What is a Tropical Cyclone?

- A relatively large and long-lasting low pressure system
  - Can be dozens to hundreds of miles wide, and last for days
- No fronts attached
- Forms over tropical or subtropical oceans
- Produces organized thunderstorm activity
- Has a closed surface wind circulation around a well-defined center

- Classified by maximum sustained surface wind speed
  - Tropical depression: < 39 mph
  - Tropical storm: 39-73 mph
  - Hurricane: 74 mph or greater
    - Major hurricane: 111 mph or greater
Is This a Tropical Cyclone?

Closed surface circulation?
Organized thunderstorm activity?
Tropical Depression #5 (later Ernesto)

Advisory #1 issued based on aircraft data
The Extremes:
Tropical vs. Extratropical Cyclones

Hurricane Katrina (2005)  Superstorm Blizzard of March 1993
Tropical Cyclones Occur Over Tropical and Subtropical Waters Across the Globe

Tropical cyclones tracks between 1985 and 2005
Atlantic Basin Tropical Cyclones Since 1851
Major Hurricane History
Data since 1949 in the Pacific, since 1851 in the Atlantic
Climatological Areas of Origin and Tracks

June: On average about 1 storm every other year. Most June storms form in the northwest Caribbean Sea or Gulf of Mexico.

July: On average about 1 storm every year. Areas of possible development spreads east and covers the western Atlantic, Caribbean, and Gulf of Mexico.
August: Activity usually increases in August. On average about 2-3 storms form in August. The Cape Verde season begins.

September: The climatological peak of the season. Storms can form nearly anywhere in the basin. Long track Cape Verde storms very possible.
October: Secondary peak of season in mid-October. Cape Verde season ends. Development area shifts westward, back into the Caribbean, Gulf of Mexico, and western Atlantic.

November: Season usually slows down with about 1 storm occurring every other year. Storms that do form typically develop in central Caribbean.
Life Cycle of a Cape Verde Hurricane

- **Days 1-5**: Tropical disturbance
- **Days 5-6**: Tropical depression
- **Days 7-9**: Tropical storm
- **Days 10-15**: Extratropical transition
- **Days 16-17**: Extratropical cyclone
## How to Build a Tropical Cyclone

<table>
<thead>
<tr>
<th>Mechanical</th>
<th>Thermodynamic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) A pre-existing disturbance (vorticity or spin)</td>
<td>4) Warm sea-surface temperatures (usually at least 80°F)</td>
</tr>
<tr>
<td>2) Location several degrees north of the equator</td>
<td>5) Unstable atmosphere (temperature goes down as you go up)</td>
</tr>
<tr>
<td>3) Little change in wind speed and/or direction with height (vertical wind shear)</td>
<td>6) High atmospheric moisture content (relative humidity)</td>
</tr>
</tbody>
</table>
Pre-existing Disturbances

- Tropical waves play a role in about 70% of all Atlantic basin TC formations
- Cold-core low pressure systems in the upper levels of the atmosphere (e.g., Michael 2012)
- Decaying frontal systems (Alberto 2012)
- Thunderstorm clusters produced by non-tropical weather systems (Danny 1997)
Tropical Cyclone Motion

- Track forecasting is a relatively simple problem with well-understood physics
  - Cork in stream analogy
- Important atmospheric features are relatively large and easy to measure
- Numerical computer models forecast track quite well
  - Constantly improving with upgrades to model physics and resolution
  - Long ago surpassed statistical models in accuracy
Tropical Cyclone Intensity

• Multi-scale problem that involves complex interactions between thunderstorms in the core and the environment, as well as atmosphere-ocean interactions

• Depends strongly on track
  – Interactions with land or subtle variations in sea-surface temperature and/or ocean heat content

• Depends critically on wind, temperature, and moisture patterns over the core and near environment
  – Often difficult or impossible to measure

• Depends on internal processes, such as eyewall replacement cycles, that are poorly understood
Factors Influencing TC Intensity

many of the same factors that govern development

- Sea surface temperature (SST) and upper ocean heat content (OHC)
- Interaction with land/topography
- Vertical wind shear
- Interactions with upper-level troughs, other cyclones (tropical and extratropical)
- Temperature and moisture patterns in the storm environment
- Internal structural changes, such as eyewall replacement cycles
How do Tropical Cyclones die?

