Tropical Cyclones

FIU Undergraduate Hurricane Internship

Lecture 2

8/11/2011

Objectives

- From this lecture you should understand:
  - Global tracks of TCs and the seasons when they are most common
  - General circulation of the tropics and the force balances involved
  - 5 conditions required for TC formation and intensification
  - Properties of TC of different intensities and a general understanding of the Saffir-Simpson Scale
  - TC Horizontal and Vertical structure
  - How the Dvorak Technique is used to estimate TC intensity from satellites

2005 Hurricane Season Video

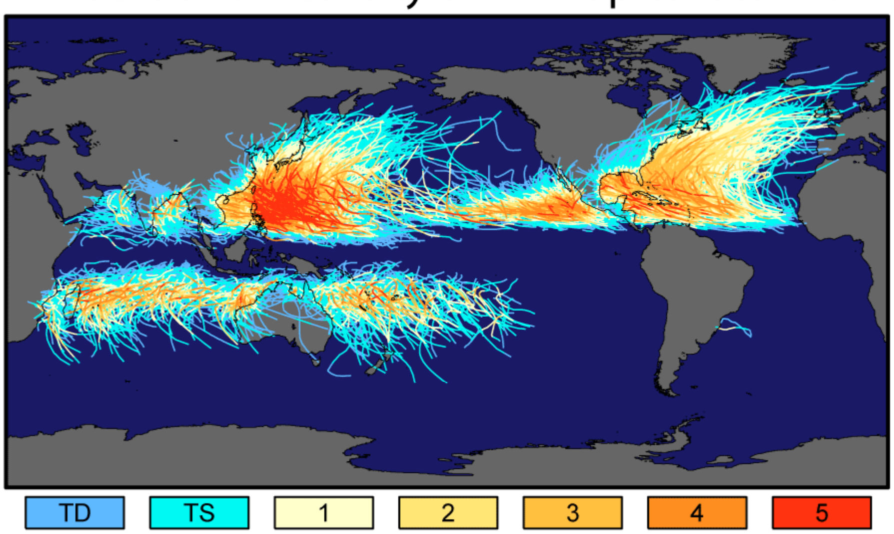
- http://www.youtube.com/watch?v=0woOxPYJz1U&feature=related
- Consider the following while watching video:
  - General flow pattern of clouds and weather systems
  - Origin/location of tropical storms in early season compared to later
  - Where are the most intense hurricanes located?

What is a Tropical Cyclone?

Defining a Tropical Cyclone (TC)

- Tropical:
  - Consistently warm, high humidity, very heavy rainfall
- Cyclone:
  - Winds rotating around a low pressure center
- Energy source:
  - Derived from latent energy in oceans
- Energy transport:
  - Vertical, through convection (thunderstorms)
- Center: "Warm Core"
  - Very low pressure and warm temperatures in the "eye" of a TC
- Size:
  - Technically a "Mesoscale" size system—very powerful, but not nearly as large as a mid-latitude cyclone

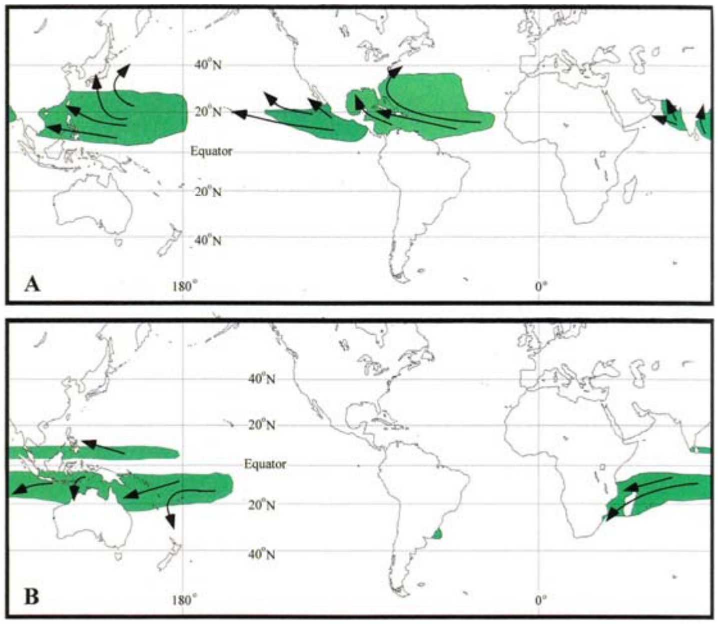
Tracks and Intensity of All Tropical Storms



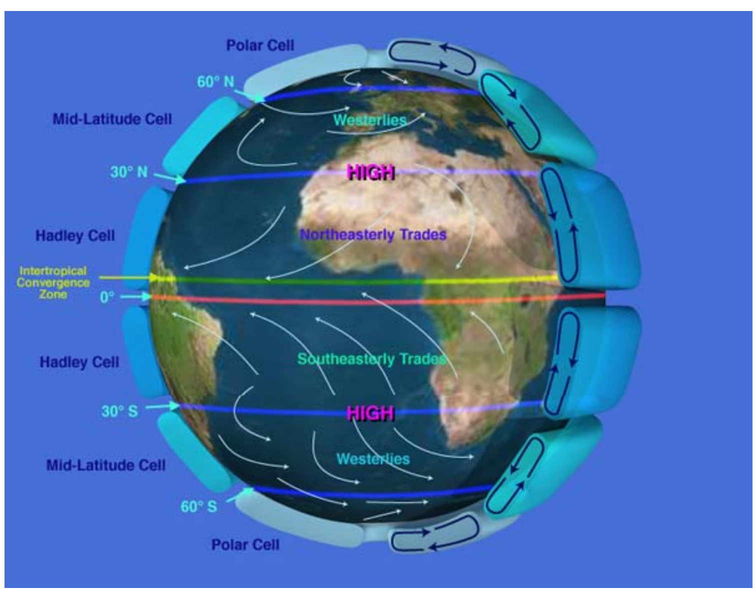
Saffir-Simpson Hurricane Intensity Scale

