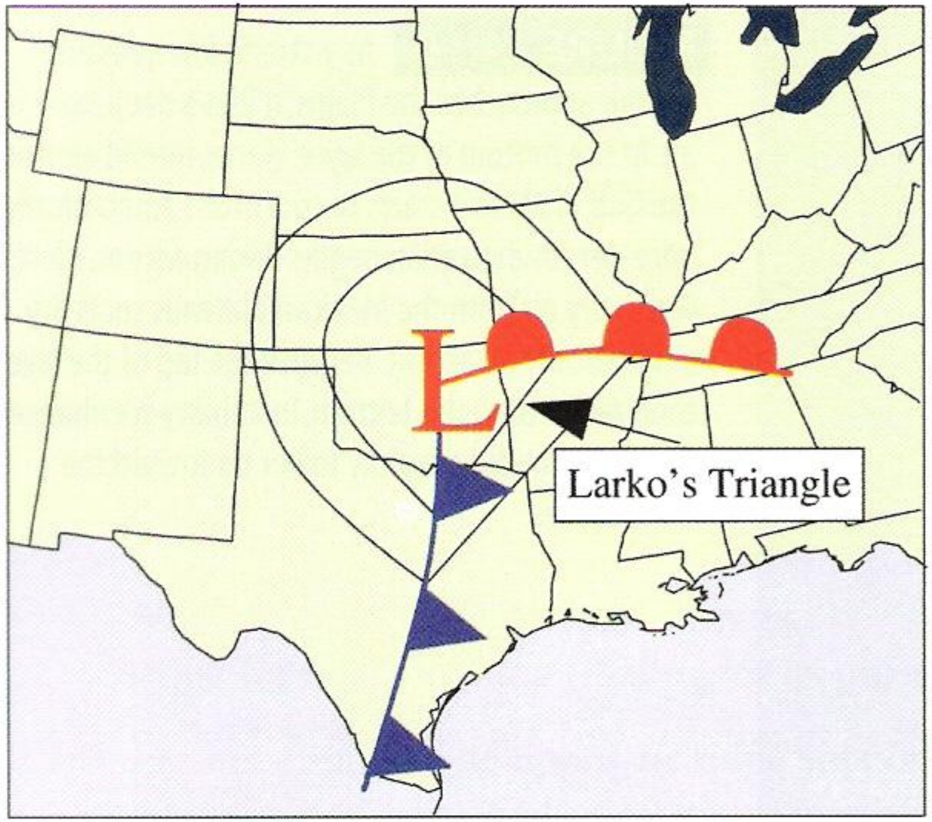
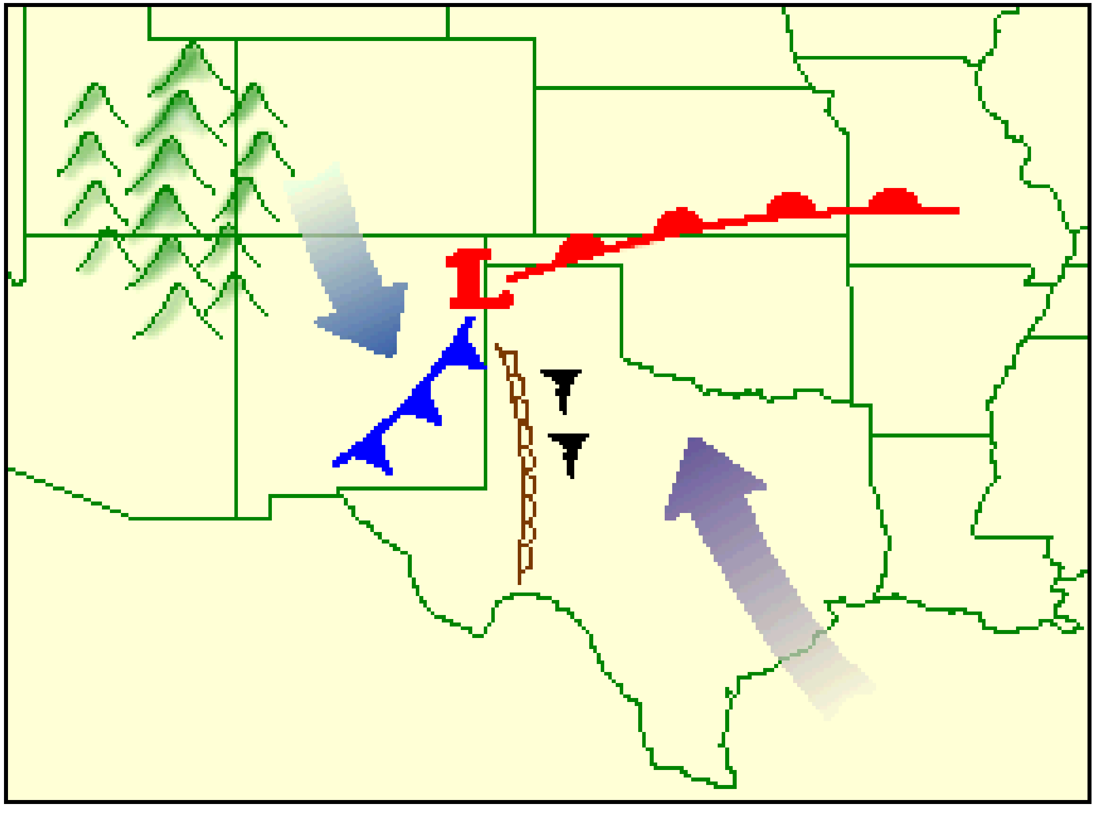