- Weaken over land
- Become “post-tropical”
  - Transform into an extratropical cyclone
  - Weaken over water due to hostile environmental conditions such as strong wind shear or cool SSTs, leaving a remnant low
- Merge with or be absorbed by a larger weather system (usually an extratropical cyclone or front)
Tropical cyclones are born, live, and die in a variety of ways
Tropical Cyclones Come in All Sizes

Hurricane Charley

Hurricane Wilma
Hurricane Hazards

Wind
- Hurricane Charley
  Ft. Myers, FL (YouTube/moviemagg)

Waves / Rip Currents
- Hurricane Sandy
  Ft. Lauderdale, FL (YouTube/Mmatch)

Tornadoes
- Tropical Storm Debby
  West Palm Beach, FL (ParsAreOk)

Storm Surge
- Hurricane Sandy
  Jersey City, NJ (YouTube/echtjbm)

Rainfall / Inland Flooding
- Tropical Storm Debby
  Anclote River, FL (NYRAPTOR6)
### Saffir-Simpson Hurricane Wind Scale

<table>
<thead>
<tr>
<th>Category</th>
<th>Winds</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>74-95 mph</td>
<td>Very dangerous winds will produce some damage</td>
</tr>
<tr>
<td>2</td>
<td>96-110 mph</td>
<td>Extremely dangerous winds will cause extensive damage</td>
</tr>
<tr>
<td>3</td>
<td>111-129 mph</td>
<td>Devastating damage will occur</td>
</tr>
<tr>
<td>4</td>
<td>130-156 mph</td>
<td>Catastrophic damage will occur</td>
</tr>
<tr>
<td>5</td>
<td>157+ mph</td>
<td>Catastrophic damage will occur</td>
</tr>
</tbody>
</table>

www.nhc.noaa.gov/aboutsshs.shtml
Category 1 (74 – 95 mph)

Very dangerous winds will produce some damage

Katrina (2005)
Miami, FL

Humberto (2007)
Southeast TX

Claudette (2003)
Palacios, TX

Lili (2002)
Louisiana
Category 2 (96 – 110 mph)

Extremely dangerous winds will cause extensive damage

Ike (2008)
Houston, TX

Juan (2003)
Halifax, NS

Wilma (2005)
SE Florida
Category 3 (111 – 129 mph)

Devastating damage will occur

Sandy (2012)
Santiago de Cuba, Cuba

Jeanne (2004)
Cape Canaveral, FL

Rita (2005)
Orange, TX
Category 4 (130 – 156 mph)

*Catastrophic damage will occur*

Charley (2004)
Punta Gorda, FL

Hugo (1989)
Sullivans Island, SC

Ike (2008)
Holguin, Cuba
Category 5 (greater than 156 mph)

Catastrophic damage will occur

Andrew (1992)
Florida City, FL

Andrew (1992)
South Dade, FL

Felix (2007)
Nicaragua
Wind-blowed Debris can Become Deadly Projectiles in a Hurricane
Storm Surge
Stayed tuned for more this afternoon

U.S. Atlantic Tropical Cyclone Deaths, 1963-2012

- Storm Surge: 50%
- Rainfall-induced Flood: 25%
- Surf: 5%
- Offshore: 5%
- Wind 5-10: 5%
- Tornado: 5%
- Unknown: 5%
- Other: 5%
Fresh Water Flooding

US Army Corps of Engineers

NC DENR

[Bar chart showing percent occurrence in deadly U.S. tropical cyclones across different hazards: Rainfall induced, Surf, Wind, Offshore, Tornado, Surge, Other, Unknown.

Road sign indicating "Road Ends 500 FT."
About one quarter of all deaths from 1970-1999 occurred to people who drowned in, or attempted to abandon, their vehicles.
Interstate 10
Houston, Texas
Tropical Storm Allison (2001)
Houston, Texas

Interstate 10, Looking West, Houston, Texas
Tropical Storm Allison
FACTORS AFFECTING RAINFALL AMOUNTS AND DISTRIBUTION IN TROPICAL CYCLONES

1. SIZE (Bigger storm = more rain)
2. MOTION (Slower storm = more rain)
3. RAIN RATE (Higher rain rate = more rain)
4. VERTICAL WIND SHEAR (more rain on one side)
5. TOPOGRAPHY (more rain on windward side)
6. FRONTAL BOUNDARIES / UPPER LEVEL TROUGHS
Hurricane-Induced Tornadoes

- Nearly 70% of landfalling hurricanes (1948-2000) spawned at least 1 tornado
- 40% of landfalling hurricanes spawn more than 3 tornadoes
- Some hurricanes produce tornado “outbreaks”
  - Hurricane Beulah (1967): 141
  - Hurricane Ivan (2004): 117
  - Hurricane Frances (2004): 101
  - Hurricane Rita (2005): 90
  - Hurricane Camille (1969): 80
  - Hurricane Katrina (2005): 43
Friction over land creates low-level wind conditions favorable for the development of tornadoes.
Waves and Rip Currents

6 deaths in the U. S. occurred during the 2010 hurricane season resulted from waves and rip currents along the coast.

Hidden danger because it can occur when a storm is well offshore.
Waves and Rip Currents

Swell from a large hurricane can affect the beach of the entire western Atlantic

Hurricane Bertha (2008):
- Over 1500 rescues in Ocean City, Maryland
- 3 people drowned along the coast of New Jersey

Hurricane Bill (2009)
- 1 person died in Maine
- 1 person died in Florida