

12.103
The Science and Policy of
Natural Hazards

Module 3:
Tornadoes

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What is a Tornado?

Glossary Definition: A violently rotating column of air, in contact with the ground, either pendant from a **cumuliform** cloud or underneath a cumuliform cloud, and often (but not always) visible as a **funnel cloud**.

Tornadoes need not have funnel clouds

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<http://www.newtonarc.net/weather/tornado2.jpg>

TORNADO

- **WORD DERIVED FROM SPANISH WORD 'TORNADA' – THUNDERSTORM**
- **TORNADOS ARISE FROM SEVERE THUNDERSTORMS**
- **MOST TORNADOS OCCUR IN THE CENTRAL US**
- **ON AVERAGE ABOUT 770 TORNADOS ARE REPORTED ANNUALLY IN THE US**
- **OCCUR ALL YEAR ROUND, BUT MAINLY FROM APRIL TO JUNE**

TORNADO

- **LESS THAN 1.6 KM WIDE, AND SHORT LIVED – A FEW SECONDS TO MORE THAN AN HOUR...MOST ~10 MINUTES**
- **TRAVELS AT ABOUT 45 KM PER HOUR AND AVERAGE PATH IS ABOUT 8 KM LONG**
- **PRESSURE AT CENTER OF VORTEX AS MUCH AS 10% LOWER THAN SURROUNDINGS.**
- **WIND SPEEDS AS LARGE AS 140 M/S (300 MPH) HAVE BEEN MEASURED**

TORNADO MORPHOLOGY

Formative Stage

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<http://www.image.ucar.edu/GSP/Projects/KhareTornado.jpg>

Mature Stage

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http://texastailchaser.com/chases/2008/20080523/IMG_6429.JPG

Rope Stage

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[http://www.jondavies.net/photos/tornadoes/061204mulvanetor_rope2\(c\)_sml.jpg](http://www.jondavies.net/photos/tornadoes/061204mulvanetor_rope2(c)_sml.jpg)

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Orienta, Oklahoma, 2 May 1979

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http://2.bp.blogspot.com/_EnpquhPP5Hw/SordHJRIfnI/AAAAAAAAAEkk/rPvKWNg3UoE/s400/bulacan+tornado+august+16+2009.jpg

http://upload.wikimedia.org/wikipedia/commons/d/d1/Binger_Oklahoma_Tornado.jpg

<http://weatherpictureoftheday.files.wordpress.com/2008/08/07-11-01tornado.jpg>

Tornado Damage

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Ranking Tornado Strength: The Fujita Scale

The Fujita Scale for Tornadoes

Category	Damage		Wind speed range	
			mph	km/hr
F0	Light	Tree branches broken; heavy damage to crops; chimneys damaged.	40-73	64-118
F1	Moderate	Trees uprooted, some snapped; mobile homes overturned; moving cars pushed off road.	74-112	119-181
F2	Considerable	Large trees uprooted and snapped; mobile homes destroyed; roofs torn off houses; railroad boxcars pushed off track.	113-157	182-253
F3	Severe	Most trees in a forest uprooted or snapped; walls torn off well-constructed farm houses; trains overturned; autos lifted off ground and moved.	158-206	254-332
F4	Devastating	Trees debarked by flying debris; well-constructed frame houses leveled; autos thrown some distance.	207-206	333-419
F5	Incredible	Trees completely debarked; strong frame houses lifted off foundations and demolished over some distance; steel-reinforced concrete structures badly damaged; autos becomes missiles and fly distances of 100 meters.	261-318	420-513

Enhanced Fujita Scale

FUJITA SCALE

DERIVED EF SCALE

OPERATIONAL EF SCALE

F Number	Fastest 1/4-mile (mph)	3 Second Gust (mph)	EF Number	3 Second Gust (mph)	EF Number	3 Second Gust (mph)
0	40-72	45-78	0	65-85	0	65-85
1	73-112	79-117	1	86-109	1	86-110
2	113-157	118-161	2	110-137	2	111-135
3	158-207	162-209	3	138-167	3	136-165
4	208-260	210-261	4	168-199	4	166-200
5	261-318	262-317	5	200-234	5	Over 200

F0

Here are broken tree branches and only superficial house damage; so this scene was rated F0. Elsewhere in the tornado path through Columbus GA, on 13 March 1997, there was isolated F1 damage



Image courtesy of NOAA.

F1

This wood-frame house was pushed bodily off its concrete block foundation by the Spencer SD tornado of 30 May 1998 (a tornado which later did marginal F4 damage in the town of Spencer). Here, the house had no bottom anchoring at all. It was simply resting on its foundation by gravity alone; so it was easy for relatively weak winds near the edge of the tornado to slide the house aside with minor structural damage. It experienced partial roof removal, only on the windward (near) side; therefore, this damage site was rated F1.



Image courtesy of NOAA.

F2

On 3 January 2000, a tornado struck this wood-frame home near Paris, MS.

The roof and one large outer wall segment came off; while the remaining inner and outer walls were left (barely) standing. Quality of construction must be considered when rating damage; since the F scale is best applied to *well-built* homes. Here, the wall-to-roof and wall-to-wall attachments were very weak or nonexistent; so this is only marginal F2 damage.

Photo courtesy NWS Memphis



Image courtesy of NOAA.

F3

All but a few parts of the outer and inner walls were toppled or removed from this house in Moore, OK, on 3 May 1999. For a well-built home, any removal of inner walls constitutes F3 damage; so this site was rated high-end F3. The same tornado caused F5 damage in several locations elsewhere in its path.



Image courtesy of NOAA.

F4

A tornado in Moore, OK on 3 May 1999 demolished this house (foreground) down to a short pile of debris on and around the foundation, with no walls standing. In order for this scene to be rated F5, the debris must have been swept away, leaving behind evidence that the house was well-attached to its slab. [The brick house in the left background suffered F3 damage, with a mixture of inner and outer walls removed.] This tornado caused an immense amount of F4 damage on its path through the southern portion of the Oklahoma City metropolitan area, and several locales of F5 damage.

NWS photo by Mike Branick



Image courtesy of NOAA.

F5

This is classic F5 damage. The Bridge Creek/Moore, Oklahoma, tornado of 3 May 1999 leveled this house, swept the foundation almost completely clean, shredded the house remains into small pieces and scattered the debris downwind to the northeast (rear). The house was relatively well-constructed with slab-to-wall anchor bolts evenly spaced around the bottom plate. Some of those bolts can be seen in this photo, protruding upward from just inside the edges of the concrete slab.



Image courtesy of NOAA.