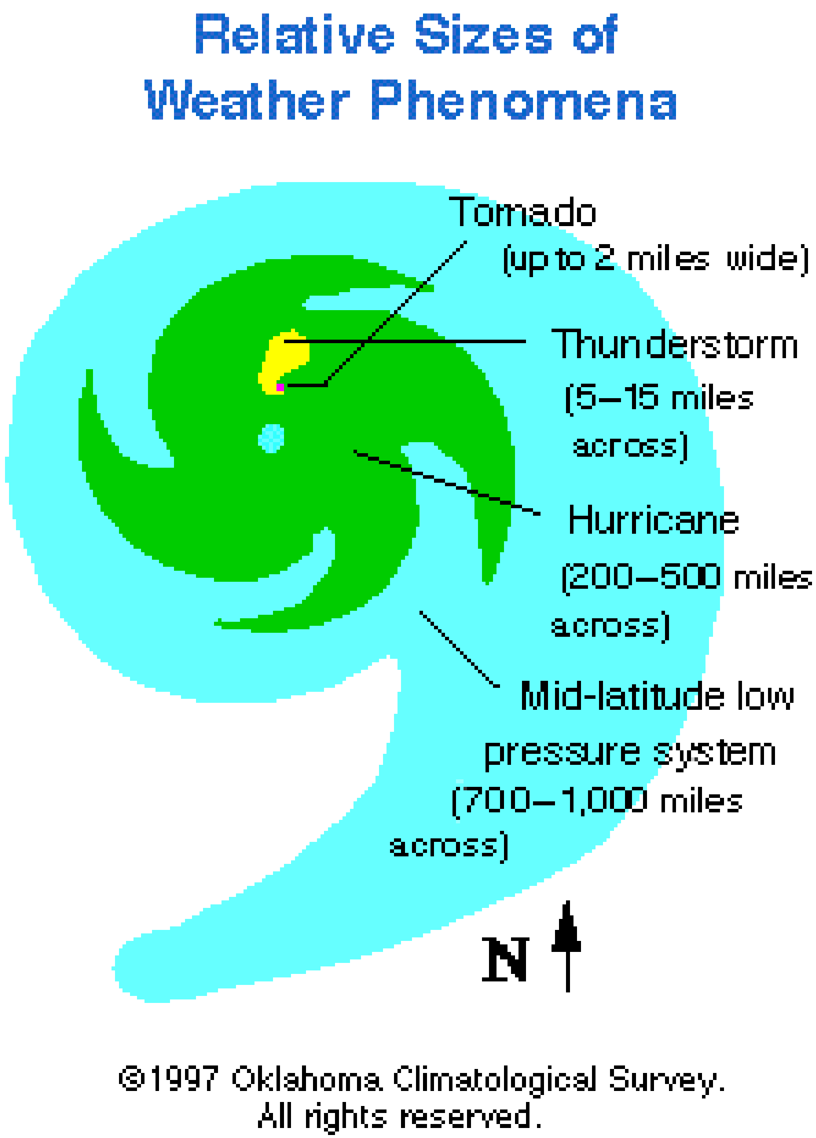
FIGURE 14.18 For synoptic patterns that favor outbreaks of tornadoes, the forecasting tool called Larko's Triangle, defined as the triangular area bounded by the cold front, warm front, and first isobar around the low, can be used as a first estimate for the region where tornadoes will develop. If the area inside the first isobar is small, the region can be expanded to include the second or even the third isobar.