A) July-
September

B) Jaunary-
March

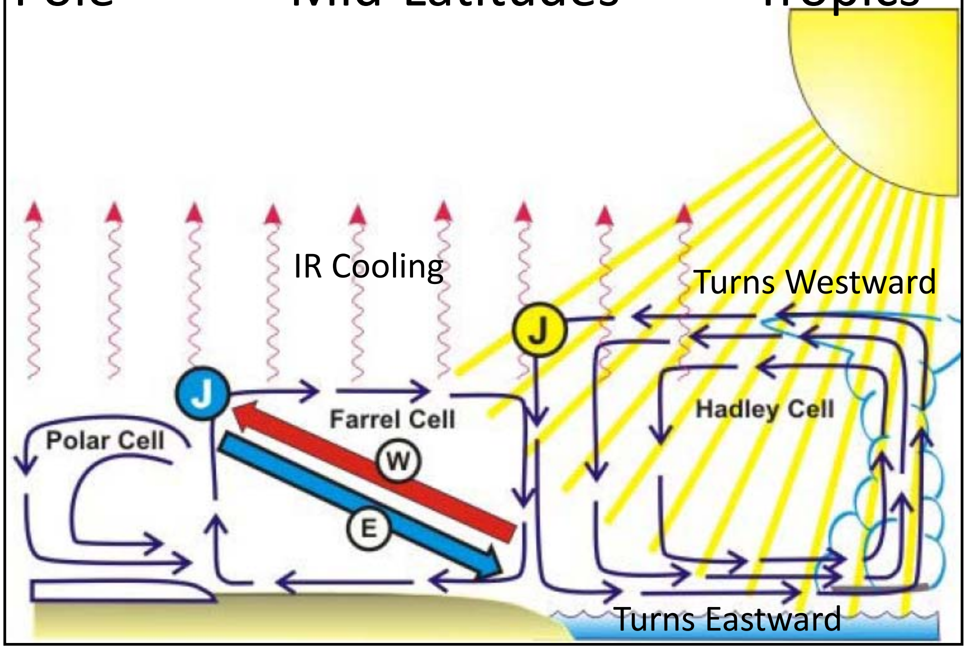


Global Circulation



Primary driving forces: Heat and Angular Momentum

Pole Mid-Latitudes Tropics

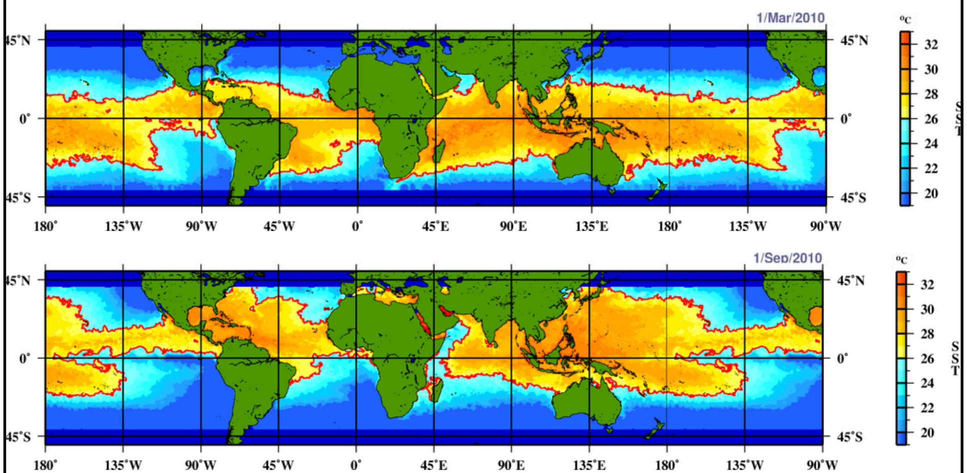


Necessary Conditions for TC Formation

1. Ocean surface warmer than 26°C
2. Reasonably humid at 2-5 km (low/mid-level) altitude, at least 80% RH or so
3. Weak vertical shear (< 15 m/s or so)
4. Pre-existing disturbance
5. More than 5° latitude from the Equator

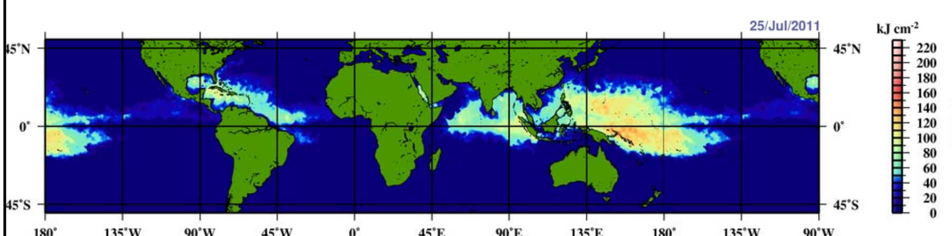
1. Ocean Temperature > 26 °C

Top: March 1, 2010, Bottom: September 1, 2010

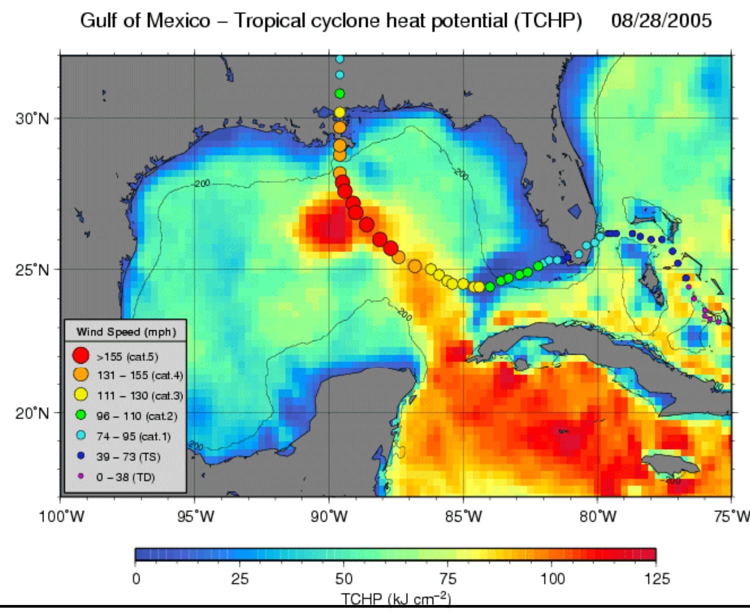


TCHP: Tropical Cyclone Heat Potential

- In strong and slow-moving TCs, wave action often mixes cooler water from below up to the surface
- TCHP considers how **deep** the 26 °C isotherm lies below the ocean surface, so a deep layer of warm water yields a higher TCHP
- Key factor in determining Maximum Potential Intensity (MPI) of a TC