Greensburg, Kansas, 2007

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Please see a similar image on:

<http://www.drjudywood.com/articles/erin/spics/tornado-760291.jpg>

Tornado Climatology

Global Distribution

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Please see the image on:

http://www.windows2universe.org/earth/images/tornado_agri_map.jpg

Number of days per year with tornadoes reported

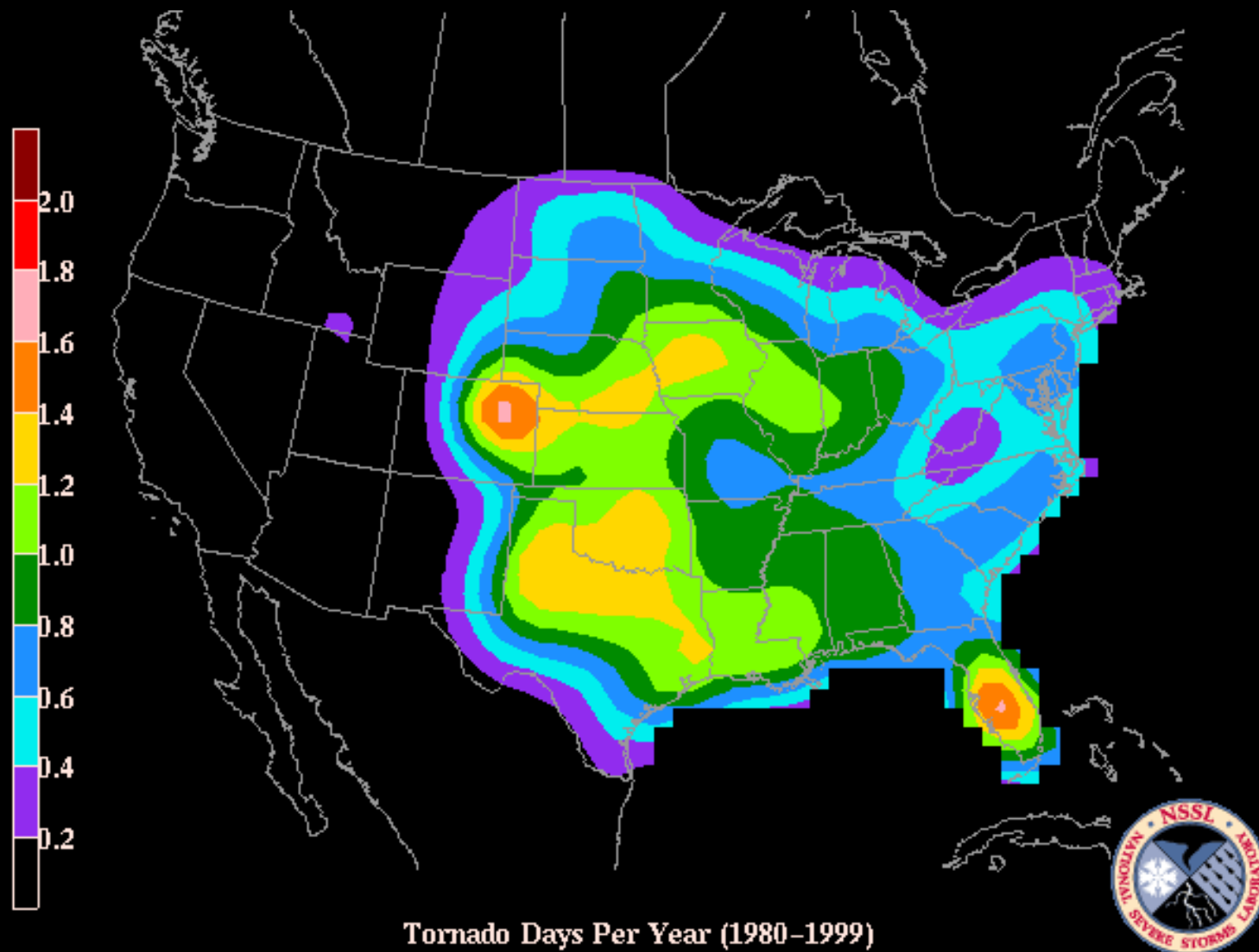
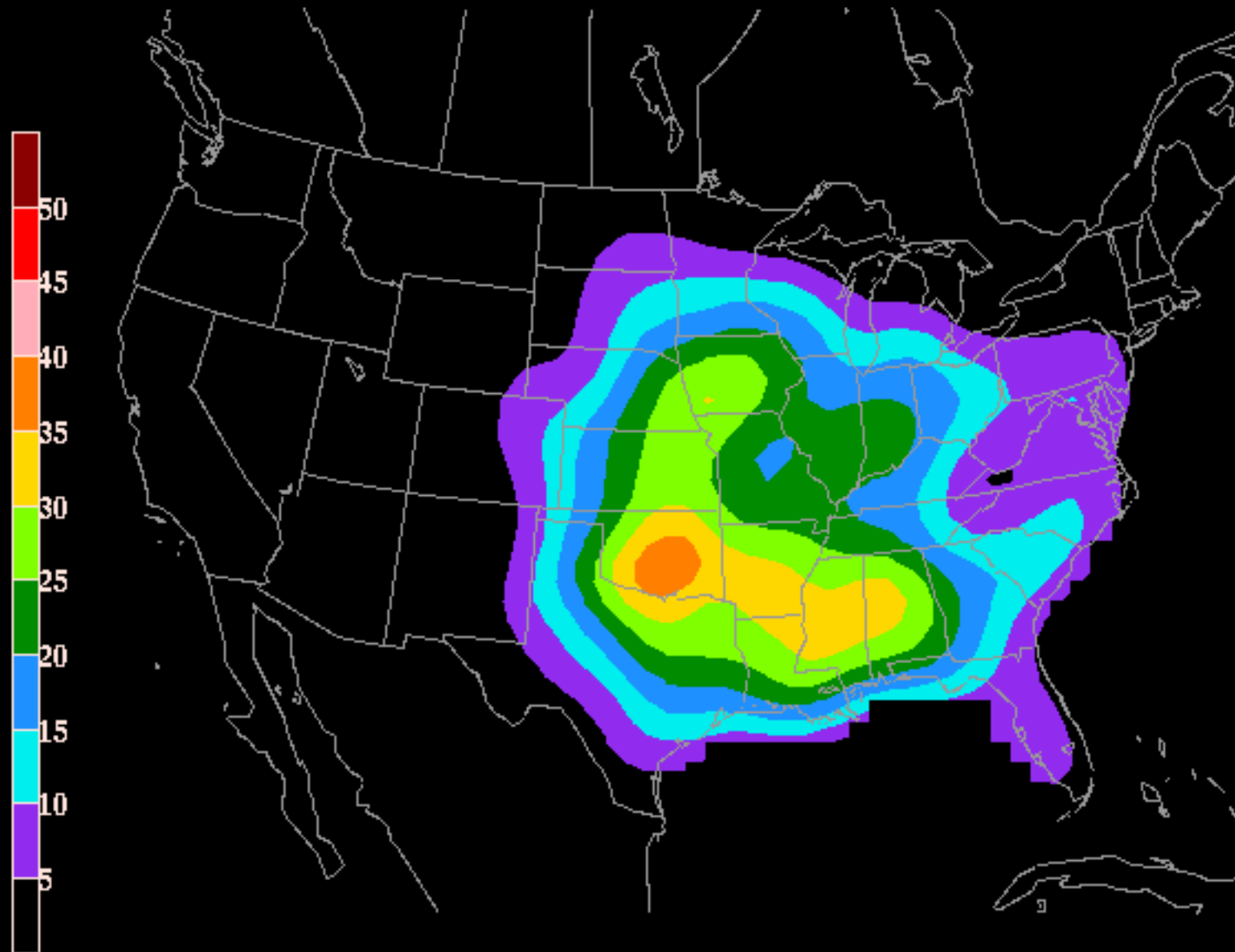


Image courtesy of NOAA.

