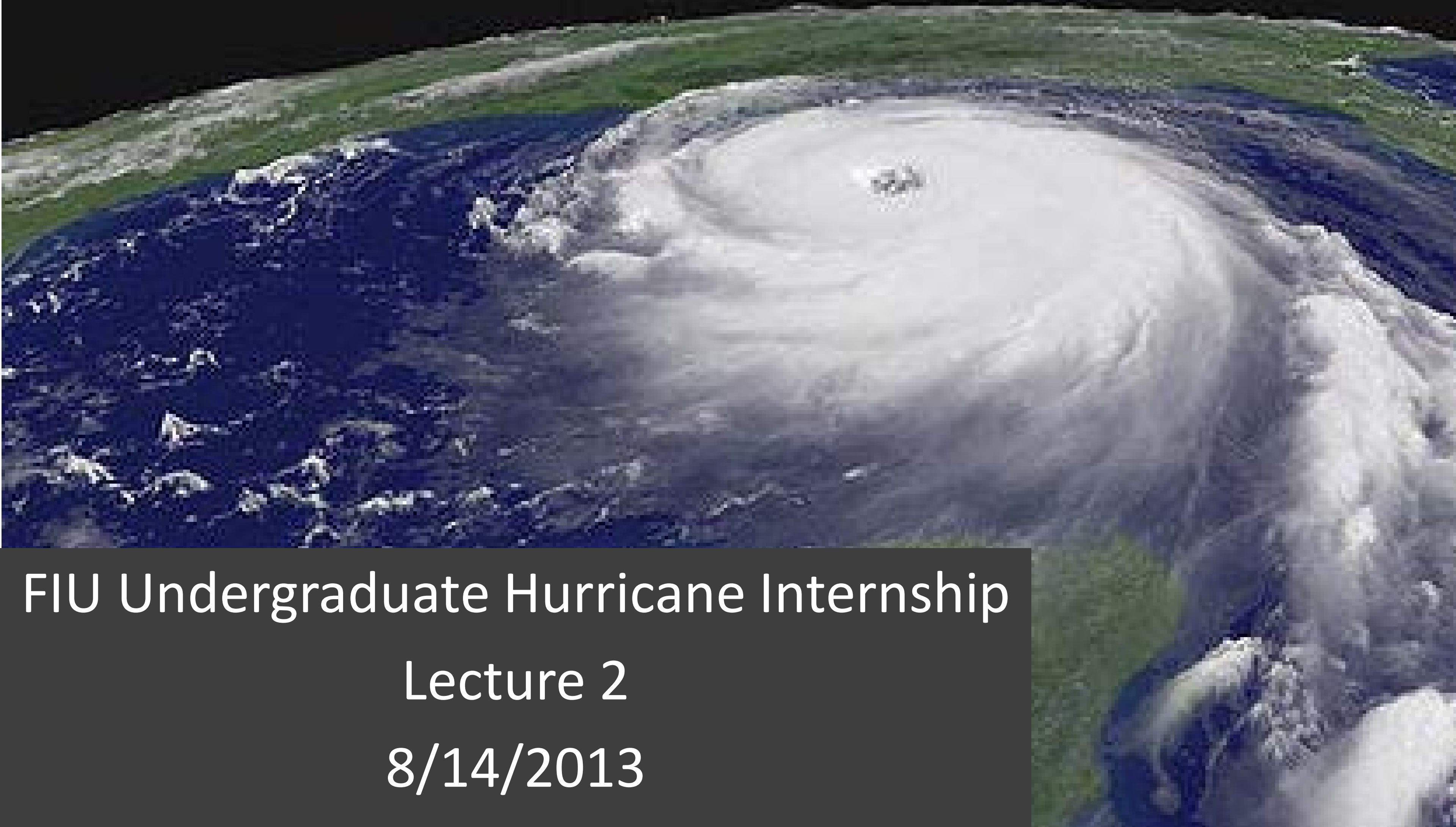
Tropical Cyclones



FIU Undergraduate Hurricane Internship

Lecture 2

8/14/2013

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
  - Conditions required for TC formation
  - 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

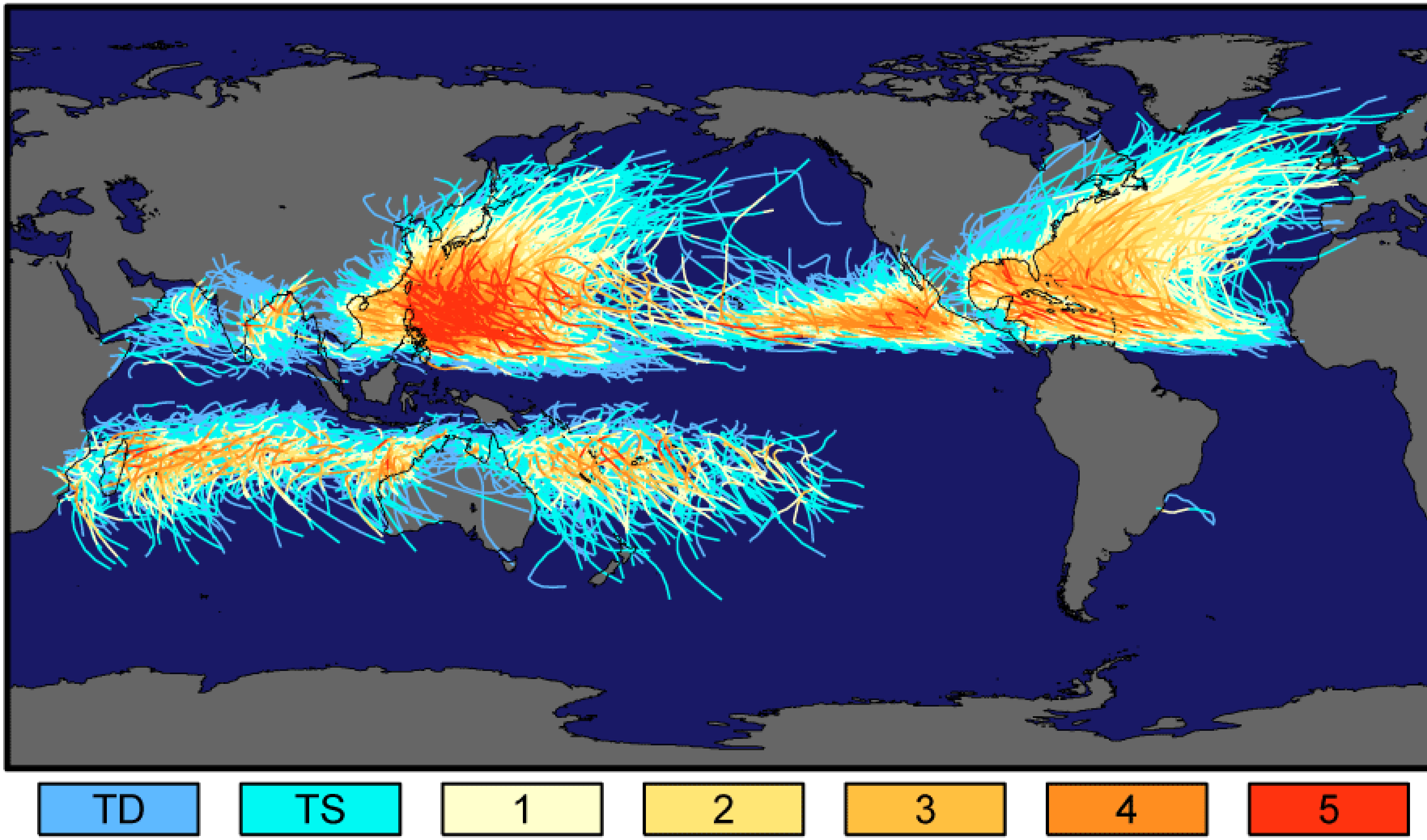
- http://www.youtube.com/watch?v=0woOxPYJz1U&feature=related
- Consider the following while watching video:
  - General flow pattern of clouds and weather systems
  - Origin/location of tropical storms in early season compared to later
  - Where are the most intense hurricanes located?

What is a Tropical Cyclone?

Defining a Tropical Cyclone (TC)

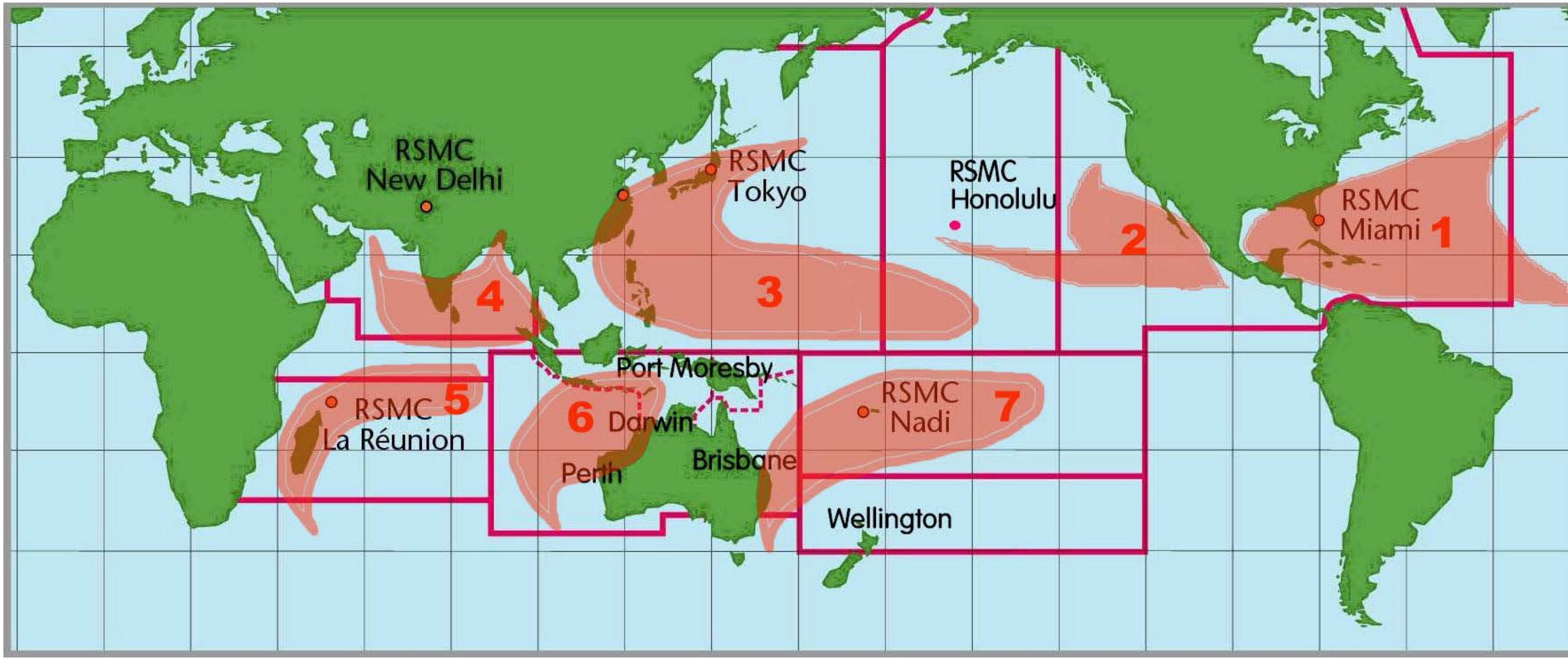
- Warm-core, non-frontal, synoptic scale cyclone
- Originates over tropical or subtropical waters
- Maintains organized deep convection (banding features, central dense overcast)
- Closed surface wind circulation around well-defined center
- Maintained by barotropic energy…
  - Heat extracted from ocean and exported to the upper troposphere
- …Not by baroclinic energy
  - Energy from horizontal temperature contrasts…frontal