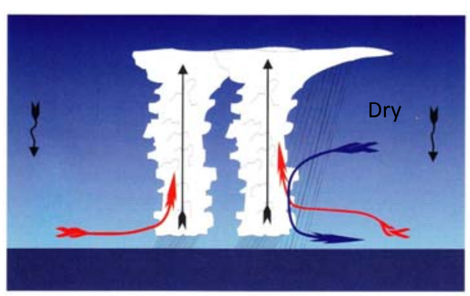


Loop Current

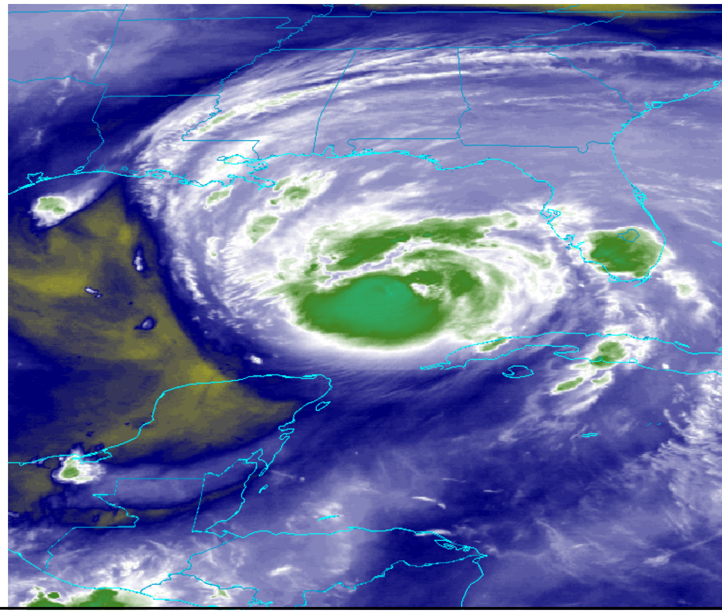


2. Reasonably humid at 2-5 km

- Problems with mid-level dry air:
  - Dry air has less stored latent energy and is less buoyant
  - Dry air near a thunderstorm causes some cloud droplets/rain to evaporate, which strengthens downdrafts and brings lower energy air to the surface

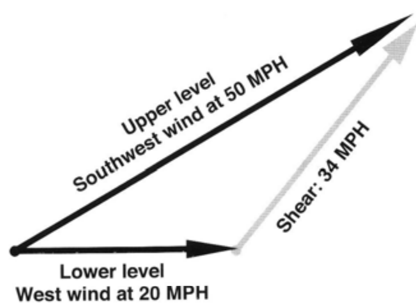


Color-Enhanced Water Vapor Imagery



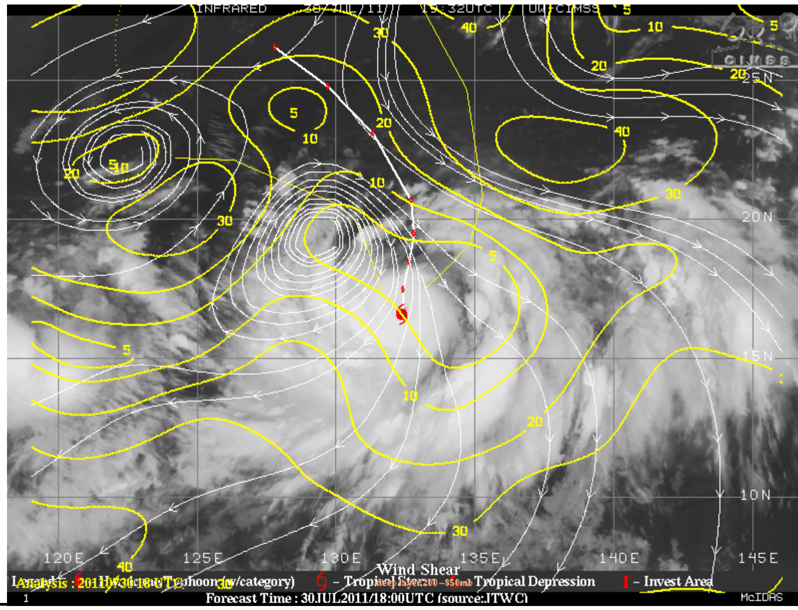
3. Weak Vertical Shear

- Definition of wind shear: vector difference between upper and lower level wind speeds
- High shear causes top and bottom of storm to move at different speeds, literally ripping the TC apart



Wind shear is usually defined as the difference between 850 and 200 mb wind vectors

Shear < 15 m/s is most favorable



4. Pre-existing disturbance

- Organized disturbances tend to be surrounded by a "pouch" of moist air, protecting them from destructive dry air
- General "trough" of low pressure helps provide focus for sustained thunderstorm activity
- Most pre-existing disturbances never develop into TCs due to lack of conditions 1-4.