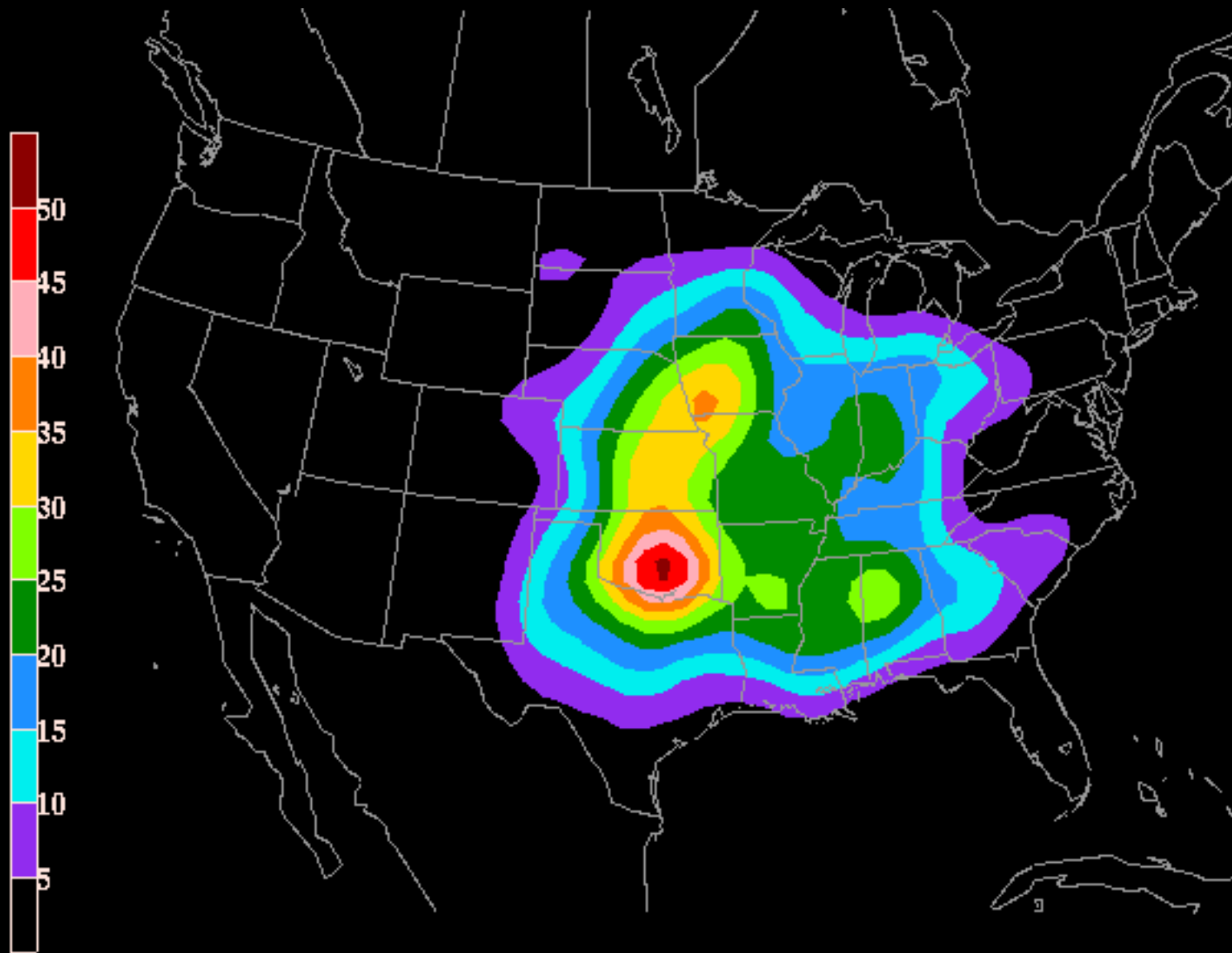
Number of Significant (\geq F2) Tornadoes per Century



Significant (F2 or greater) Tornado Days Per Century (1921-1995)

Image courtesy of NOAA.

Number of Violent (\geq F4) Tornadoes per Millenium



Violent (F4 or greater) Tornado Days Per Millenium (1921-1995)