Tracks and Intensity of All Tropical Storms



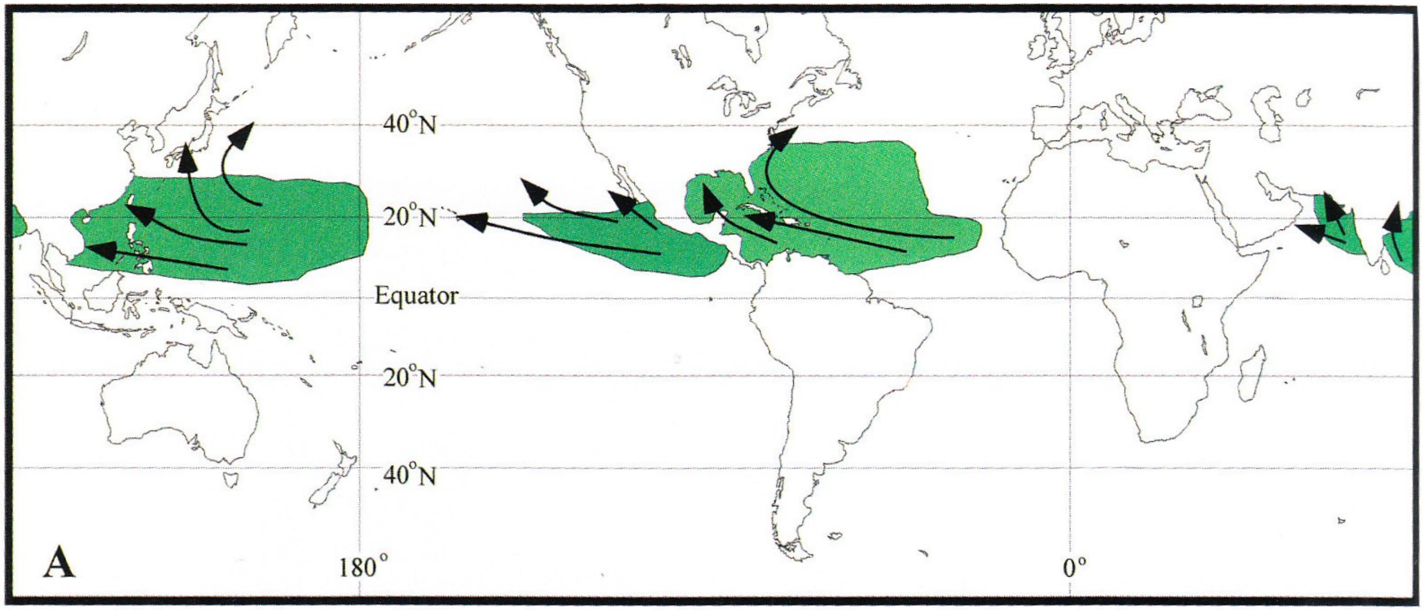
Saffir-Simpson Hurricane Intensity Scale

Tropical Cyclone Basins

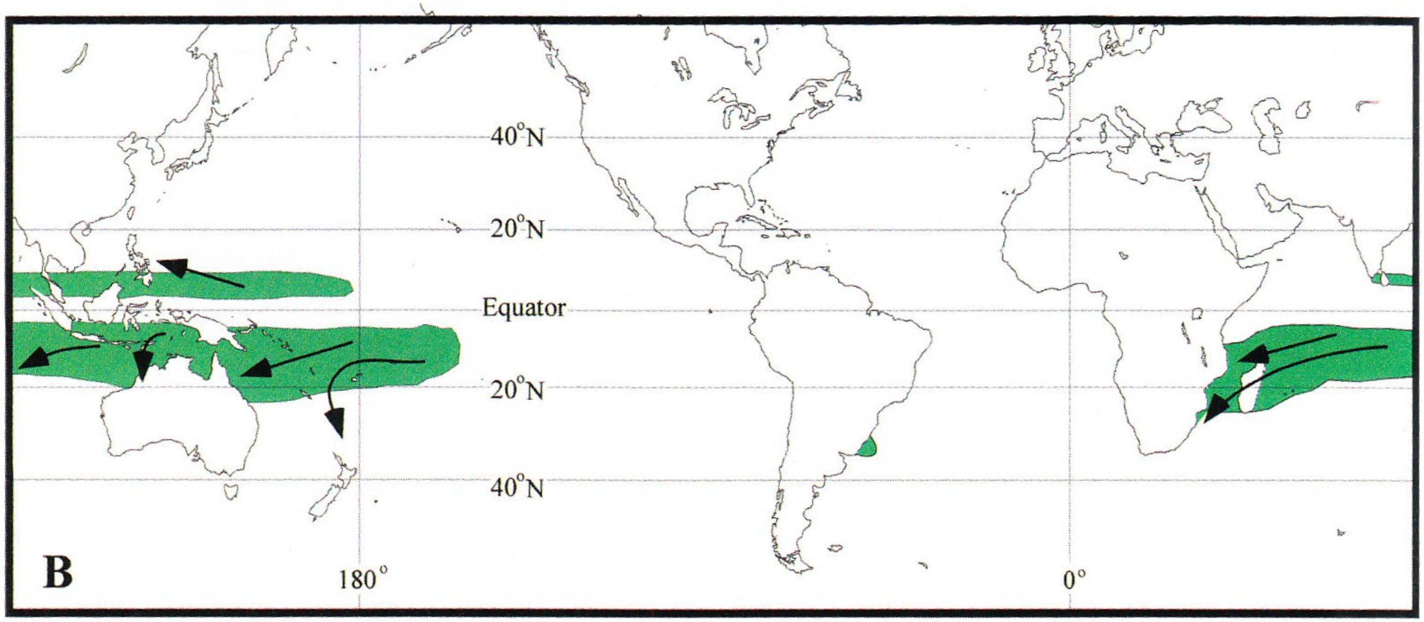


- 86 globally on average with about a quarter becoming intense
- WPAC busiest, followed by EPAC, ATL, SWIO, AU, SPAC, NIO

