Chapter 24: Tropical Cyclones

• Hurricane Naming, Track, Structure
• Tropical Cyclone Development

Tropical Cyclones vs. Mid-latitude Storms

Tropical cyclones
- The tropical cyclone is a low-pressure system which derives its energy primarily from evaporation from the sea in the presence of high winds and lowered surface pressure.
- It has associated condensation in convective clouds concentrated near its center.

Mid-latitude storms
- Mid-latitude storms are low pressure systems associated cold fronts, warm fronts, and occluded fronts.
- They primarily get their energy from the horizontal temperature gradients that exist in the atmosphere.

An Overview of Tropical Cyclone

Secondary Circulation: A Carnot Cycle (Carnot Heat Engine) (Kerry Emanuel 1988)

- A heat engine acts by transferring energy from a warm region to a cool region of space and, in the process, converting some of that energy to mechanical work.
- The Carnot cycle is a theoretical thermodynamic cycle and can be shown to be the most efficient cycle for converting a given amount of thermal energy into work, or conversely, creating a temperature difference (e.g. refrigeration) by doing a given amount of work.
Two Circulation Components of Tropical Cyclone

Secondary Circulation
- Centrifugal and Coriolis Forces are not in perfect equilibrium with the pressure gradient.
- Air is forced to center and then rises
- Conservation of Angular Momentum
- As air enters to a small radius, its speed has to become faster
- Increases the rotational speed of the tropical cyclone.
- Primary Circulation

WISHE (Wind Induced Surface Heat Exchange) Mechanism

- Low pressure at the center
- Enhance surface winds
- Increase surface heat fluxes
- Some airs sink to the center
- Adiabatic warming at the center
- Lower pressure at the center
- Stronger winds
- Stronger heat exchanges
- Stronger descending
- Even warmer at the center
- Even stronger low
- …….

The Source of Strong Rotating Winds

- The strong rotating winds in the core of a hurricane is a result of the conservation of angular momentum.

Hurricane Formation

- Tropical Disturbance: Clusters of small thunderstorms.
- Tropical Depression: When at least one closed isobar is present, the disturbance is classified as a tropical depression.
- Tropical Storm: Further intensification, to wind speeds of 60 km/hr (37 mph), place the storm in the category of tropical storm.
- Hurricane: Hurricane status is gained when winds reach or exceed 120 km/hr (74 mph).
Stages of a Tropical Cyclone Lifecycle

- **Tropical Disturbance**: A process transits the asymmetric disturbance into a self-sustaining symmetric storm.
- **Cyclogenesis**: Further development of a tropical storm to a cyclone with an axisymmetric structure and a clear eye.
- **Intensification**: Further development of a tropical storm to a cyclone with an axisymmetric structure and a clear eye.

Sources of Incipient Disturbances
- ITCZ breakdown
- Easterly waves
- Subtropical storms
- Monsoon trough
- Equatorial waves (Rossby, mixed Rossby-gravity)
- Mesoscale convective complexes

Genesis in the Monsoon Trough

- A potential vorticity model provides evidence that the continuous PV source associated with convection in the ITCZ will act to destabilize and break down the ITCZ periodically through combined barotropic-baroclinic instability.

Tropical Disturbances and Easterly Waves

- Some tropical disturbances form in association with mid-latitude troughs migrating toward lower latitudes, some form from ITCZ-related convection, but most develop from easterly waves.
- **Easterly waves**, or undulations in the trade wind pattern, spawn hurricanes in the Atlantic (typically 2–3000 km).
- Only about 10% tropical disturbances intensify into more organized, rotating storms.
Genesis from Equatorial Waves

- Twin tropical cyclones that straddle the equator at formation have a flow structure suggestive of equatorial Rossby waves.
- Equatorial Rossby waves may initiate genesis, others argue that the shorter wavelength mixed Rossby-gravity waves are also important.

Development of Hurricane

- Trigger Mechanisms for initial Thunderstorms:
  1. Intertropical convergence zone
  2. Easterly waves in trade wind flow
  3. Cold fronts extending into tropics

- Environment required for Hurricane formation:
  1. Sea surface temp > 80°F
  2. Deep layer of warm water
  3. Weak wind shear
  4. At least 5° from equator

- Spin up of thunderstorm clusters into Hurricane:
  1. Wind induced transfer of heat from the ocean to the atmosphere
  2. Conservation of angular momentum

Hurricane Dissipation

- After making landfall, a tropical storm may die out completely within a few days.
- Even as the storm weakens, it can still bring in huge amount of water vapor and rainfall hundreds of kilometers inland.