Image courtesy of NOAA

Tornados

Between 1950 - 1996

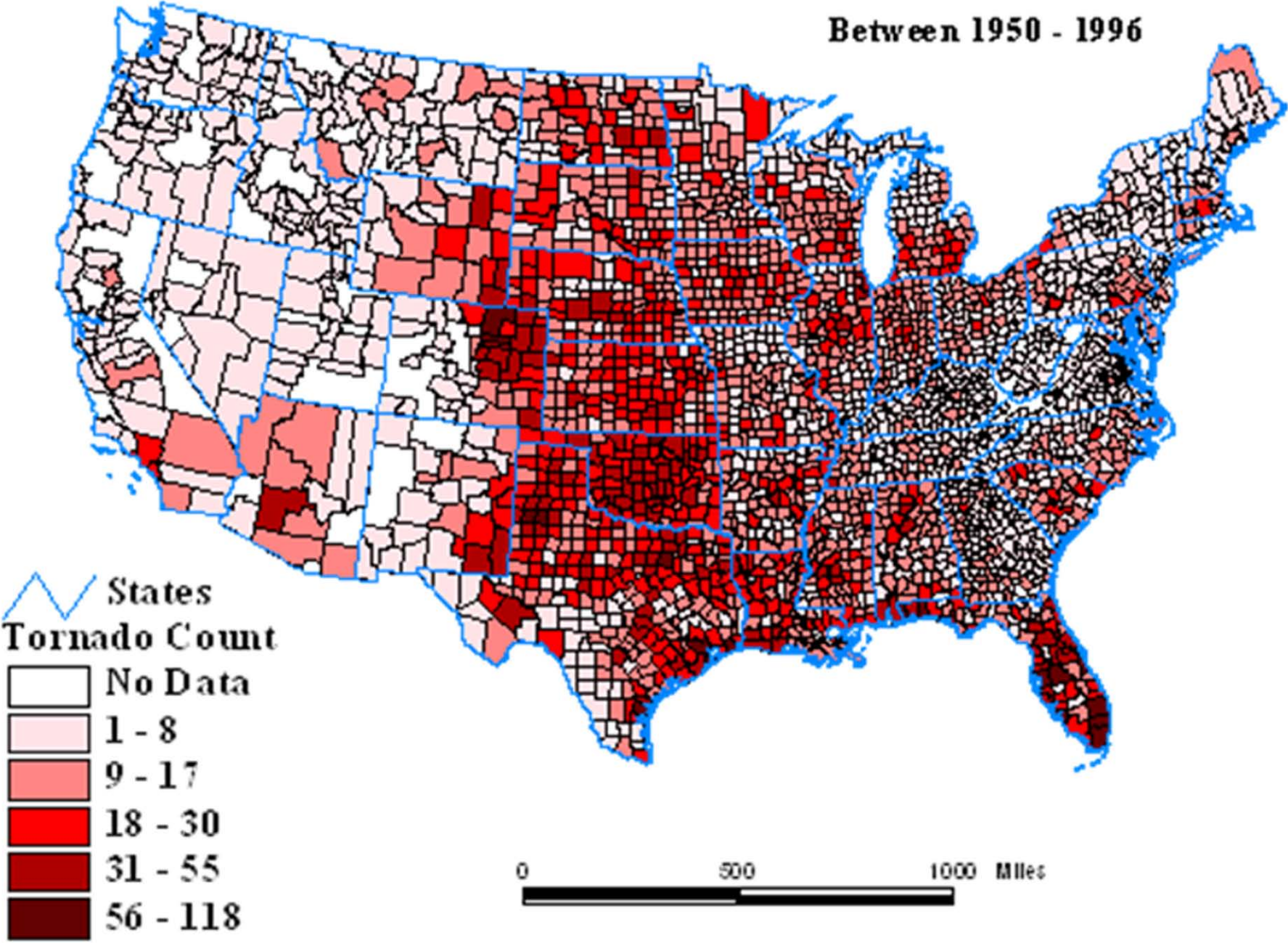


Image courtesy of NOAA.

U.S. Tornado Tracks