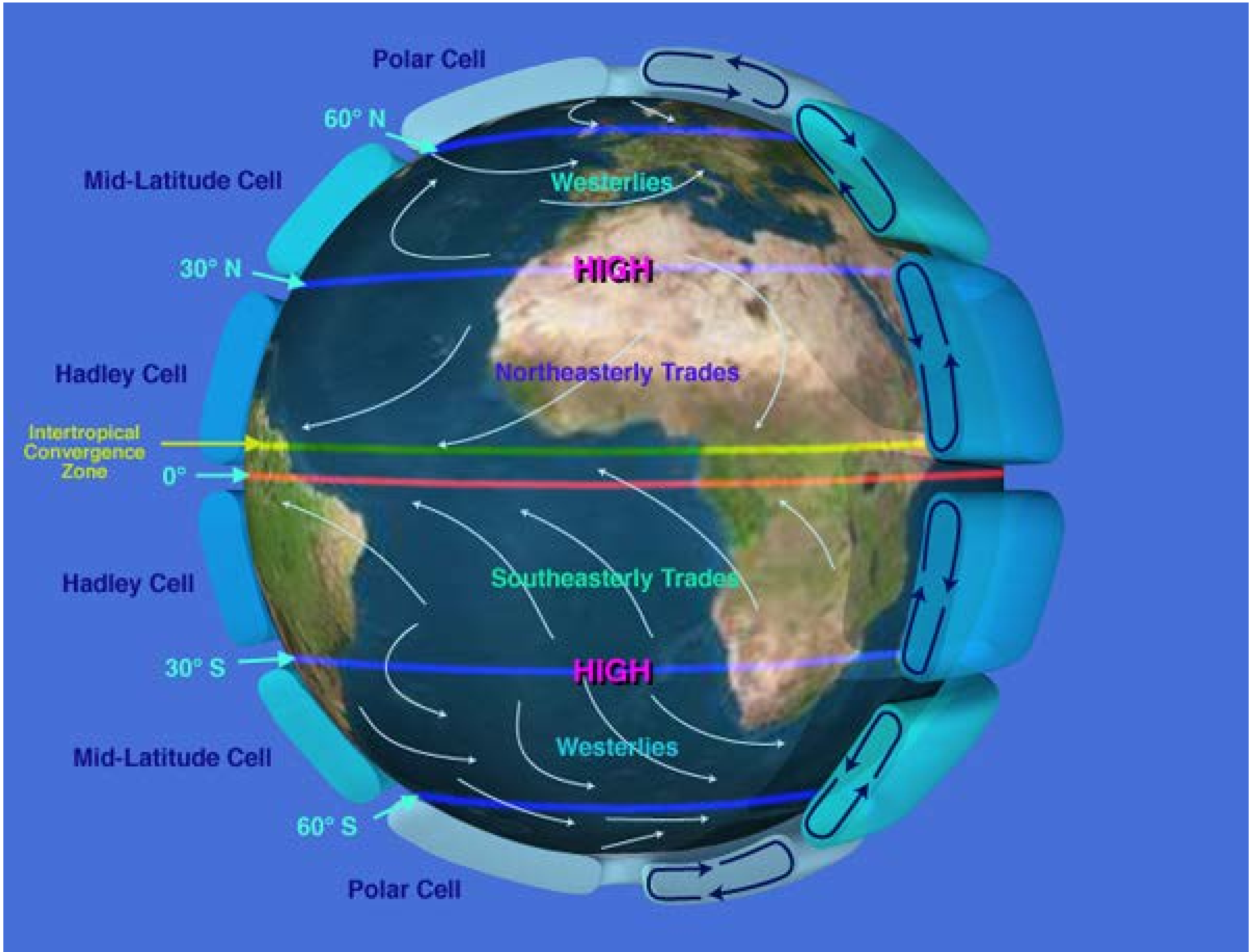
A) July-September



B) Jaunary-March

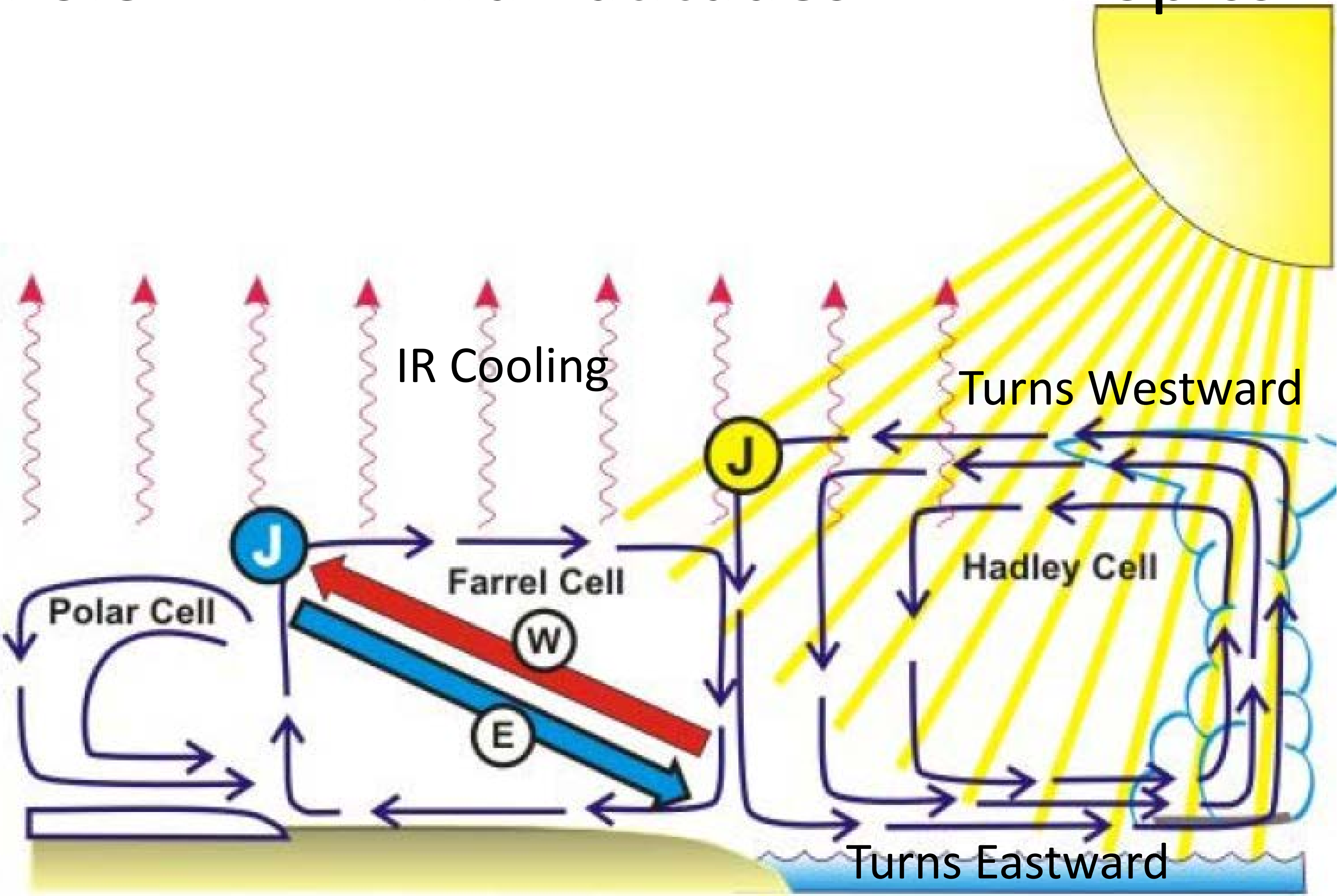


Global Circulation



Primary driving forces: Heat and Angular Momentum

Pole Mid-Latitudes Tropics

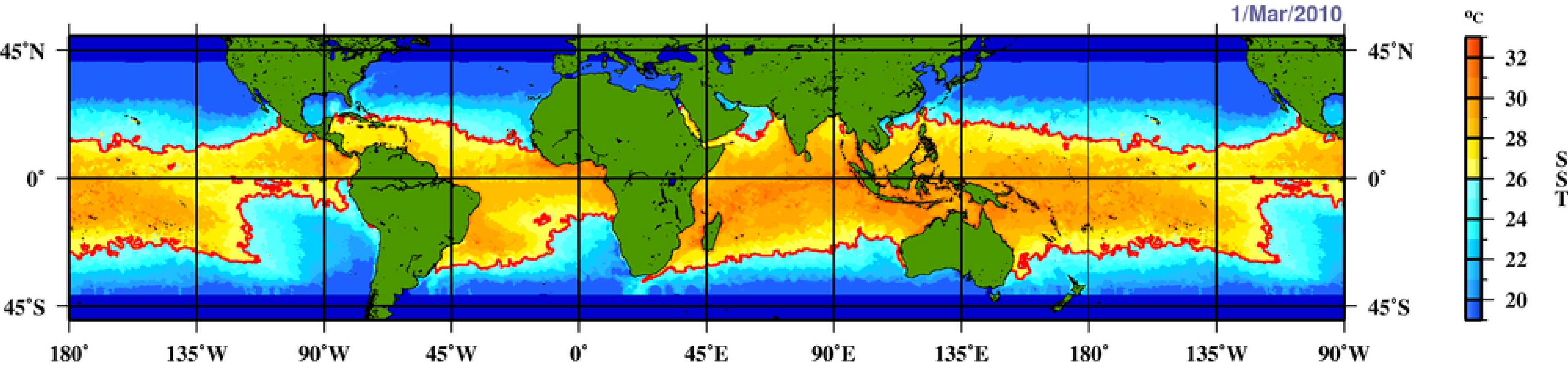


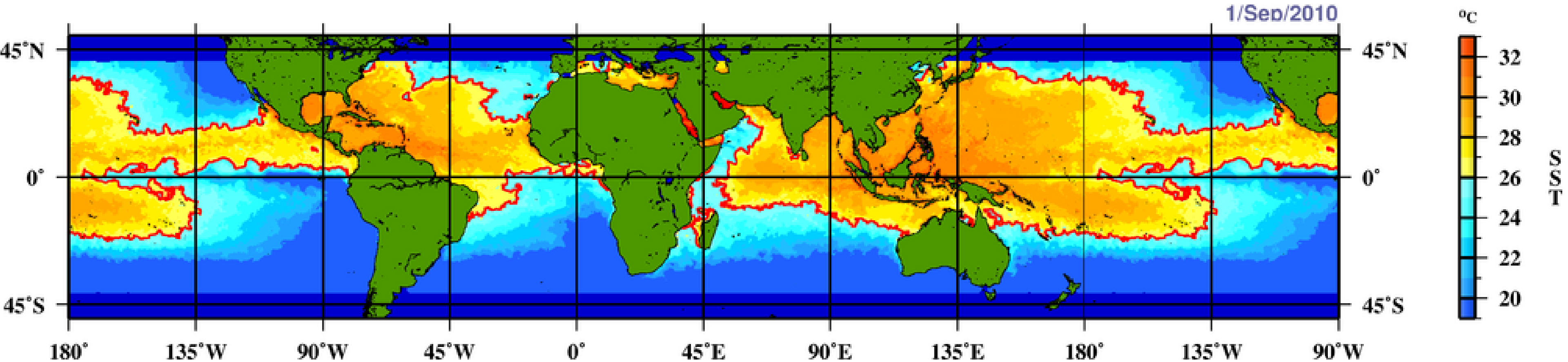
Necessary Conditions for TC Formation (Tropical Cyclogenesis)

1. Warm ocean surface (warmer than 26°C)
2. Weakly sheared troposphere (< 15 m/s or so)
3. Conditional instability
4. Pre-existing disturbance (enhanced vorticity)
5. Humid at 2-5 km (low/mid-level, around 700 mbar) altitude, at least 70-80% RH
6. Usually more than 5° latitude from the Equator (weak Coriolis force, less spin)

1. Ocean Temperature > 26 °C

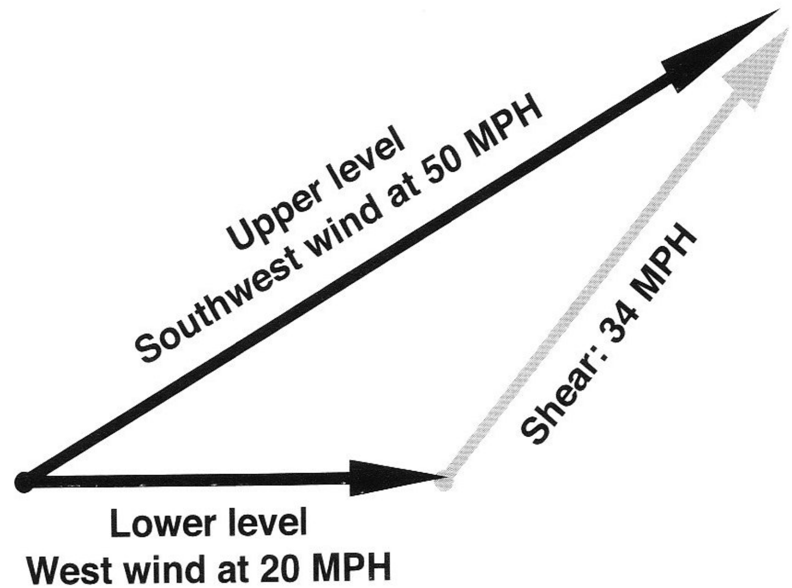
Top: March 1, 2010, Bottom: September 1, 2010