Hurricane Structure

- A central eye surrounded by large cumulonimbus thunderstorms occupying the adjacent eye wall.
- Weak uplift and low precipitation regions separate individual cloud bands.
Hurricane Characteristics

- **Definition:** Hurricanes have sustained winds of 120 km/hr (74 mph) or greater.
- **Size:** Average diameters are approximately 600 km (350 mi). (one third the size of mid-latitude cyclone)
- **Duration:** days to a week or more.
- **Strength:** Central pressure averages about 950 mb but may be as low as 870 mb.
- **Power:** The energy released by a single hurricane can exceed the annual electricity consumption of the US and Canada.
**Vertical Cross Section of Hurricane**

- Most of the air in the eye descends very slowly, taking days to traverse the eye’s depth.
- Air sinks in the eye warms adiabatically and makes the eye much warmer than other regions of the hurricane.
- In the eye, air ascends from the surface to the tropopause.
- Pressure gradient is the strongest near the eye wall, where the most violent winds are produced.
- Strongest rainfall is also produced near the eye wall.
- Strongest storm surge occurs to the right of the hurricane.

**Hurricane Eye and Eye Wall**

- The eye moves at a speed of 20 km/hr ➔ The calm weather associated with the eye will last less than an hour.

**Pressure Structure**

- The horizontal pressure gradient with altitude decreases slowly.
- At about 400 mb, pressures within the storm are approximate to that outside.
- Surface-400mb: Cyclonic circulation.
- 400mb-tropopause: Anticyclonic circulation.

- The upper portions of the storm are blanketed by a cirrus cloud cap due to overall low temperatures.

**Hurricane Wind Structure**

- Winds and surge are typically most intense in the right front quadrant of the storm where wind speeds combine with the speed of the storm’s movement to create the area of highest potential impact.
Hurricane track

- Hurricane tracks are affected by (1) subtropical high, (2) trade wind, and (3) Coriolis force.
- Hurricanes typically form within the trade wind belt and normally move westward with the winds.
- Due to the subtropical high and the Coriolis force, hurricanes tend to move poleward.
- Eventually hurricanes cross from the trade wind belt into the mid-latitude westerly belt, and begin to move eastward.

Naming Convention

- **Hurricanes**: extreme tropical storms over Atlantic and eastern Pacific Oceans.
- **Typhoons**: extreme tropical storms over western Pacific Ocean.
- **Cyclones**: extreme tropical storms over Indian Ocean and Australia.

Ocean Temperature And Hurricane

- Hurricanes depend on a large pool of warm water.

Annual Hurricane Frequency

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<tr>
<th>Basin</th>
<th>Maximum</th>
<th>Minimum</th>
<th>Average</th>
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<td>2</td>
<td>5.4</td>
</tr>
<tr>
<td>Eastern Pacific</td>
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<td>4</td>
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<tr>
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<td>16.0</td>
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<tr>
<td>Northern Indian Ocean</td>
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<tr>
<td>Southeastern Indian Ocean/Australia</td>
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<tr>
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<tr>
<td>Global</td>
<td>65</td>
<td>34</td>
<td>44.9</td>
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Source: Colorado State University

- No hurricane in the Southern Atlantic Ocean.
- Western Pacific hurricanes are the strongest.
Hurricanes form only over deep (several tens of meters) water layers with surface temperatures in excess of 27°C. Poleward of about 25°, water temperatures are usually below this threshold. Hurricanes are most frequent in late summer and early autumn during high SST times.

Coriolis force is an important contributor, and as such, hurricanes do not form equatorward of 5°.

Need an unstable atmosphere: available in the western tropical ocean but not in the eastern parts of the ocean.

Strong vertical shear must be absent for hurricane formation.

Hurricanes obtain their energy from latent heat release in the cloud formation process.

Hurricanes occur where a deep layer of warm waters exists and during the times of highest SSTs.

For the N.H., August and September are the most active months.

For the S.H., the hurricane season is January-March.

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Five categories: larger numbers indicate lower central pressure, greater winds, and stronger storm surges.

Hurricane Season

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Hurricane Damages

- Heavy rainfalls
- Strong winds
- Tornadoes
- Storm Surges: A rise in water level induced by the hurricane.

Hurricane Induced Tornadoes

- Most hurricanes also contain clusters of tornadoes.
- Most of these tornadoes occur in the right front quarter of the hurricane movement.
- It appears the slowing of the wind by friction at landfall contribute to the formation of tornadoes.

Hurricane Wind Structure

- Winds and surge are typically most intense in the right front quadrant of the storm where wind speeds combine with the speed of the storm’s movement to create the area of highest potential impact.

Storm Surges

- Process 1: Hurricane winds drag surface waters forward and pileup the waters near coasts.
- Process 2: Lower atmospheric pressure raises sea level (for every 1 mb pressure decrease, sea level raises 1 cm).
- Storm surges raise costal sea level by a meter or two for most hurricanes, but can be as much as 7 meters.
Hurricane Watches and Warnings

- **Hurricane watch**: if an approaching hurricane is predicted to reach land in more than 24 hours.

- **Hurricane Warning**: if the time frame is less, a warning is given.