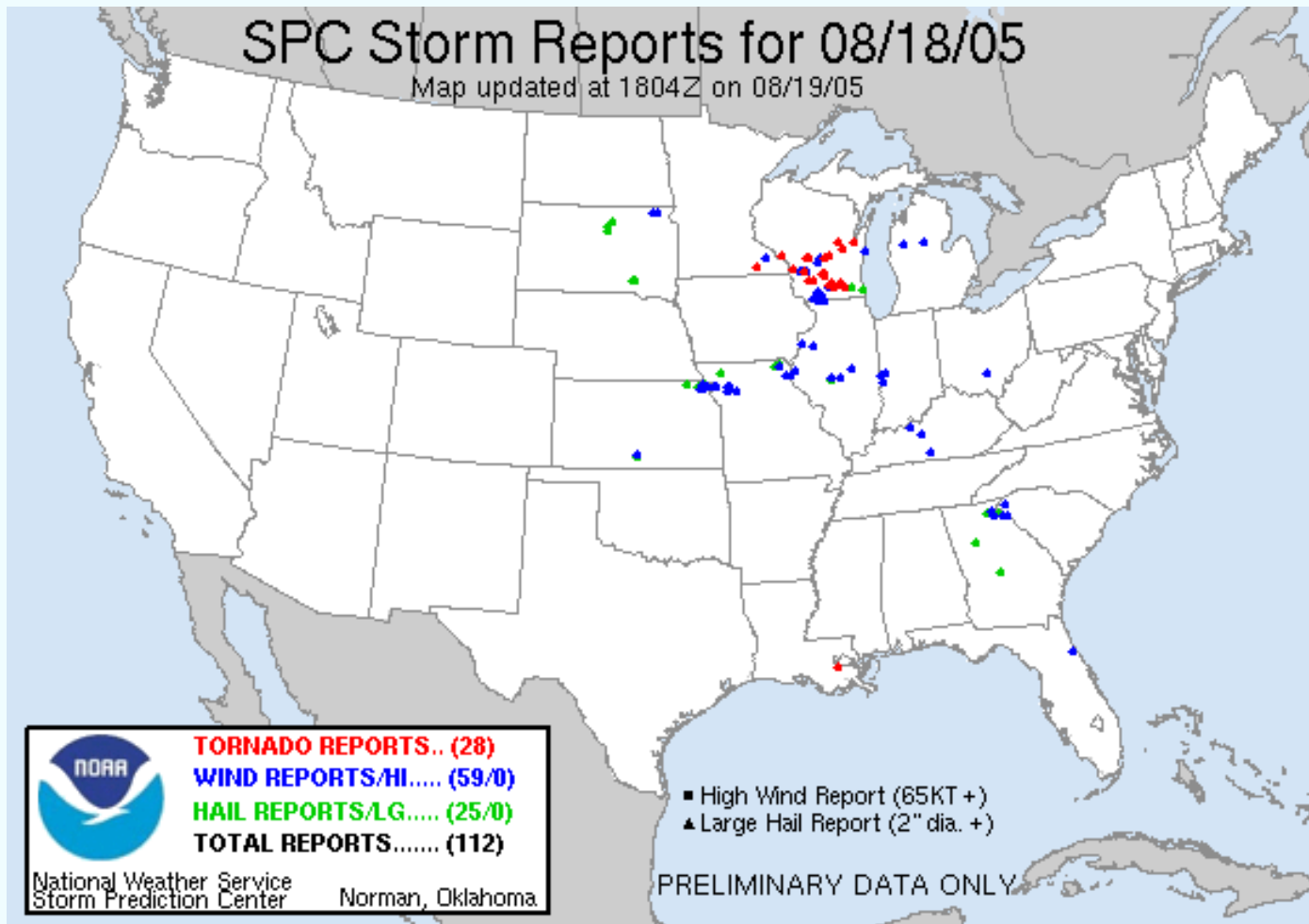
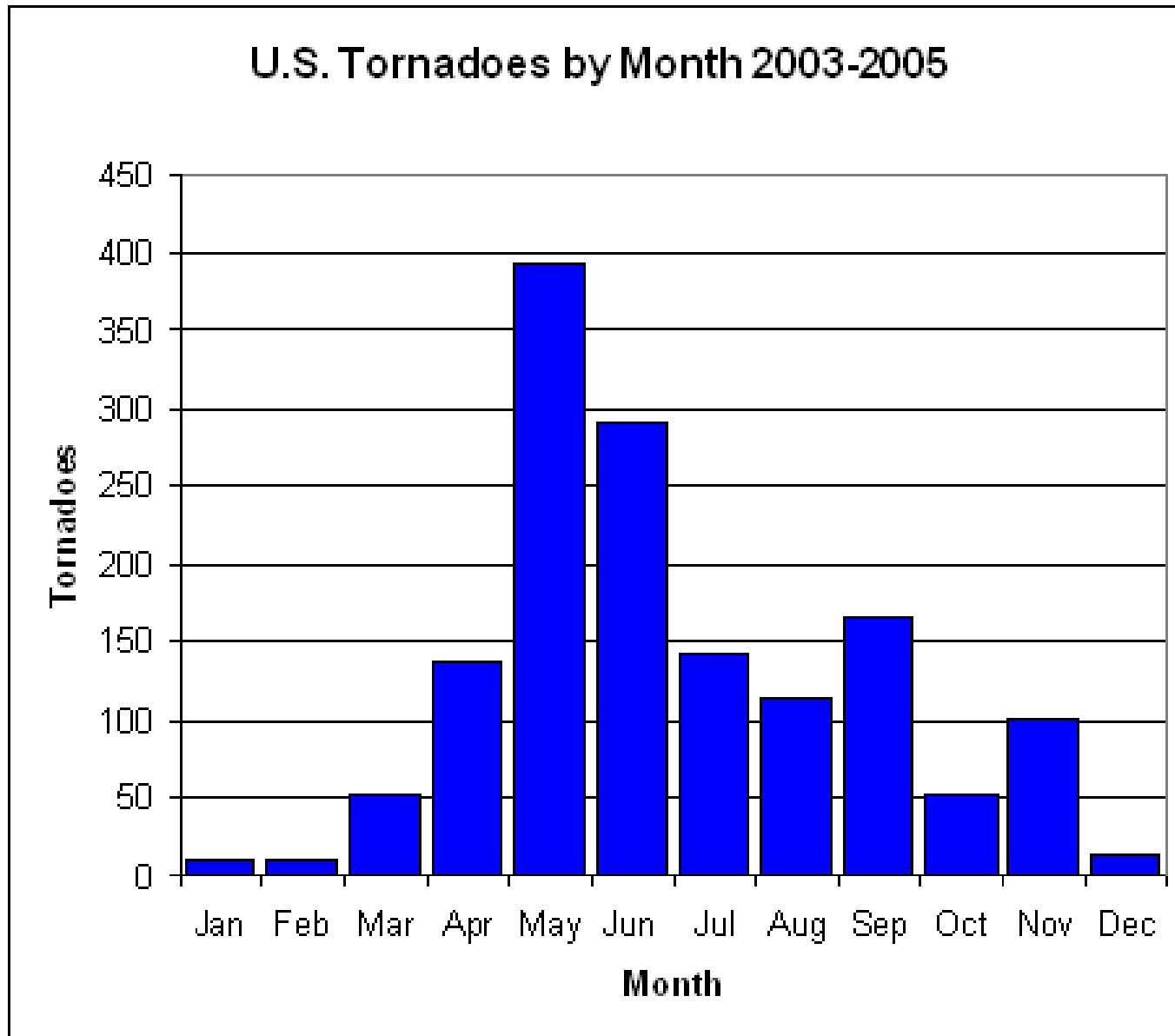
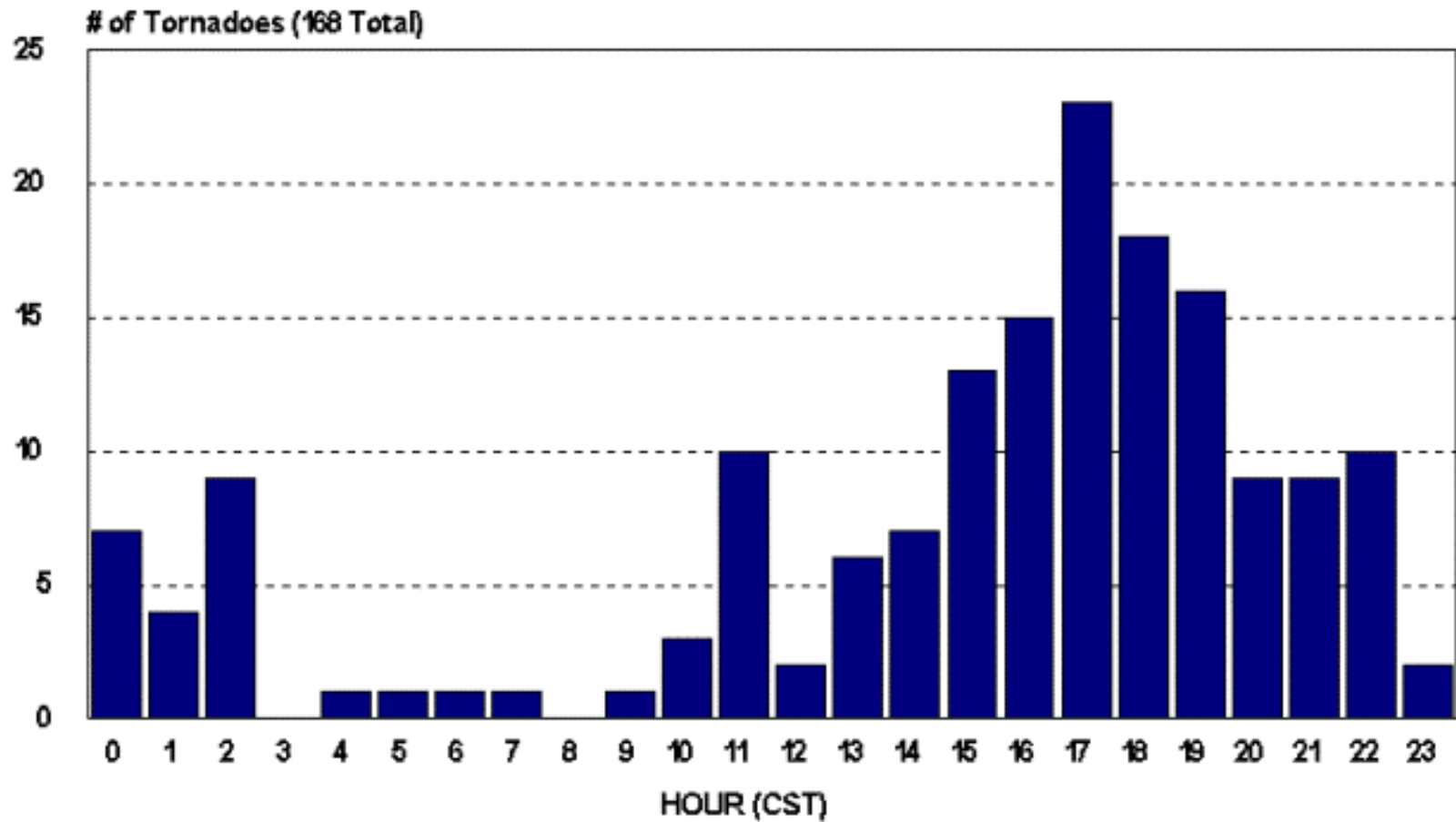