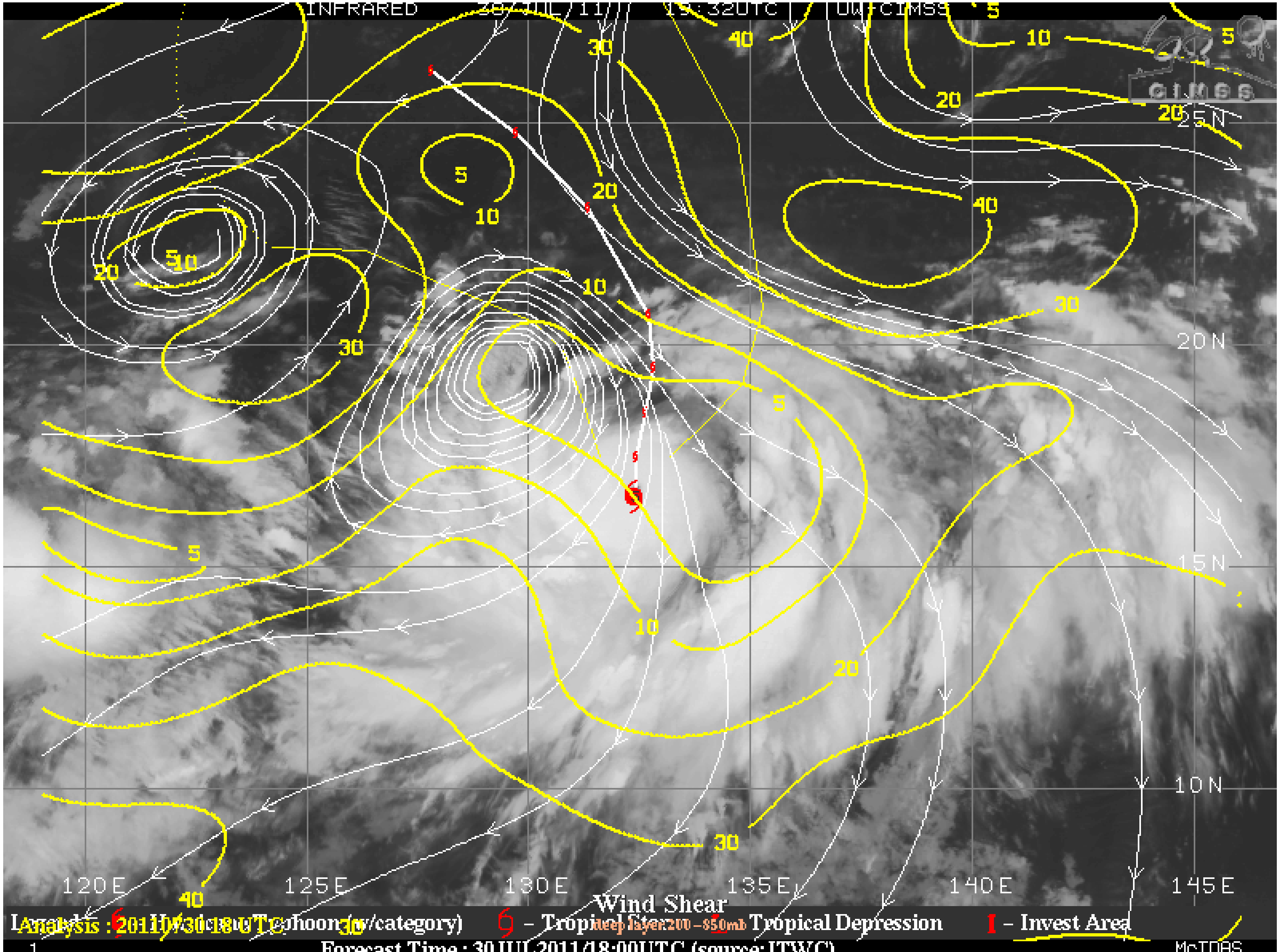
2. Weak Vertical Shear

- 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

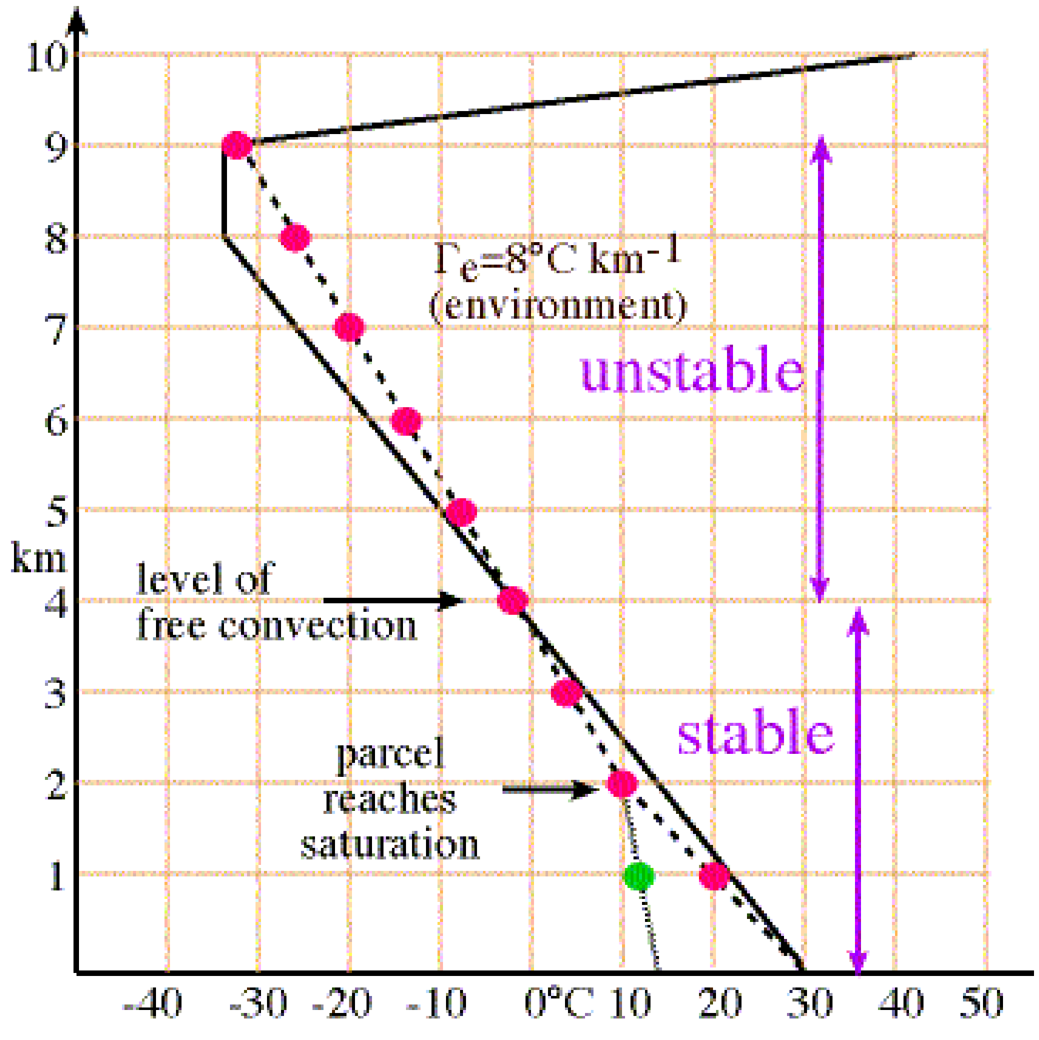


Wind shear is usually defined as the difference between 850 and 200 mb wind vectors