Types of Pre-existing disturbances

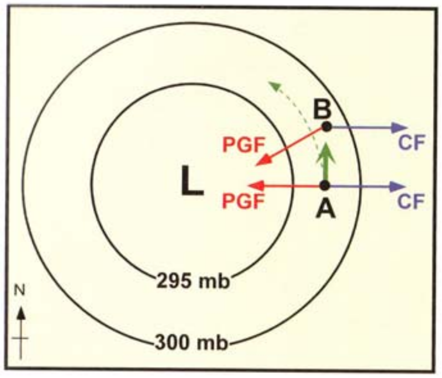
- Easterly Wave
  - Originates in sub-Saharan Africa, one wave every 3 days during peak season
- Monsoonal Trough
  - Disturbance/wave along ITCZ
- Mesoscale Convective Complex (MCC)
  - Long lasting T-storm cluster, formed over land (such as in Southeast US) and migrates over ocean
- Cold Front

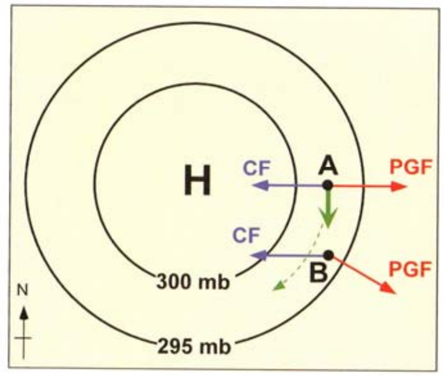
5. More than 5 degrees from Equator

- Atmospheric forces:
  - Pressure Gradient Force (PGF)
    - Wind blows from high to low pressure
  - Coriolis Force (CF)
    - "Apparent" deflection of wind to right in Northern Hemisphere (left in Southern Hemisphere)
    - Reverses direction at Equator, too low near equator for low pressure systems to "spin up"
  - Friction (F)
    - Slows speed of wind
    - When wind is slowed by friction, PGF > CF, causing wind to deflect inward, "filling in" and weakening low pressure systems
    - Friction is greater over land than water, contributing to the weakening of a landfalling hurricane

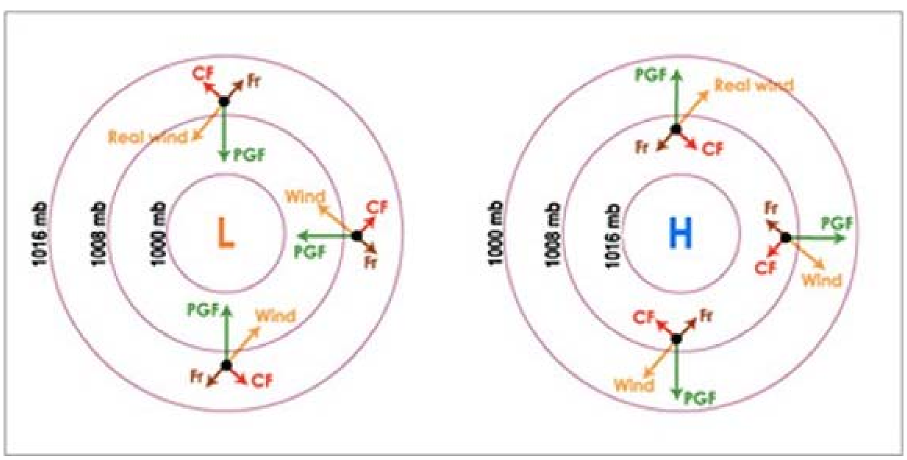
Ideal "Frictionless" Flow

- PGF and Coriolis (+ Centripetal) forces balance, wind blows parallel to isobars





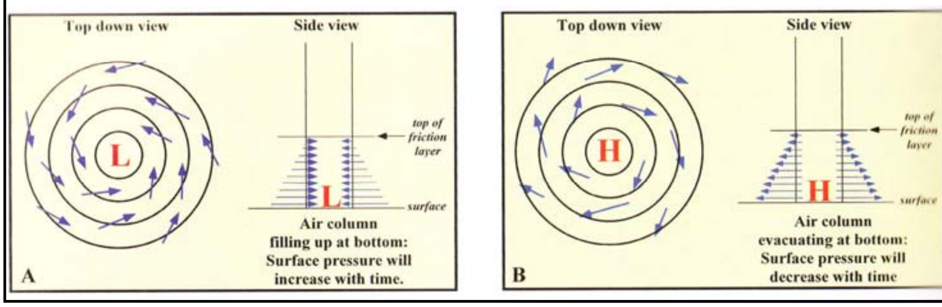
Flow with Friction

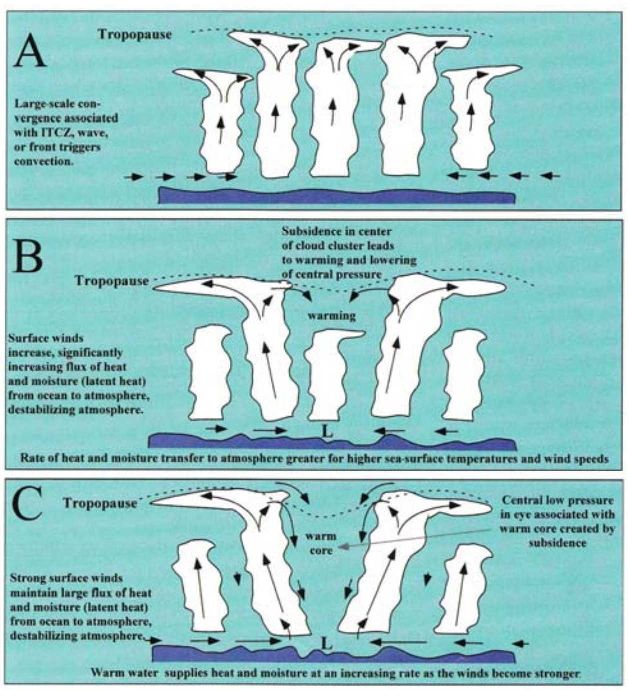


- Important: Coriolis force is proportional to wind speed, so friction reduces both Wind and CF