Image courtesy of NOAA.

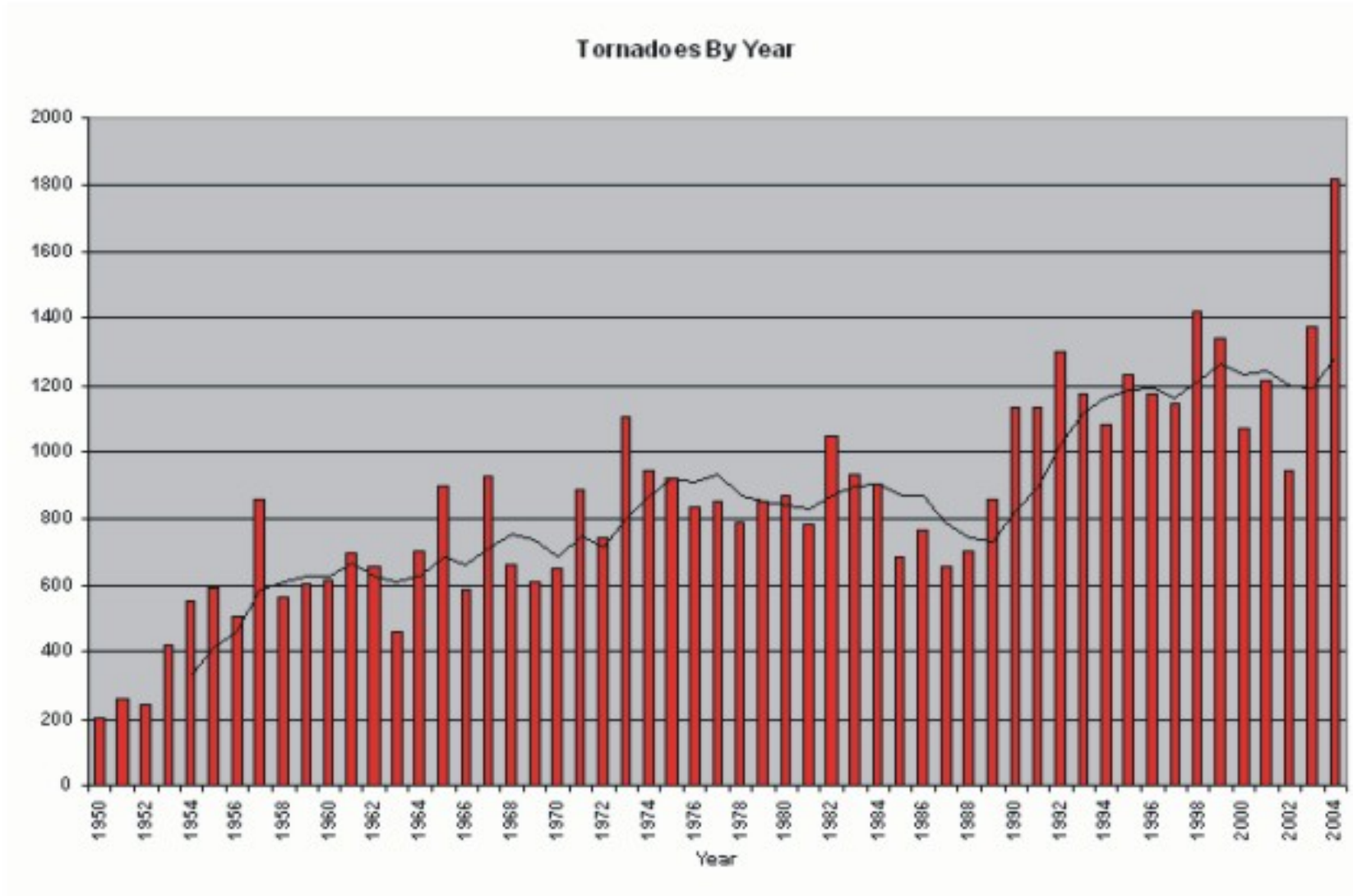
Seasonality



Diurnal Variation



Trends in U.S. Tornadoes



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<http://www.tornadoproject.com/graphics/pie2rb.gif>

Tornado Physics

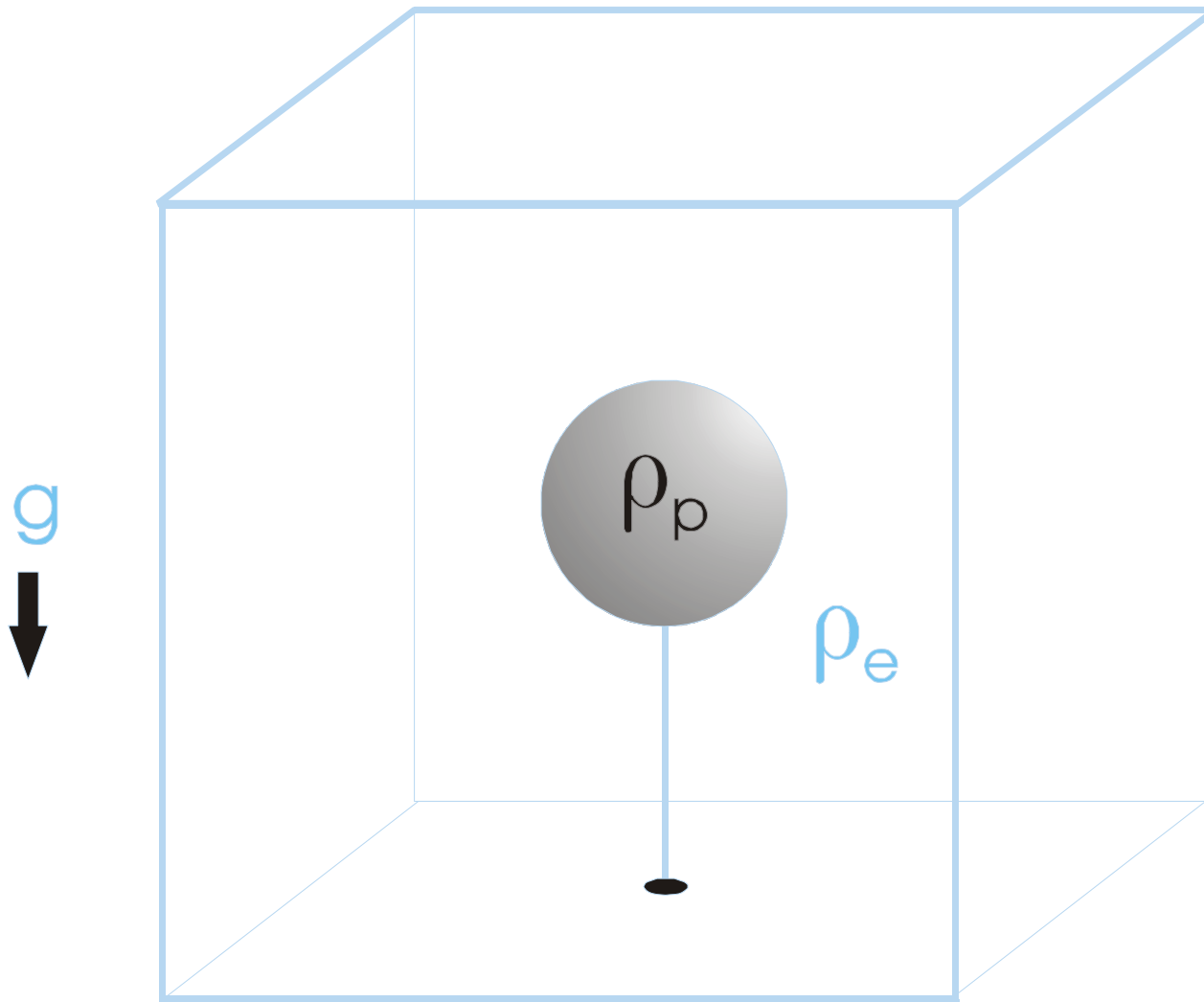
Fundamentals of Convection

- **Buoyancy**
- **Moist thermodynamics**
- **Stability**
- **Meta-stability**
- **Effects of precipitation**
- **Non-equilibrium convection**

When is a fluid unstable to convection?