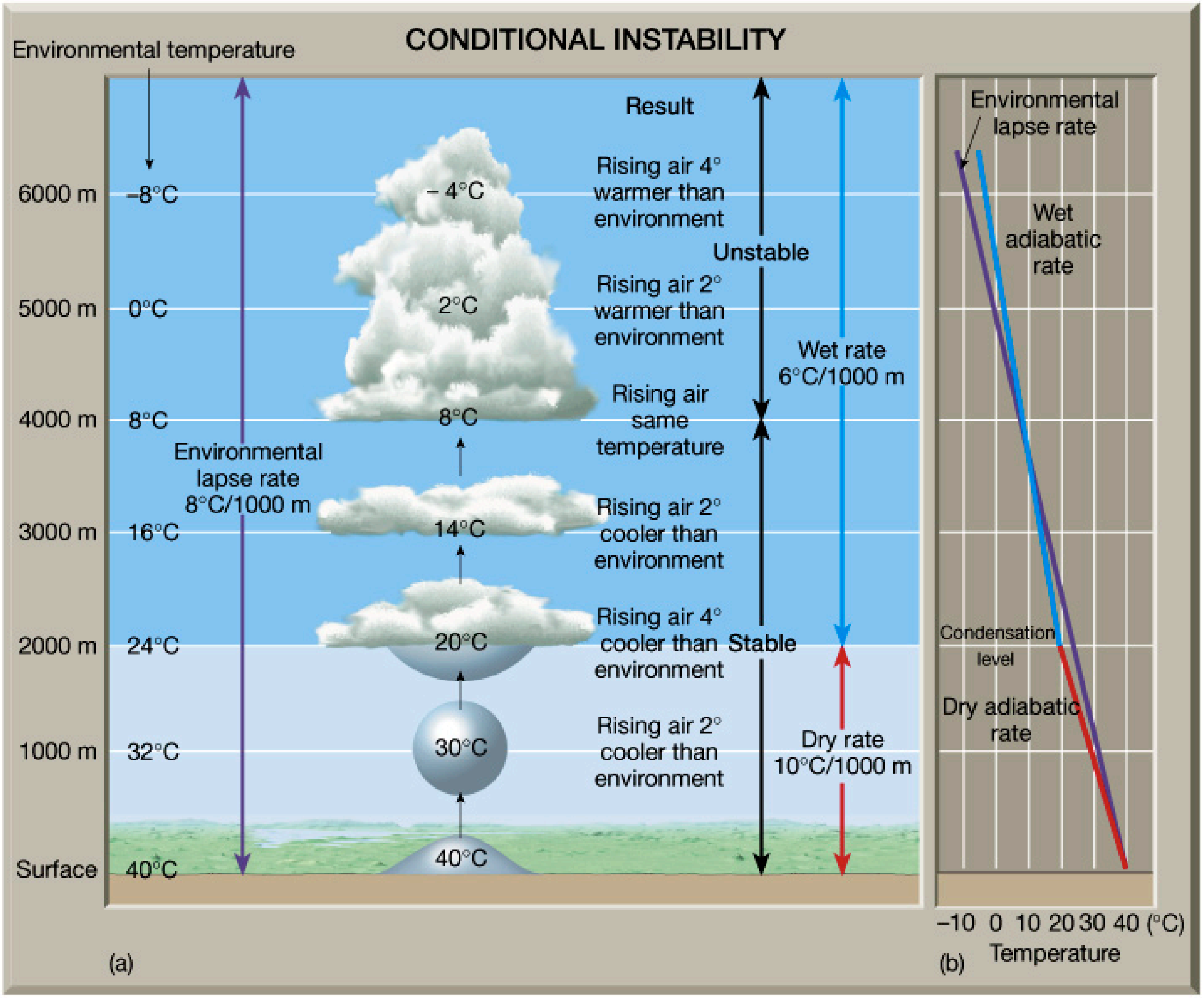
Shear < 15 m/s is most favorable



3. Conditional Instability

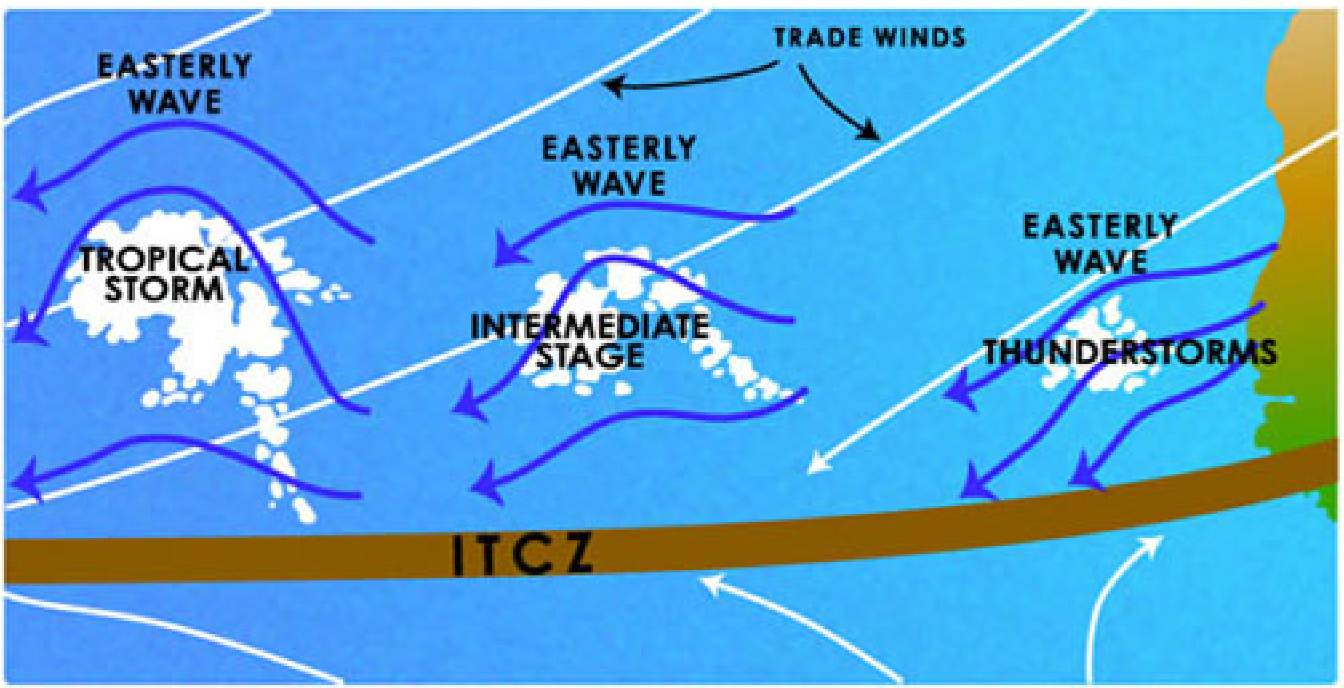


3. Conditional Instability



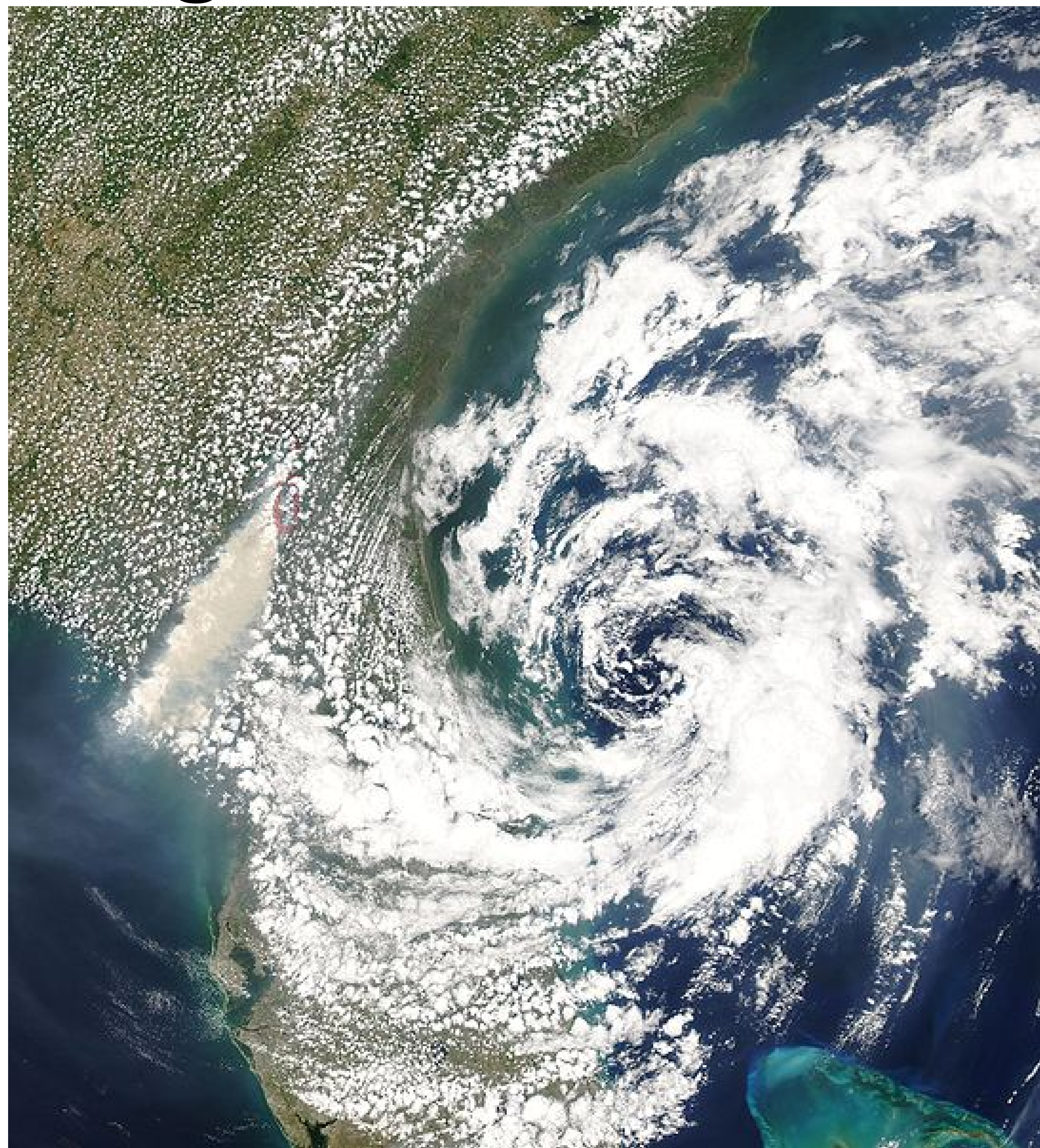
4. Pre-Existing Disturbance

- Tropical Wave or Easterly Wave – moves off Africa into ATL and sometimes EPAC basins



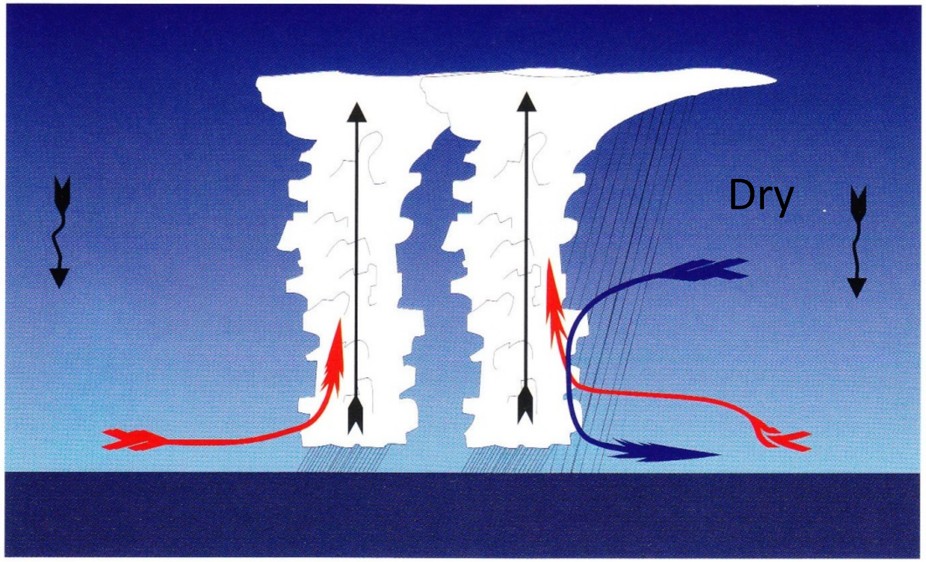
4. Pre-Existing Disturbance

- Cutoff low at the tail of a trough can develop into a tropical or subtropical cyclone