Effect of Friction on TCs

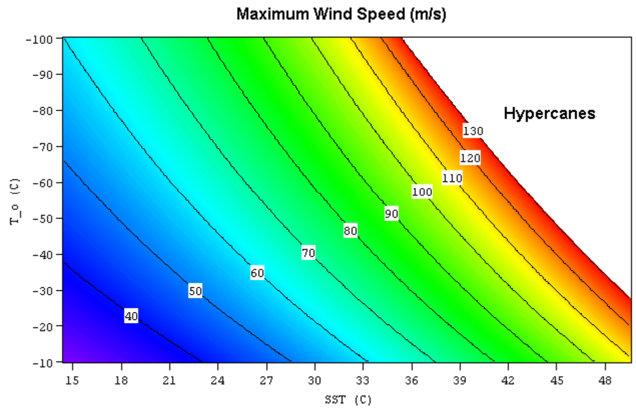
- Friction causes wind to cross isobars
- Result is that both low and high pressure systems are weakened over time
- Friction over land > Friction over water, so a landfalling hurricane “fills in” quickly





Maximum Potential Intensity (MPI)

- Depends on two factors:
  1. Sea surface temperature
  2. Temperature at top of tropopause



Hurricanes rarely reach MPI because:

1. Environmental conditions are usually less than ideal (wind shear)
2. It can take up to a week or more for a TC to organize and strengthen
3. Upwelling of cooler ocean temperature from below due to winds
4. Eyewall replacement cycles

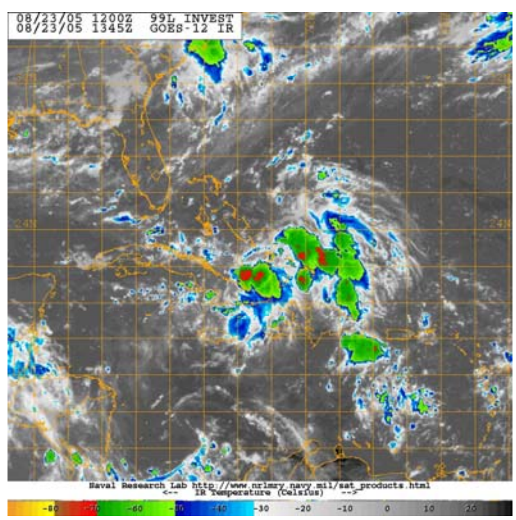
- However, if a TC is well below MPI and has favorable environmental conditions, it may undergo rapid intensification.

TC Lifecycle

- Tropical Disturbance
- Tropical Depression
- Tropical Storm
- Hurricane
- Major Hurricane (Cat 3-5)
- Extratropical Transition or Dissipation

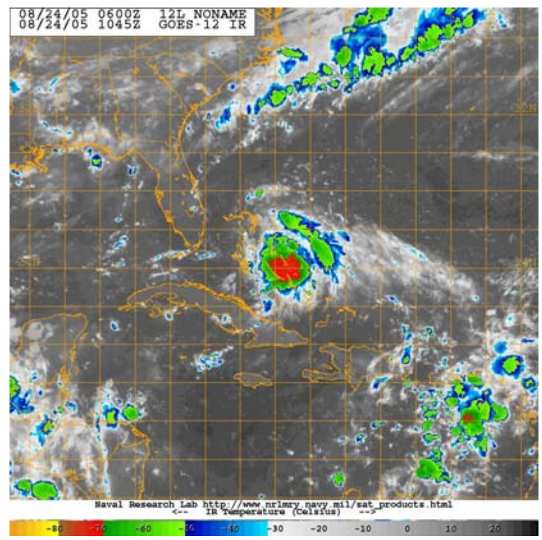
Tropical Disturbance

- Cluster of Thunderstorms maintaining identity for >24 hours
- Poor organization
- Max sustained surface winds < 23 mph (20 kts)
- General area of low pressure, no surface circulation
- Classified numerically: “91L”, “92L”, etc.



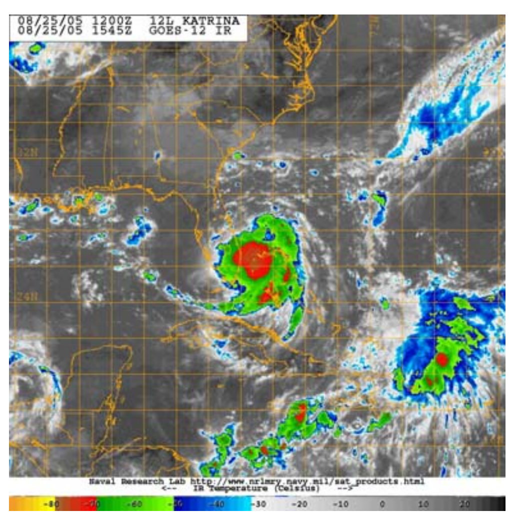
Tropical Depression

- Area of convection with cyclonic circulation around a low pressure center
- Max sustained surface winds 23-39 mph (20-34 kts)
- Classified in ascending numeric order by basin:
- “TD #1”, “TD #2”, etc.



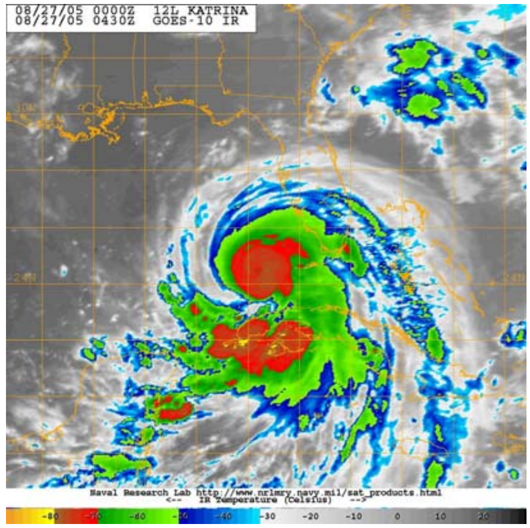
Tropical Storm

- Max sustained surface winds 40-74 mph (34-64 kts)
- Convection is concentrated near the center with outer rainfall organizing into distinct bands.
- Wide range of sizes, shapes, and intensities depending on environment
- Named: Arlene, Bret, Cindy, etc.