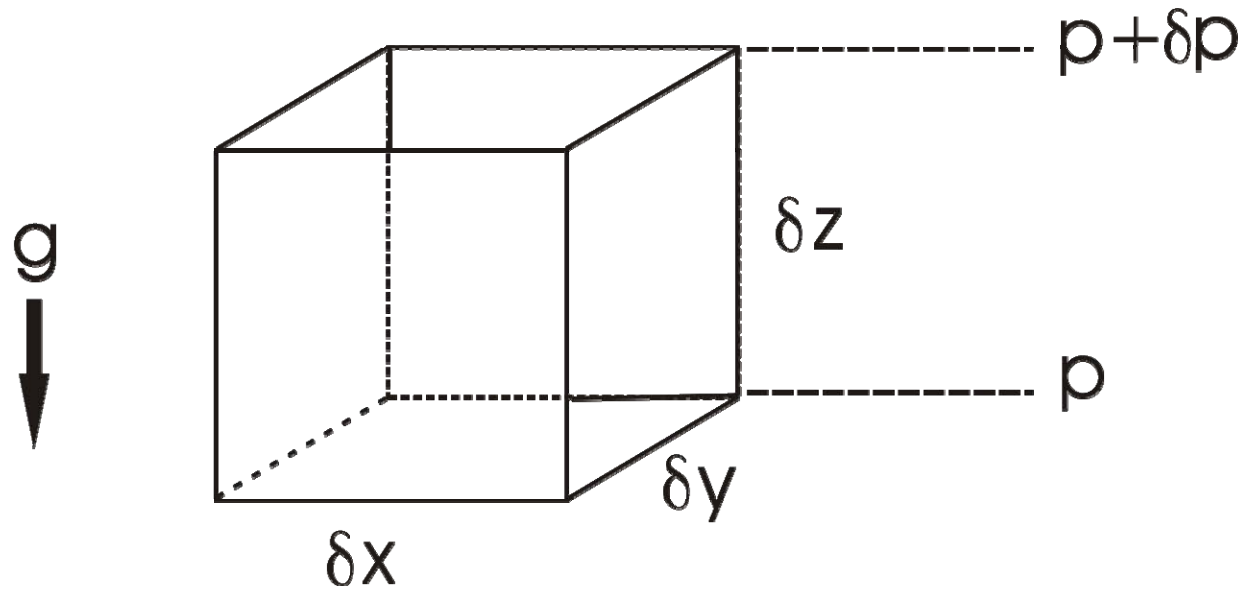
- Pressure and hydrostatic equilibrium
- Buoyancy
- Stability

Buoyancy



$$B = g \frac{\rho_e - \rho_p}{\rho_p}$$

Hydrostatic equilibrium:



$$\text{Weight: } -g\rho\delta x\delta y\delta z$$

$$\text{Pressure: } p\delta x\delta y - (p + \delta p)\delta x\delta y$$

$$F = MA: \quad \rho\delta x\delta y\delta z \frac{dw}{dt} = -g\rho\delta x\delta y\delta z - \delta p\delta x\delta y$$

$$\frac{dw}{dt} = -g - \alpha \frac{\partial p}{\partial z}, \quad \alpha = \frac{1}{\rho} = \text{specific volume}$$

Pressure distribution in atmosphere at rest:

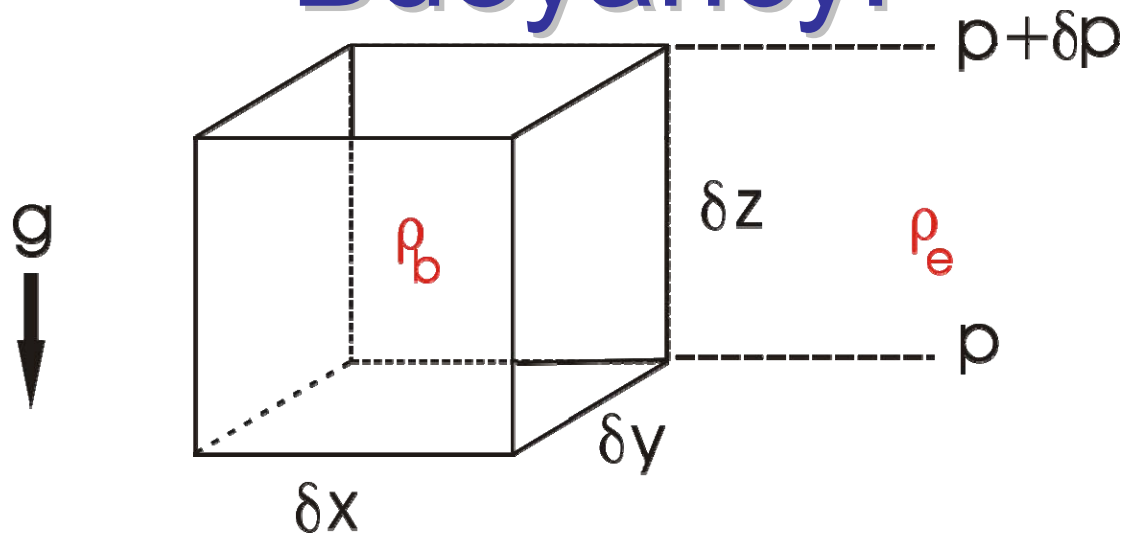
Ideal gas : $\alpha = \frac{RT}{p}$, $R \equiv \frac{R^*}{\bar{m}}$

Hydrostatic : $\frac{1}{p} \frac{\partial p}{\partial z} = -\frac{g}{RT}$

Isothermal case : $p = p_0 e^{-z/H}$, $H \equiv \frac{RT}{g} = \text{"scale height"}$

Earth: $H \sim 8 \text{ Km}$

Buoyancy:



$$\text{Weight: } -g \rho_b \delta x \delta y \delta z$$

$$\text{Pressure: } p \delta x \delta y - (p + \delta p) \delta x \delta y$$

$$F = MA: \quad \rho_b \delta x \delta y \delta z \frac{dw}{dt} = -g \rho_b \delta x \delta y \delta z - \delta p \delta x \delta y$$

$$\frac{dw}{dt} = -g - \alpha_b \frac{\partial p}{\partial z} \quad \text{but} \quad \frac{\partial p}{\partial z} = -\frac{g}{\alpha_e}$$