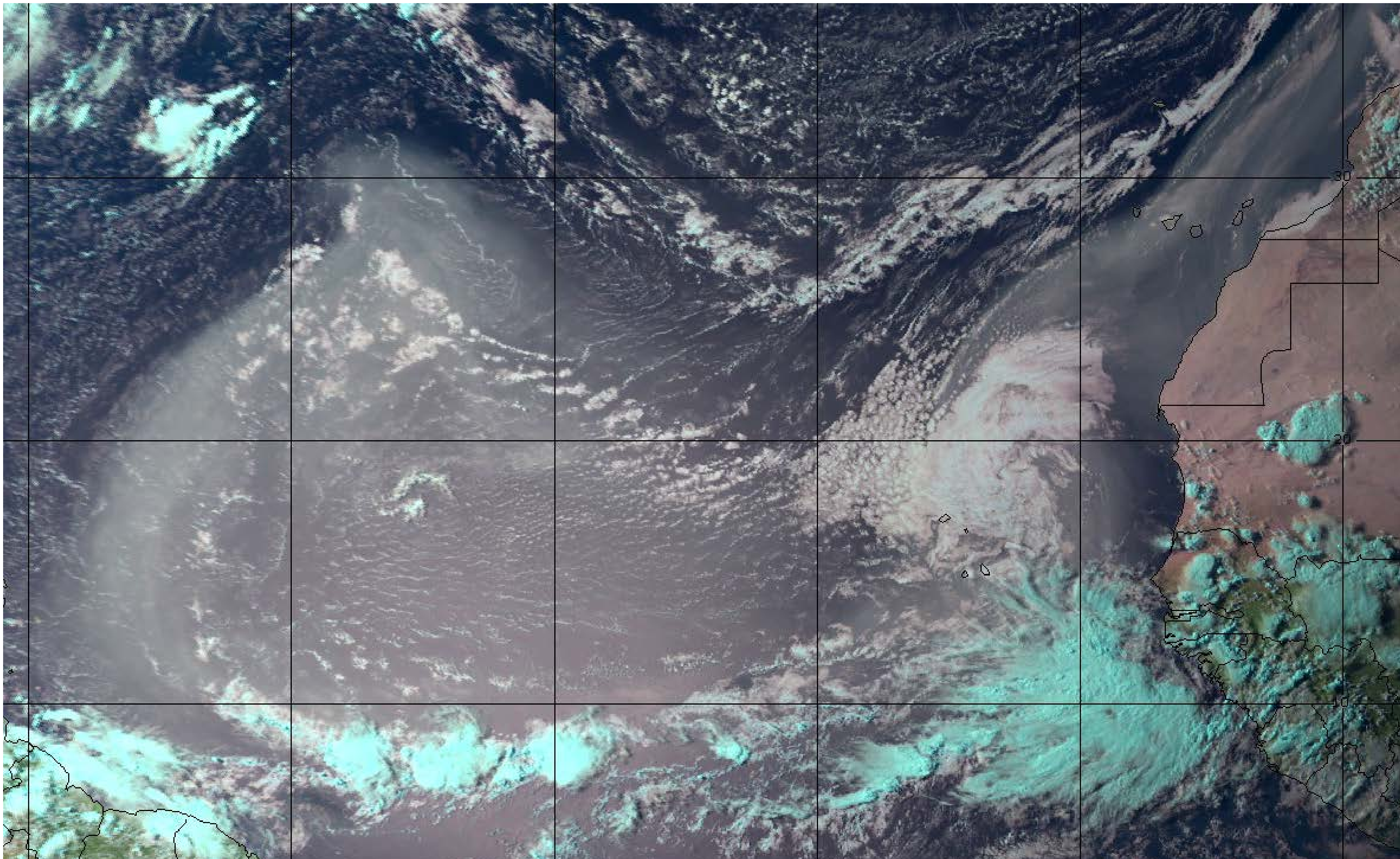


5. Reasonably humid at 2-5 km

- 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



5. Mid-Level Humidity - Saharan Air Layer (SAL)

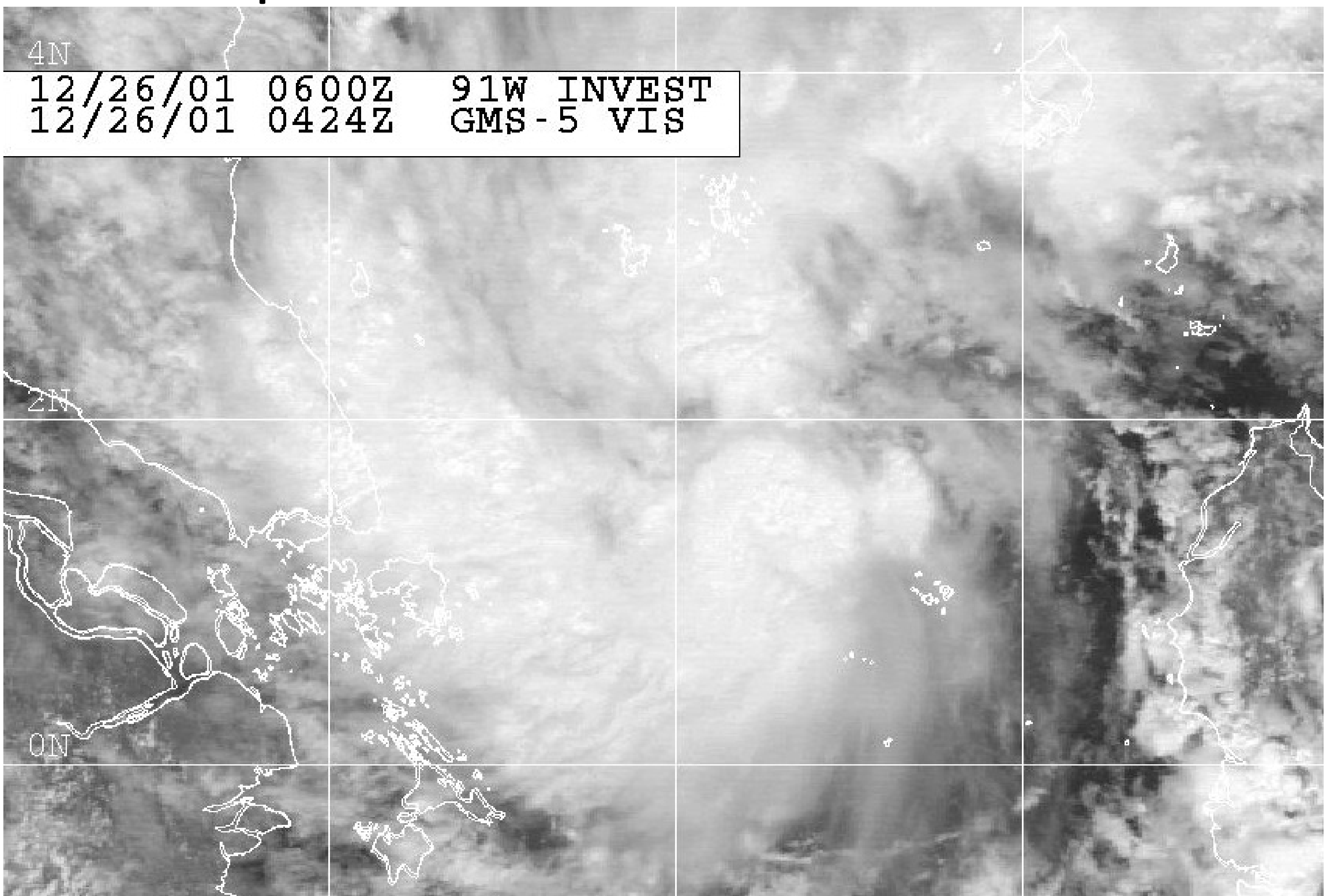


6. Tendency to Induce Spin

- It is easier for tropical cyclones to form further than 5 degrees away from the equator where the Coriolis force is not weak
- However TC can occasionally form closer to the equator given a strong westerly wind burst (the ITCZ / monsoon trough surface winds are moving east)
- Westerly wind burst can be caused by a Kelvin Wave