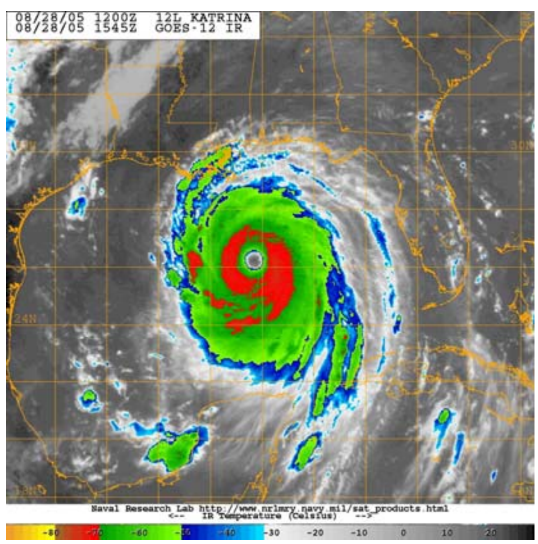
Hurricane

- Max sustained surface winds > 74 mph (64 kts)
- Large area of convection on visible/IR satellite imagery, known as a Central Dense Overcast (CDO)
- Almost always has an eyewall or at least banded eyewall features visible on Radar/Microwave Satellite images



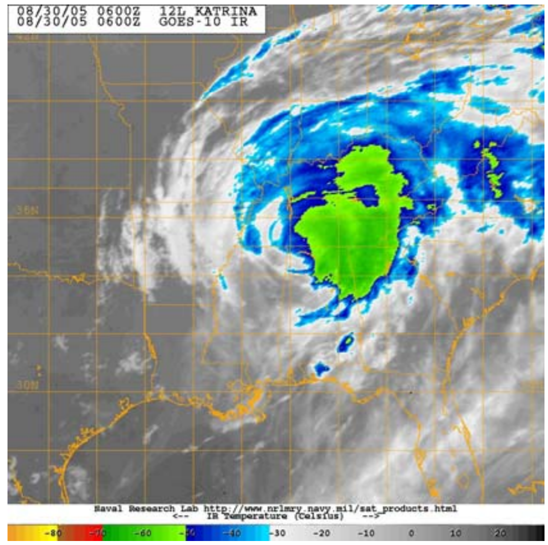
Major Hurricane

- Max sustained surface winds > 111 mph (96 kts)
- Usually close to symmetric, with an eye, eyewall, and spiral bands
- Responsible for majority of deaths/damage



Extratropical Transition

- Characterized by a loss of tropical characteristics (warm core) but not necessarily a large drop in intensity
- Occurs when a TC merges with a frontal system or mid-latitude trough
- Does not happen in all cases, sometimes a TC will simply move over land/cold water and dissipate



Saffir-Simpson Scale

Category	Wind (mph)	Pressure (mb)	Storm Surge (ft)
1	74-95	> 980	4-5
2	96-110	965-979	6-8
3	111-130	945-964	9-12
4	131-155	920-944	13-18
5	>1 55	< 920	> 18

- Major hurricanes are Categories 3-5, responsible for 80% of damage in US
- Size/shape/location of Hurricane determines type and extent of damage
  - Example: Compare damage of Katrina and Andrew

Vertical Structure

- **Lower levels:** cyclonic inflow, latent energy gained through exchange with sea
- **Mid levels:** strong vertical updrafts, condensation releases latent energy
- **Upper Levels:** anticyclonic outflow, some air sinks into eye and warms core, rest is expelled and slowly sinks away from storm

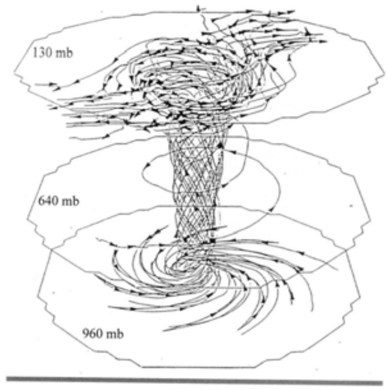
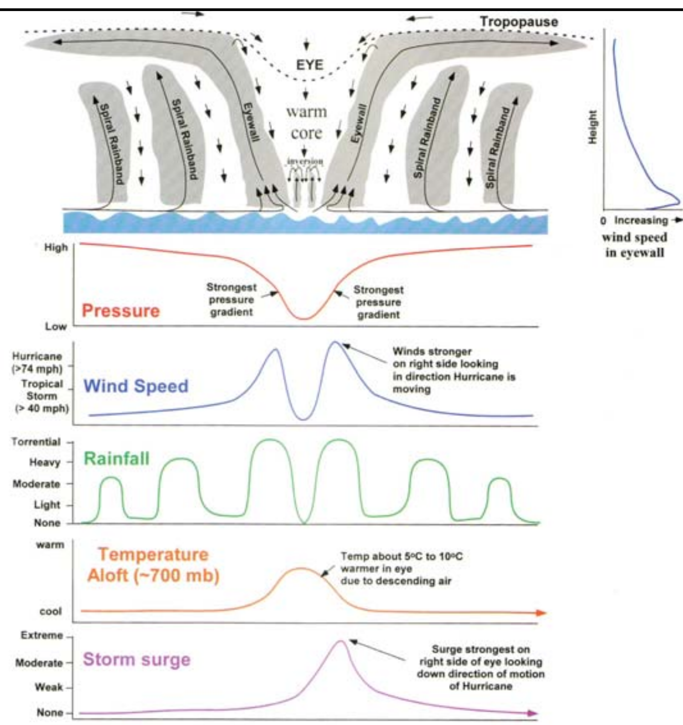


Figure 23.7 Trajectories of air parcels as they move through a numerically modeled hurricane. A full trajectory covers a period of eight days and each arrow head along a trajectory denotes a nine-hour interval. (From Anthes, R.A., Trout, J. W., and S. S. Ostlund. 1971. Three-dimensional particle trajectories in a model hurricane. *Weatherwise* 24: 176. Reprinted with permission of the Helen Dwight Reed Educational Foundation and Heldref Publications, 1319 18th Street, NW, Washington, DC 20036-1802.)