$$\rightarrow \frac{dw}{dt} = g \frac{\alpha_b - \alpha_e}{\alpha_e} \equiv B$$

Buoyancy and Entropy

Specific Volume: $\alpha = 1/\rho$

Specific Entropy: s

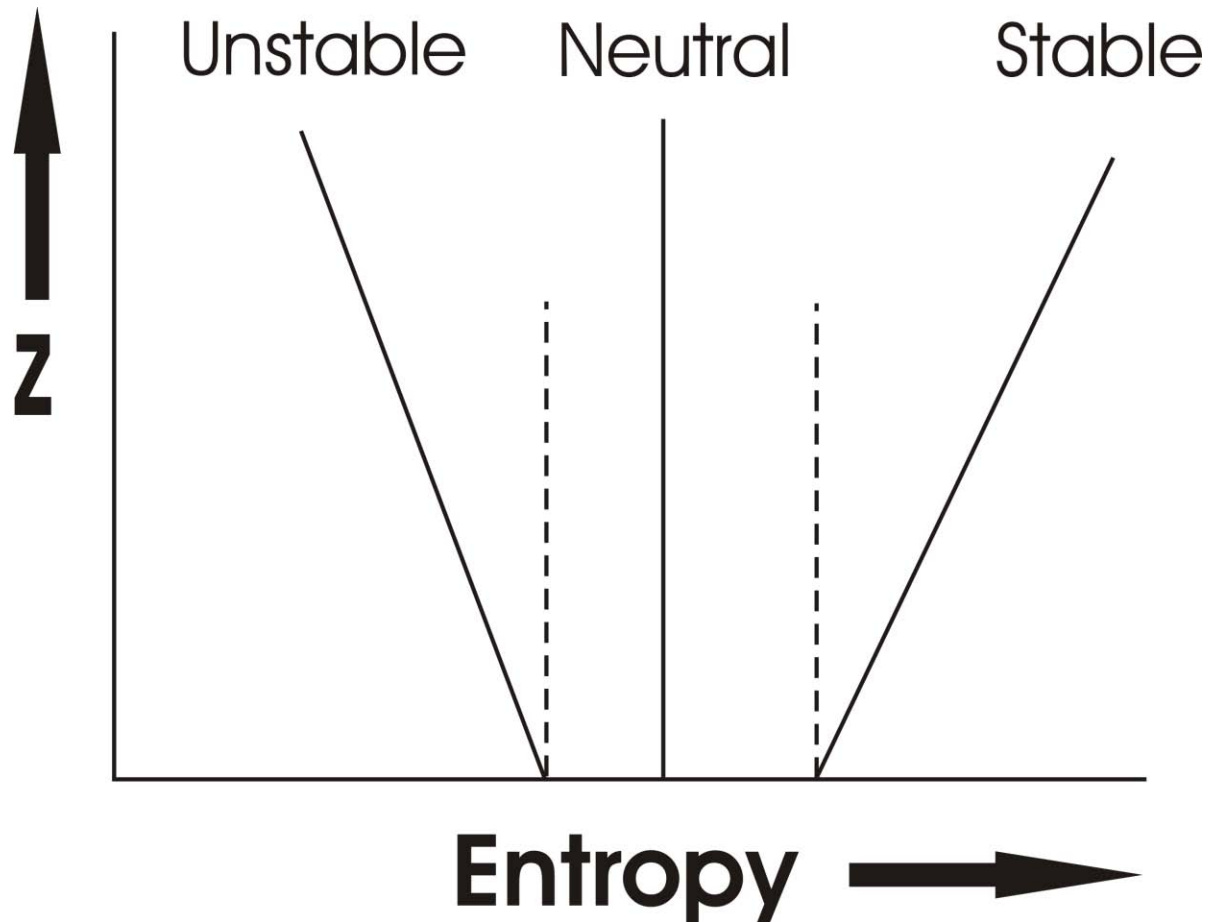
$$\alpha = \alpha(p, s)$$

$$(\delta\alpha)_p = \left(\frac{\partial\alpha}{\partial s}\right)_p \delta s = \left(\frac{\partial T}{\partial p}\right)_s \delta s$$

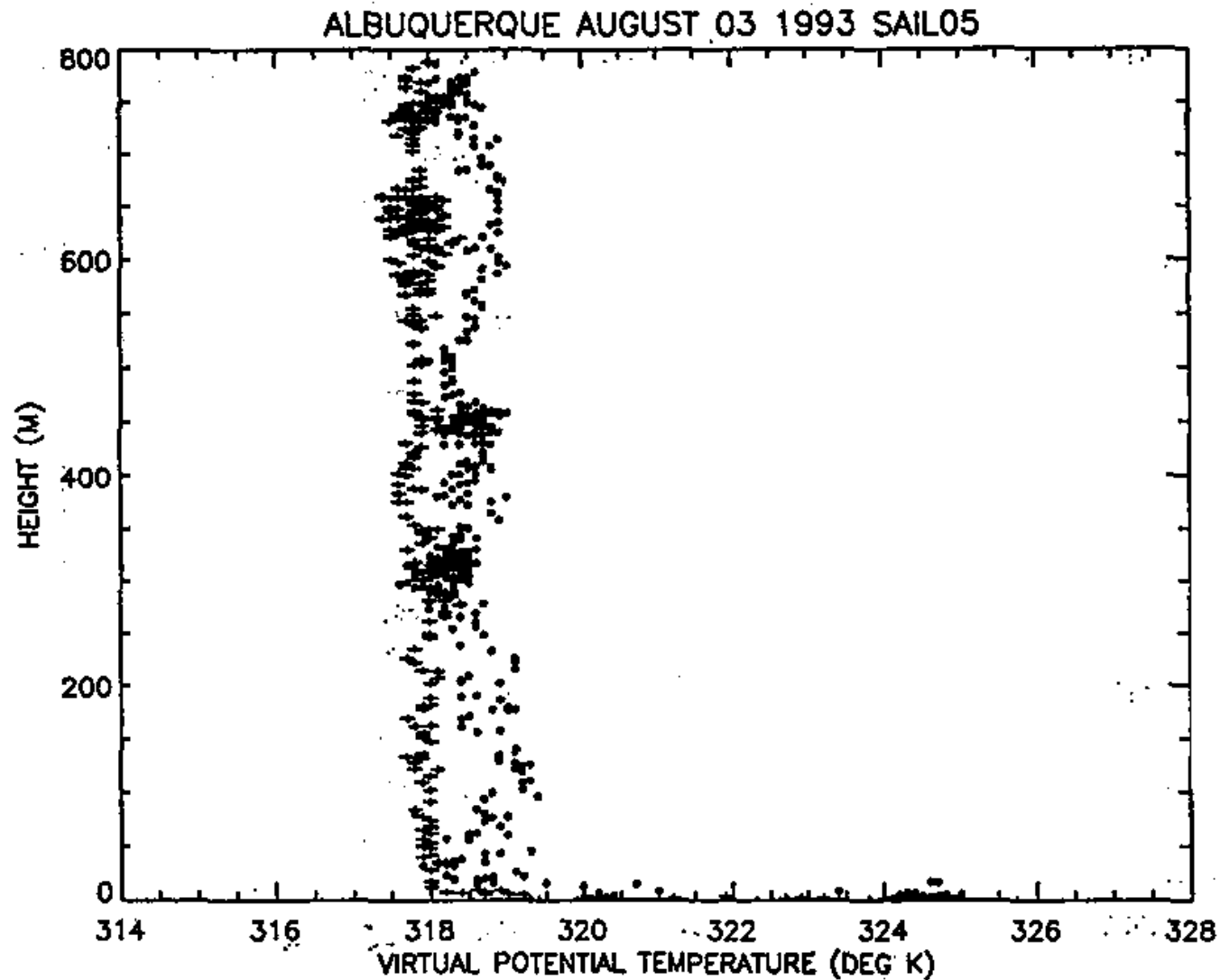
$$B = g \frac{(\delta\alpha)_p}{\alpha} = \frac{g}{\alpha} \left(\frac{\partial T}{\partial p}\right)_s \delta s = - \left(\frac{\partial T}{\partial z}\right)_s \delta s \equiv \Gamma \delta s$$

Note: For ideal gas: $\Gamma = g / c_p$

Earth's atmosphere: $\Gamma = 1 K / 100 m$



Model Aircraft Measurements (Renno and Williams, 1995)



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