Chapter 19: Tornadoes

- Tornadoes formation in supercell thunderstorms
- Tornadoes formation in non-supercell thunderstorms

Tornadoes

- Tornadoes are violently rotating columns of air that extend from a thunderstorm cloud to the ground.
- On average, over 1,000 tornadoes are reported in the US each year.
- Tornadoes primarily develop within supercell thunderstorms, but also form in thunderstorms along squall lines, near the ends of thunderstorm bow echoes, and within landfall hurricane.
- Most tornados are short lived.

Life Cycle of Long-lived Tornadoes

- Funnel cloud: emerging from the wall cloud
- Dust swirl stage: tornadoes make contact with the ground
- Organizing stage: funnel cloud descends to the ground and intensify
- Mature stage: at its peak intensity and largest size
- Shrinking stage: vortex tilts over more; rope-like appearance
- Decay stage

Tilting

- Supercell thunderstorms rotate about a vertical axis as a result of tiling.
- Vertical shear associated with the storm produce a rotation tube, whose rotation axis is in parallel to the ground.
- Warm airs within the tube is drawn into the thunderstorm updraft, which at the same time "tilt" the rotation axis vertical.
Location of Tornado within Supercell Thunderstorm

- The rotating updraft that produces the “tilting” is within the mesocyclone of supercell thunderstorms.

Tornadogenesis

- Tornadogenesis: the formation of tornadoes, whose detail processes are not clear due to limited observations.
- Tornadogenesis appears to occur in one of three ways: (1) top down process (a dynamic pipe effect), (2) bottom up process, and (3) vortex breakdown.

Top-Down Process / Dynamic Pipe Effect

- With this process, tornadoes descend from midlevels within the thunderstorm and then emerge from the base of the wall cloud.
- A narrowly constricted flow in the middle atmosphere that might develop when the mid-level mesocyclone is stretched.
- Air entering this narrow “pipe” from below must itself constrict as it approaches the entry point.
- That constriction in effect lowers the “pipe”, and the constriction grows downward.
- When the constricted “pipe” reaches the ground, tornadoes touchdown occur.

Bottom-Up Process

- This process is believed to occur as a result of tilting of the horizontal circulation along the forward gust front as it moves under the ascending updraft.
- Air behind the gust front is cool, negatively buoyant, and descending. In the updraft air adjacent to the gust front, air is warm, positively buoyant, and ascending.
- This leads to a sense of rotation along the interface between the gust front and warm air.
- If this region advances under the strong updraft of the mid-level mesocyclone, it can be tilted to the vertical, leading to rapid rotation very close to earth’s surface.
- With further vortex stretching, the rotation can spin up to become a “bottom up” tornado.
Vortex Breakdown

- Most tornadoes remain as a narrow column of rising rotation air, but vortex breakdown can occur in some tornadoes, which can cause the tornado to expand to a very large size.
- **A→B**: the tornado vortex transforms from a rotating updraft to a structure with a downdraft at its core.
- **B→C**: updraft displaced to the outside of the central downdraft.
- **C→D**: when the central downdraft reaches the ground, strong wind shear between the downdraft and updraft areas lead to the formation of smaller vortices, called suction vortices.
- The strongest winds in tornadoes occur in suction vortices (can be 290mph).

Decay of a Tornado

- A tornado may be on the ground for a few minutes to as long as an hour.
- The typical tornado life cycle concludes as the rear flank downdraft wraps completely around the tornado circulation.
- In this process, cool, denser air encircles the tornado, eventually weakening and finally eliminating the tornado’s circulation.
- As a supercell moves, typically northeastward, the upper part of the updraft that contains the tornado is tilted downstream by the mid-level winds relative to the lower part of the tornado.
- As this occurs, the tornado is stretched into a narrow vortex with a rope-like shape.
- Without an updraft to sustain, the tornado spins down.

3D View of Supercell

- Full formation of both forward and rear downdrafts.
- The mature super with a strong rotating updraft and tornado (red) located at the coupling of the updraft and rear flank downdraft.
- The decaying supercell storm – the rear flank downdraft wrapping around the updraft and cutting off the supply of warm, moist air. A new updraft is forming to the southeast of the previous updraft.

Tornado Family

- A tornado supercell may pass through the sequence of growing and dying a few times in its lifetime.
- Each cycle is associated with a new updraft that forms just outside and southeast of the previous cell that produced the earlier tornado.
- The tornadoes emerging from the supercell over its lifetime constitutes a tornado family.
Example of a Tornado Family

- A supercell thunderstorm produced eight tornadoes within five hours when it moved over Illinois and Indiana on 3 April 1974.
- The local time that the mesocyclone (the gray line) passed an area is noted along the track.

Tornadoes Formed within Non-Supercell Thunderstorms

- Tornadoes sometimes develop within squall line thunderstorm aligned along fronts or along outflows from mesoscale convective systems (MCS).
- These tornadoes are called non-supercell tornadoes, landspout tornadoes, mesovortices, or gustnadoes.
- These tornadoes are generally short-lived and not as intense as their supercell tornado counterparts.