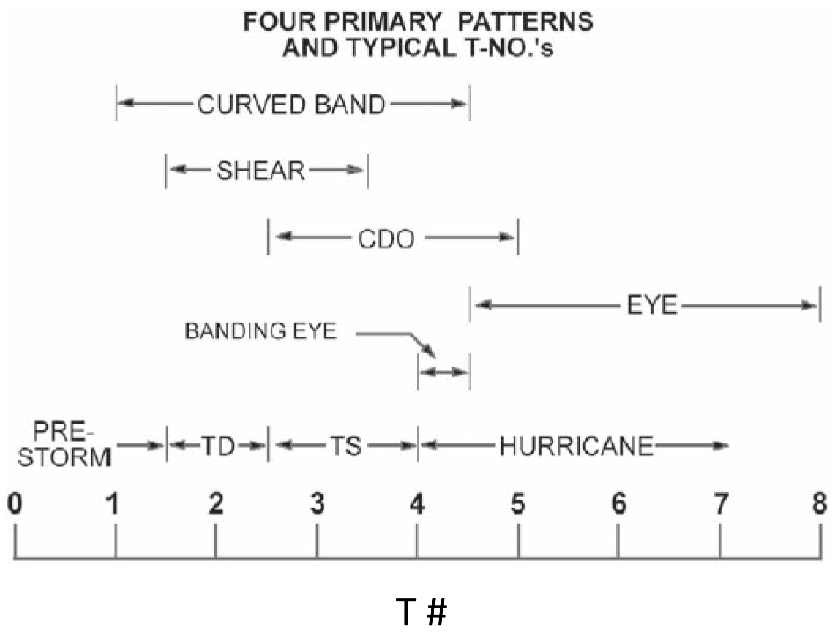


Determining TC Intensity from Satellites

1. Statistical Methods (Dvorak Technique)
   - Use cloud pattern to estimate intensity based on similar historic storms
2. Satellite-Derived Wind Speeds
   - Estimate wind speed from cloud tracks
3. Microwave Satellite Imagery
   - Observe structure of rainbands to find spiral bands, eyewalls/concentric eyewalls and other signs of organization

Dvorak Technique

- Estimates intensity in terms of T (Tropical) numbers that range from T0 to T8 in steps of 0.5
- Originally used Visible imagery, new techniques have been developed for IR and Microwave Imagery
- Combines
  - Model Estimated T-number (MET) based upon climatological rates of intensification
  - Data T-number (DT) based upon recognition and analysis of "scene types"
- Scene types:
  - Curved Band Pattern
  - Shear Pattern
  - Central Dense Overcast (CDO) Pattern
  - Eye Pattern or Banding Eye Pattern
- Relationship between T number and maximum surface wind



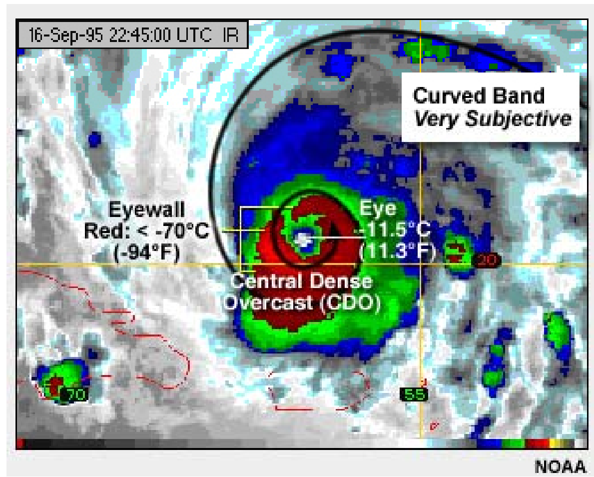
Dvorak T-Number and Corresponding Intensity[3]

T-Number	Winds (knots)	Winds (mph)	Winds (km/h)	Category (SSHS)	Min. Pressure (millibars) Atlantic	Min. Pressure (millibars) NW Pacific
1.0 - 1.5	25	29	46	TD	----	----
2.0	30	35	56	TD	1009	1000
2.5	35	40	65	TS	1005	997
3.0	45	52	83	TS	1000	991
3.5	55	63	102	TS	994	984
4.0	65	75	120	Cat 1	987	976
4.5	77	89	143	Cat 1–2	979	966
5.0	90	104	167	Cat 2–3	970	954
5.5	102	117	189	Cat 3	960	941
6.0	115	132	213	Cat 4	948	927
6.5	127	146	235	Cat 4	935	914
7.0	140	161	260	Cat 5	921	898
7.5	155	178	287	Cat 5	906	879
8.0	170	196	315	Cat 5	890	858

Note: The pressures shown for the NW Pacific are lower as the pressure of that whole environment is lower as well.

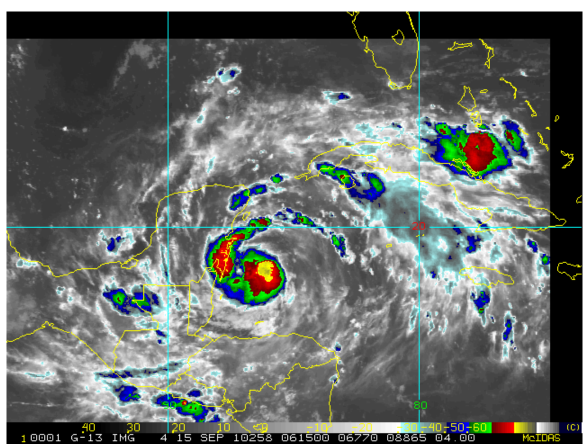
Eye Pattern

- Identifies the temperature contrast between the warmest part of the eye the coldest surrounding convection.
- The greater the temperature contrast, the stronger the system.