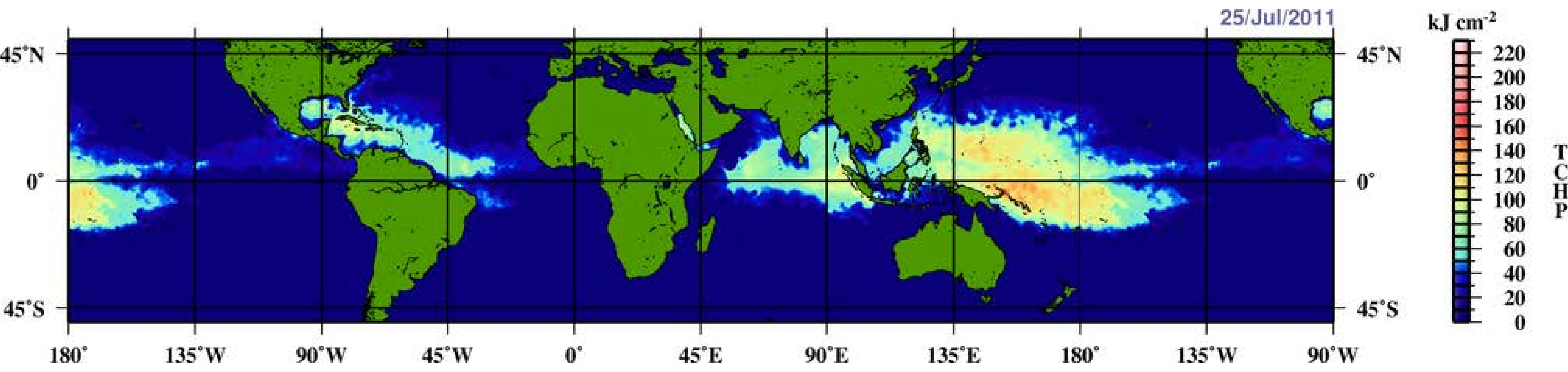
2001 Tropical Storm Vamei

- Developed at 1.4° N lat in South China Sea

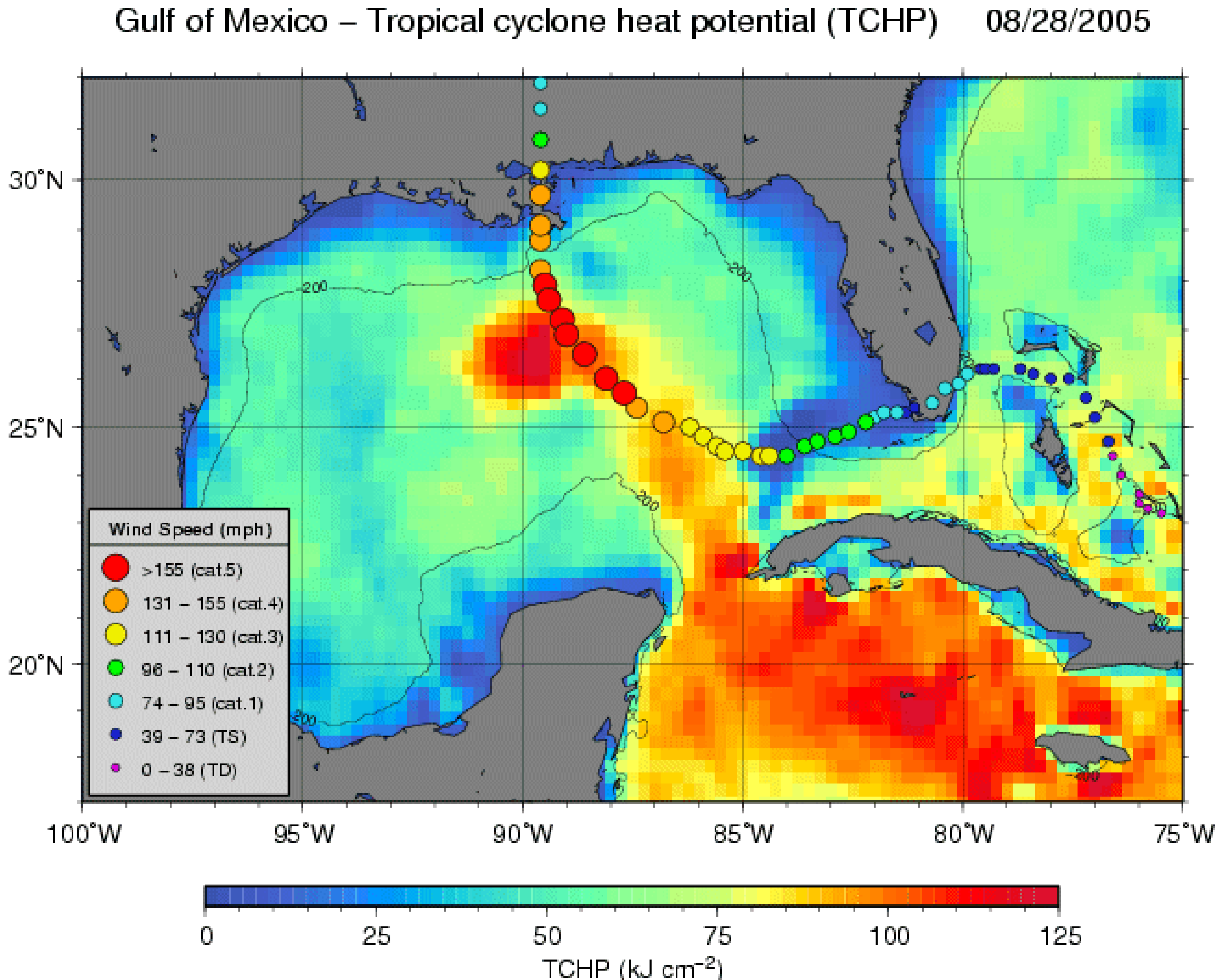


TCHP: Tropical Cyclone Heat Potential

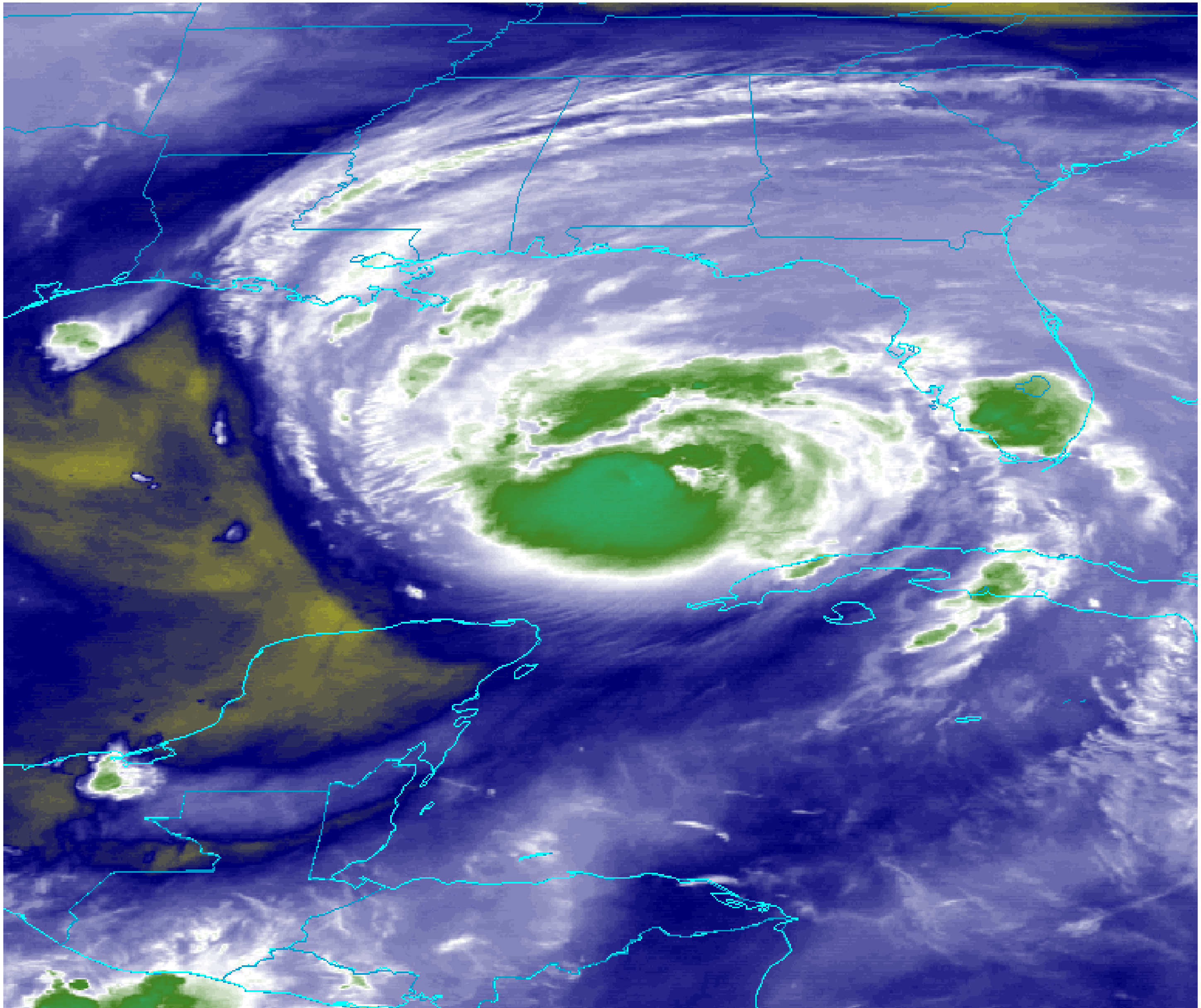
- Can be a factor in intensification
- In strong and slow-moving TCs, wave action often mixes cooler water from below up to the surface
- TCHP considers how **deep** the 26 °C isotherm lies below the ocean surface, so a deep layer of warm water yields a higher TCHP