Formation Mechanism for Non-Supercell Tornadoes

A: Some fronts are characterized by a very sharp change in wind speed and direction on either side of the front.
B: This strong horizontal wind shear can develop a series of small vortices along the front.
C: When the vortices develop under an updraft, the updraft stretches the vortex into a tighter and tighter circulation until a non-supercell tornado forms.

- Nearly all tornadoes in California in wintertime develop along cold fronts by this process.

Waterspout Tornadoes

- Waterspouts are a class of weak tornadoes that are commonly observed off coastlines, particularly in tropical regions such as the Florida Coast and the Gulf of Mexico.
- The formation mechanism of waterspouts is still not well known.
Tornado Alley

- This figure shows the annual number of tornadoes observed per 10,000 square miles in each of the fifty states during 1953-2004.
- The red states have more than 5 tornadoes annually.
- Florida has the highest numbers.
- Beside the Gulf states, tornadoes occur most frequently over the Great Plains and Midwestern states.
- These states are oriented along a southwest-northeast line called Tornado Alley.

Damage Indicators for establishing EF-Scale ratings

For the structures listed below, damage assessors use detailed tables that describe the degree of damage, together with example photographs from damaged structures to establish the likely wind speed and EF scale rating for a tornado.

<table>
<thead>
<tr>
<th>No.</th>
<th>Damage Indicator</th>
<th>No.</th>
<th>Damage Indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Small Barn or Farm Outbuilding</td>
<td>19</td>
<td>High-Rise Building (&gt;20 stories)</td>
</tr>
<tr>
<td>2</td>
<td>One or Two Family Residences</td>
<td>20</td>
<td>Institutional Building</td>
</tr>
<tr>
<td>3</td>
<td>Manufactured Home - Single Wide</td>
<td>21</td>
<td>Metal Building System</td>
</tr>
<tr>
<td>4</td>
<td>Manufactured Home - Double Wide</td>
<td>22</td>
<td>Service Station Canopy</td>
</tr>
<tr>
<td>5</td>
<td>Apartments, Condos, Townhouses</td>
<td>23</td>
<td>Warehouse Building</td>
</tr>
<tr>
<td>6</td>
<td>Mobile</td>
<td>24</td>
<td>Electrical Transmission Lines</td>
</tr>
<tr>
<td>7</td>
<td>Masonry Apartment or Hotel</td>
<td>25</td>
<td>Free Standing Towers</td>
</tr>
<tr>
<td>8</td>
<td>Small Retail Building</td>
<td>26</td>
<td>Free Standing Light Poles, Luminary Poles, Flag Poles</td>
</tr>
<tr>
<td>9</td>
<td>Small Professional Building</td>
<td>27</td>
<td>Trees (Hardwood)</td>
</tr>
<tr>
<td>10</td>
<td>Strip Mall</td>
<td>28</td>
<td>Trees (Softwood)</td>
</tr>
<tr>
<td>11</td>
<td>Large Shopping Mall</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Large Industrial Retail Building</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Automobile Showroom</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Automobile Service Building</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Elementary School</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Junior or Senior High School</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Low-Rise Building (1-4 stories)</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Mid-Rise Building (5-20 stories)</td>
<td>36</td>
<td></td>
</tr>
</tbody>
</table>

Estimating the EF scale rating from damage to a one or two family residence (Indicator 2 in Table 19.2)

<table>
<thead>
<tr>
<th>Degree of Damage</th>
<th>Damage Description</th>
<th>EXPECTED WIND SPEED</th>
<th>LOWEST WIND SPEED</th>
<th>HIGHEST WIND SPEED</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Threshold of visible damage</td>
<td>65</td>
<td>53</td>
<td>80</td>
</tr>
<tr>
<td>2</td>
<td>Loss of roof covering material (&gt;20%), gutters and/or downspouts. Loss of vinyl or metal siding</td>
<td>79</td>
<td>63</td>
<td>97</td>
</tr>
<tr>
<td>3</td>
<td>Broken glass in doors and windows</td>
<td>96</td>
<td>79</td>
<td>114</td>
</tr>
<tr>
<td>4</td>
<td>Uplift of roof deck and loss of significant roof covering material (&gt;20%), collapse of chimneys, garage doors collapse inward, failure of porch or carport</td>
<td>97</td>
<td>81</td>
<td>116</td>
</tr>
<tr>
<td>5</td>
<td>Entire house shifts off foundation</td>
<td>121</td>
<td>105</td>
<td>141</td>
</tr>
<tr>
<td>6</td>
<td>Large sections of roof structure removed, most walls remain standing</td>
<td>122</td>
<td>104</td>
<td>142</td>
</tr>
<tr>
<td>7</td>
<td>Exterior walls collapse</td>
<td>132</td>
<td>113</td>
<td>153</td>
</tr>
<tr>
<td>8</td>
<td>Most walls collapsed, except small interior rooms</td>
<td>152</td>
<td>122</td>
<td>178</td>
</tr>
<tr>
<td>9</td>
<td>All walls collapsed</td>
<td>170</td>
<td>142</td>
<td>198</td>
</tr>
<tr>
<td>10</td>
<td>Destruction of engineered and/or well-constructed residence, shaft sway evident</td>
<td>200</td>
<td>165</td>
<td>220</td>
</tr>
</tbody>
</table>