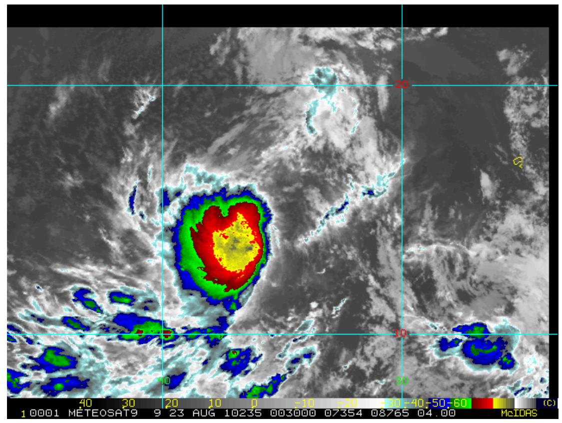
Curved Band Pattern

- The more the rainbands are wrapped around the system, the greater the TC vorticity, or spin.



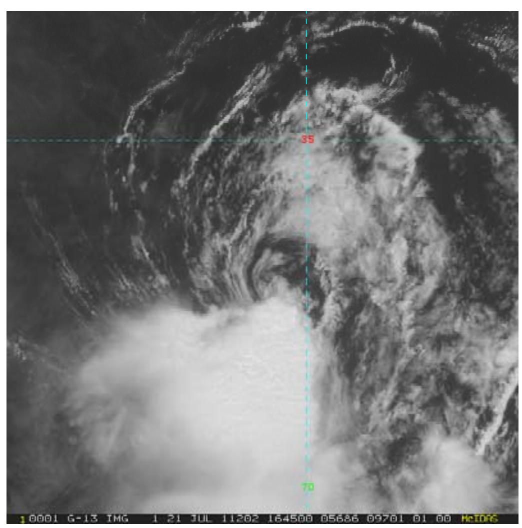
Central Dense Overcast (CDO) Pattern

- CDO: The area covered by the cirrus clouds that extend from the thunderstorms in the eyewall and rainbands of a TC
- Judged on its size and degree of banding
- Sometimes difficult to find center without help from Microwave Imagery



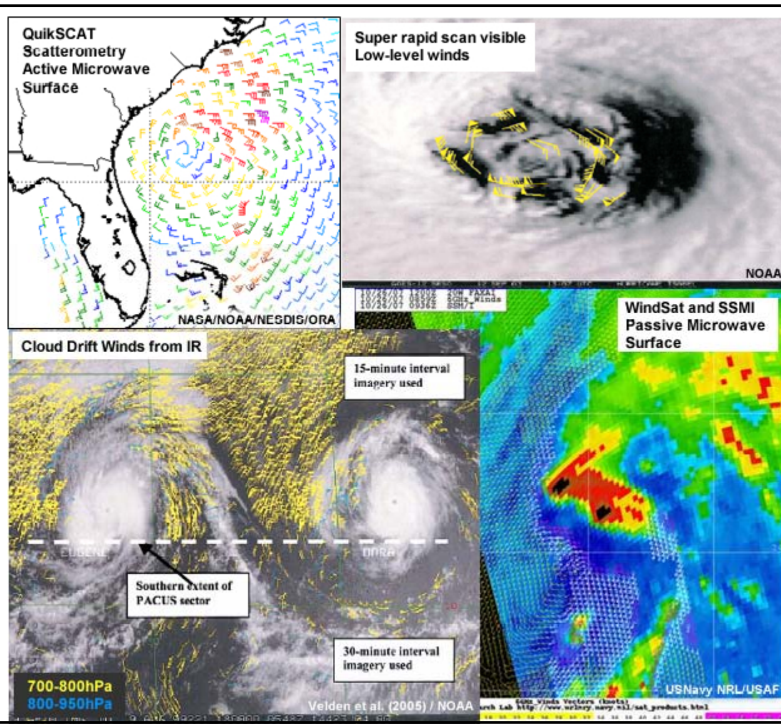
Shear Pattern

- The distance between the low-level center (LLC) and the CDO
- If the LLC and CDO are closely connected, the storm is stronger than if they are separated, or sheared apart

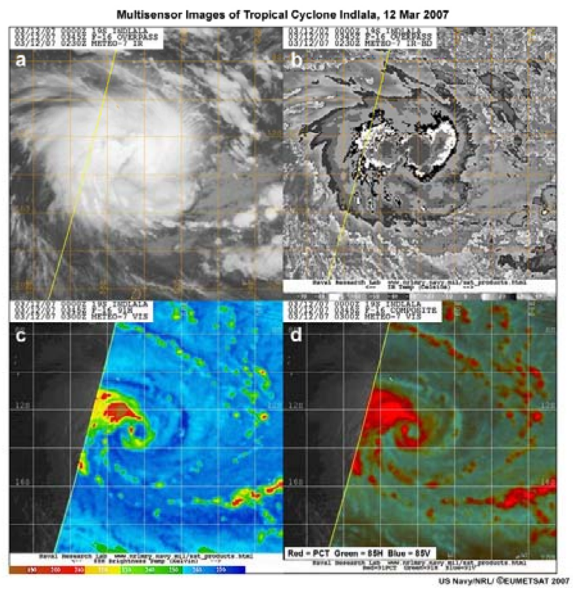


Satellite-Derived Winds

- Works best in moderate-wind and low-precipitation environments
- Not useful under deep convection
- Useful to determine wind speed radii, which is important for shipping interests, storm surge forecasts, and numerical modeling
- Wind satellites are often polar-orbiters, so real-time data is not always available
- GOES satellites can also be used by monitoring cloud drift patterns



Microwave Imagery



Review Questions

1. Name one of the 5 necessary conditions for Tropical Cyclone formation.
2. A Hurricane's Maximum Potential Intensity (MPI) depends on what two factors?
3. Name one of the 4 scene types used in the Dvorak Technique to classify TC intensity.