Tornado Facts



NSSL

Size of Tornados



DOPPLER RADAR

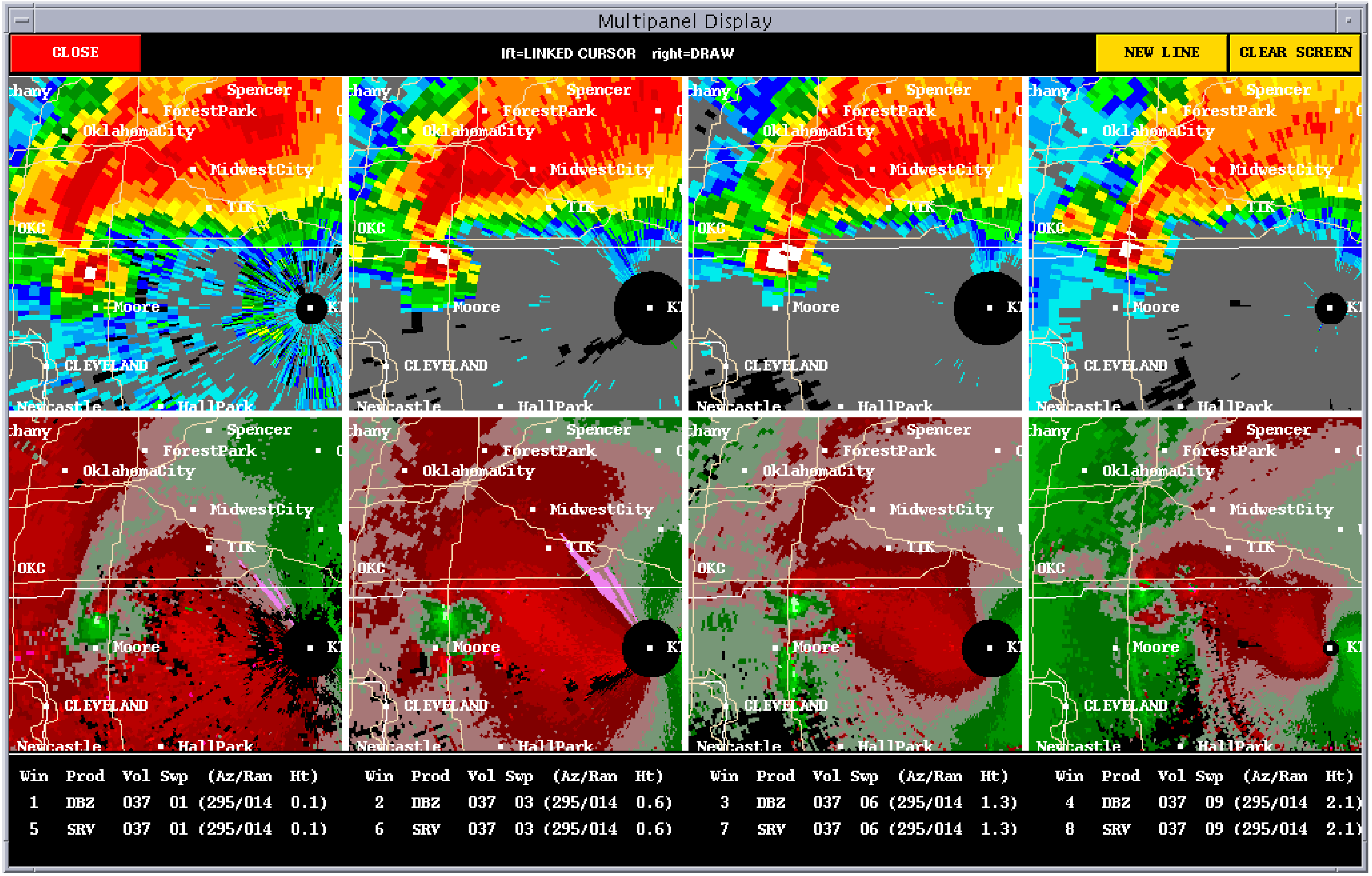
NWS

May 3, 1999 Oklahoma City Tornado Outbreak

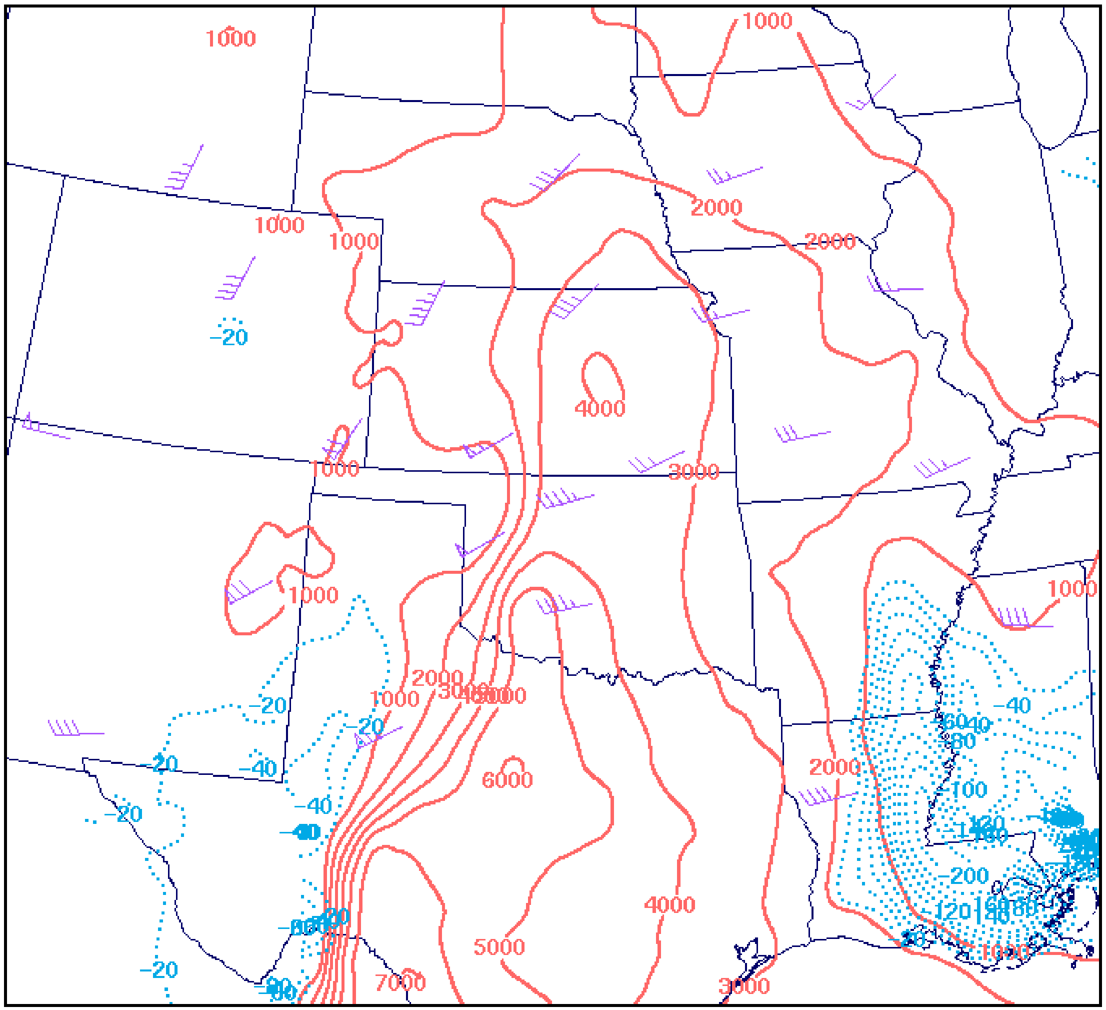
NWS Norman

May 3, 1999 Oklahoma City Tornado Outbreak

Doppler on Wheels: 301 mph record measured wind speed

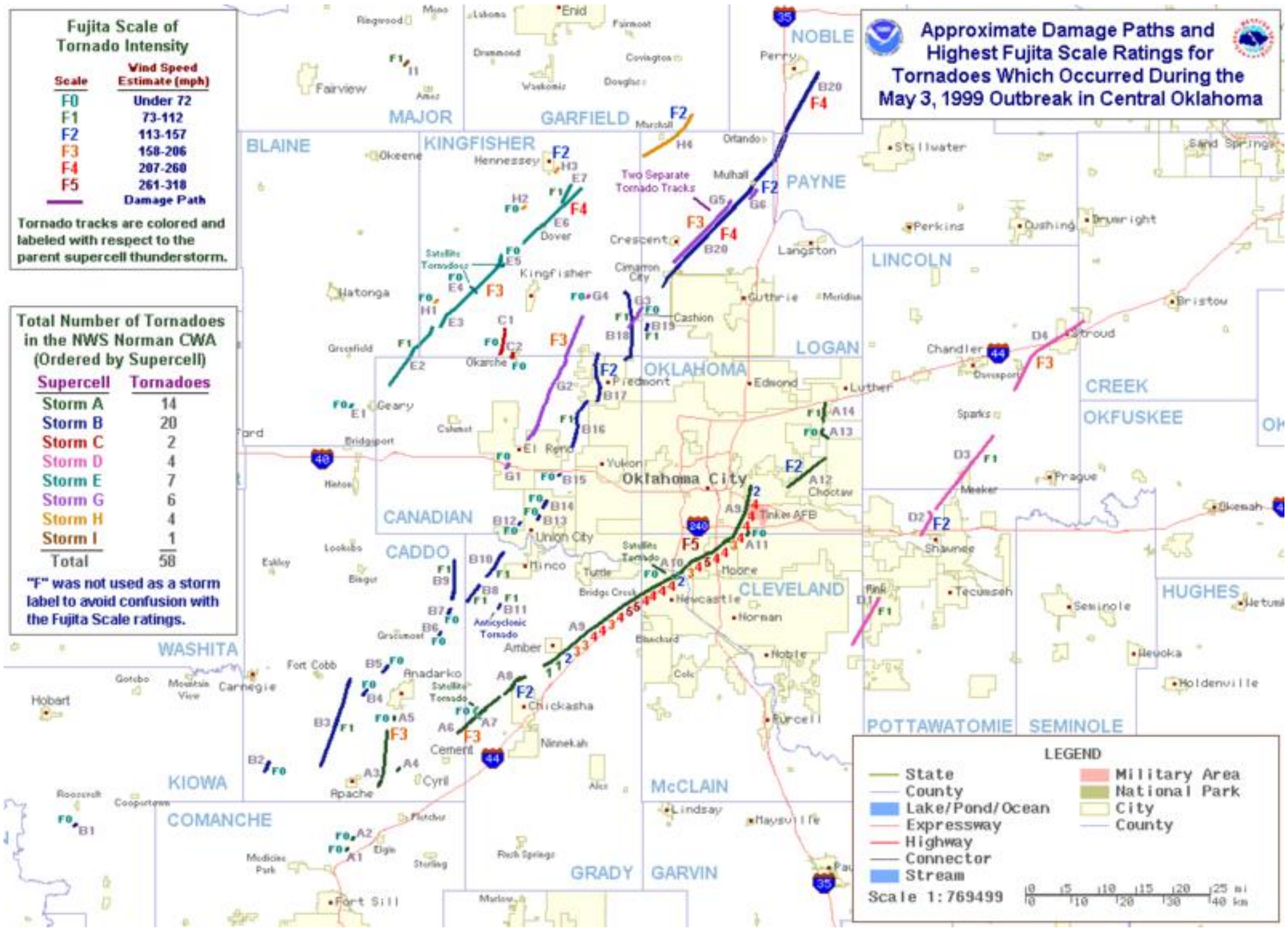


May 3, 1999 Oklahoma City Tornado Outbreak



NWS Norman

May 3, 1999 Oklahoma City Tornado Outbreak



NWS Norman

Multiple Vortex Tornado

Tornados

Merilee Thomas

Figure 11.17
Why chase tornadoes when they can come to you? Audra Thomas poses in front of a majestic tornado passing across the Thomas farm near Beaver City, Nebraska, on April 23, 1989.

Sideways Tornado

Rope Tornado

Rope Tornado

Tornado damage

Suction Vortices Signatures

SPC

Other Rotating Columns of Air: Waterspout

J. Golden, NOAA/American Red Cross

Figure 11.26

A waterspout in the Florida Keys, as photographed by meteorologist Joe Golden.

Other rotating columns of air: Dust-devil

BOM Australia