Loop Current



Color-Enhanced Water Vapor Imagery

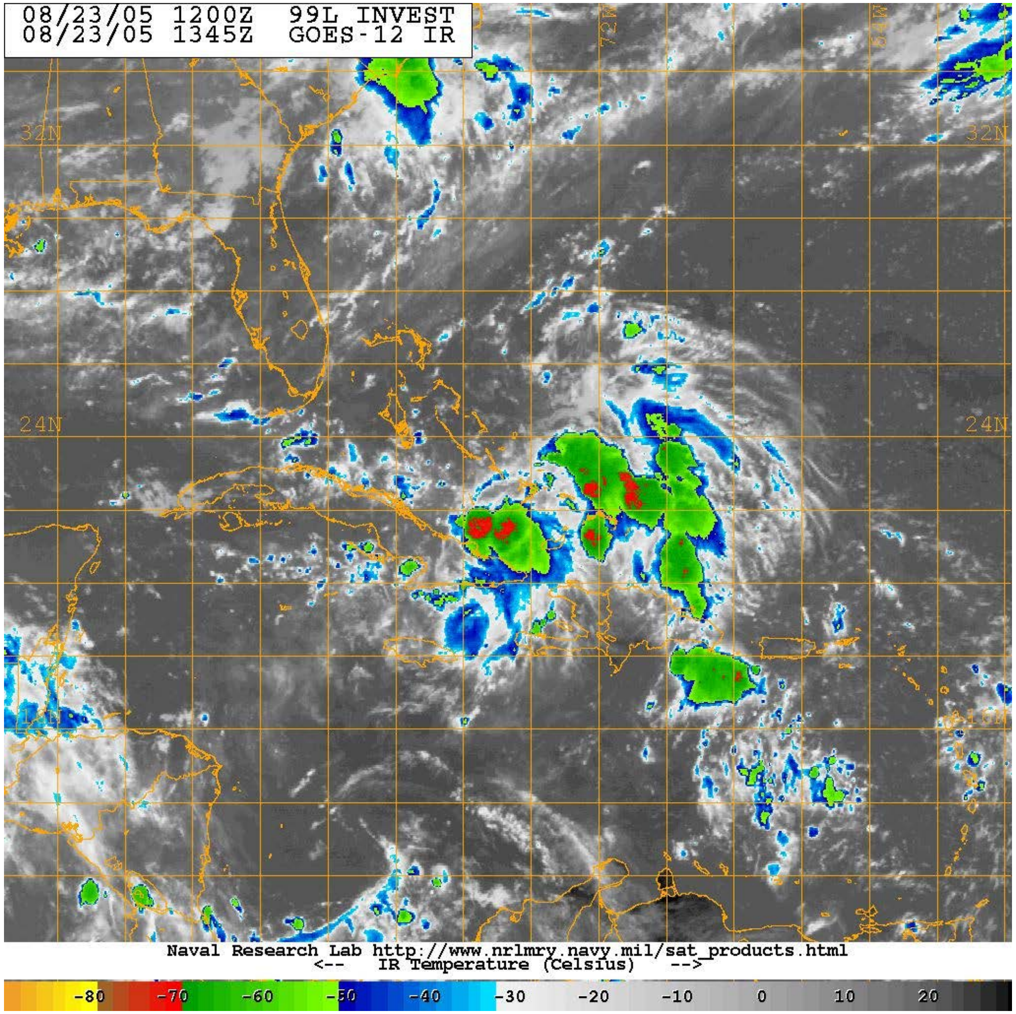


TC Lifecycle

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

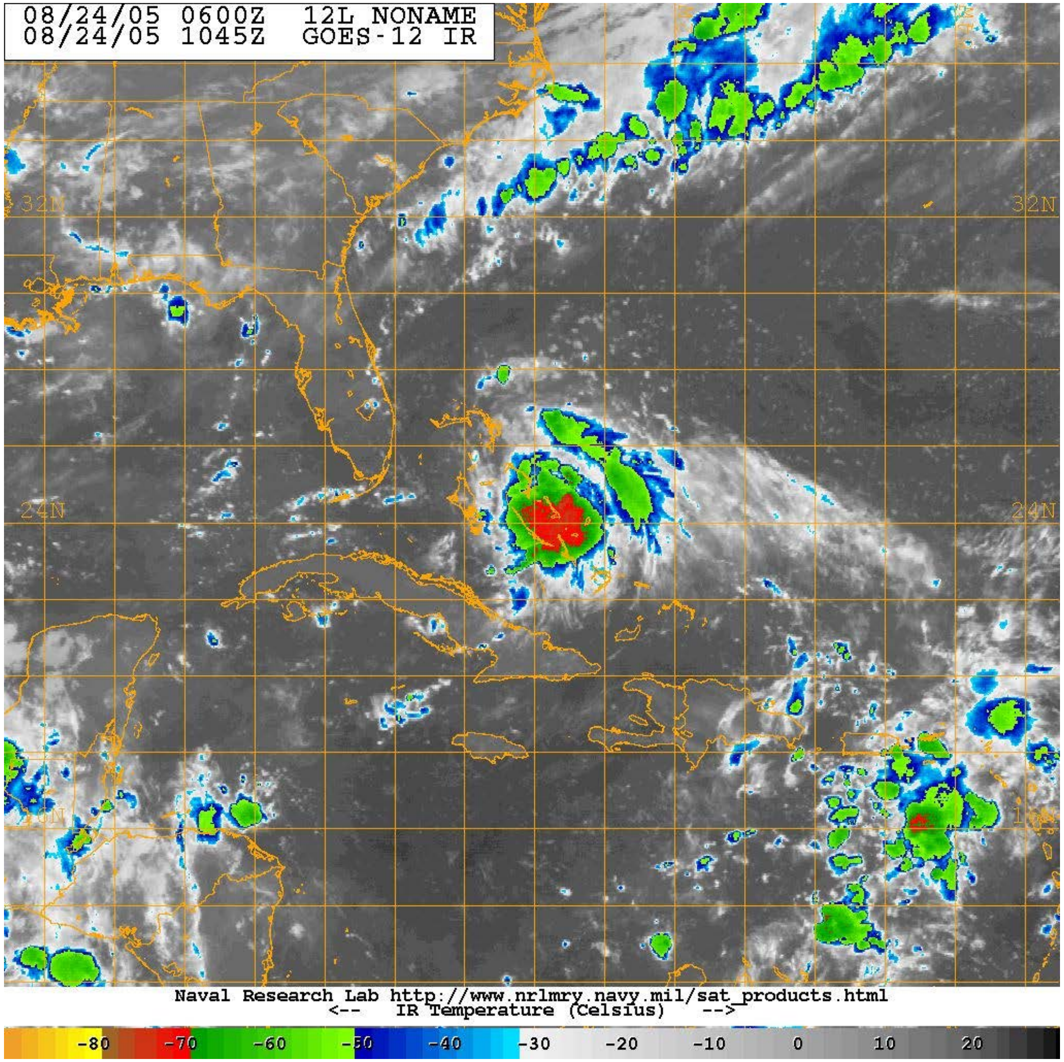
Tropical Disturbance

- 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.



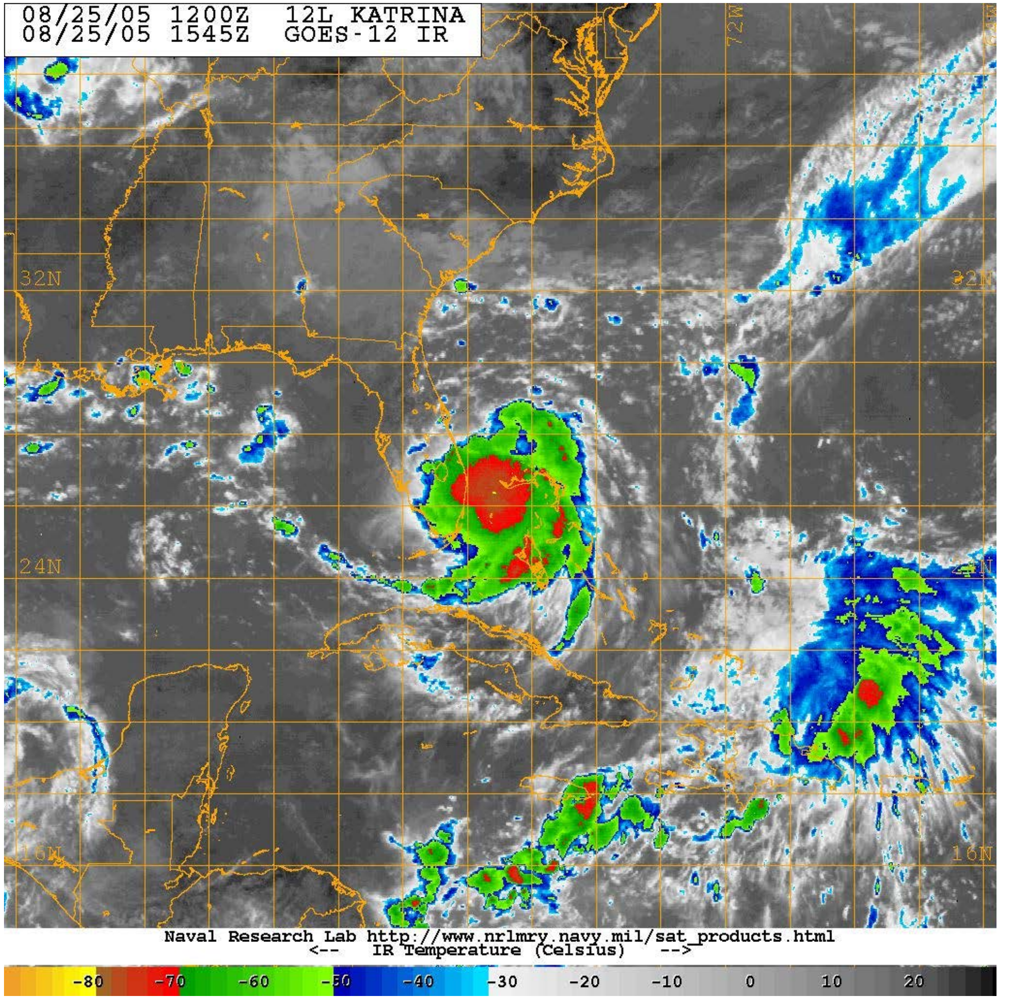
Tropical Depression

- 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.



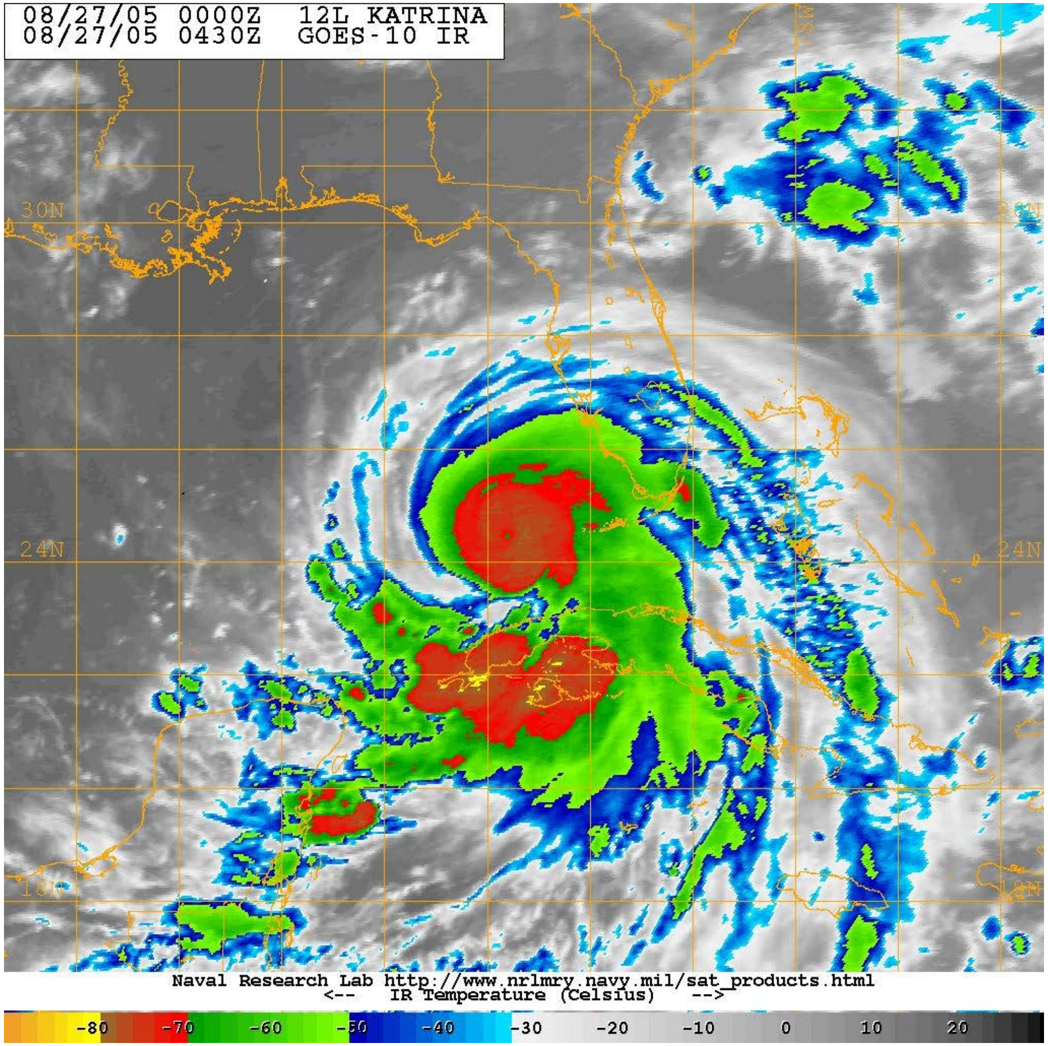
Tropical Storm

- 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.



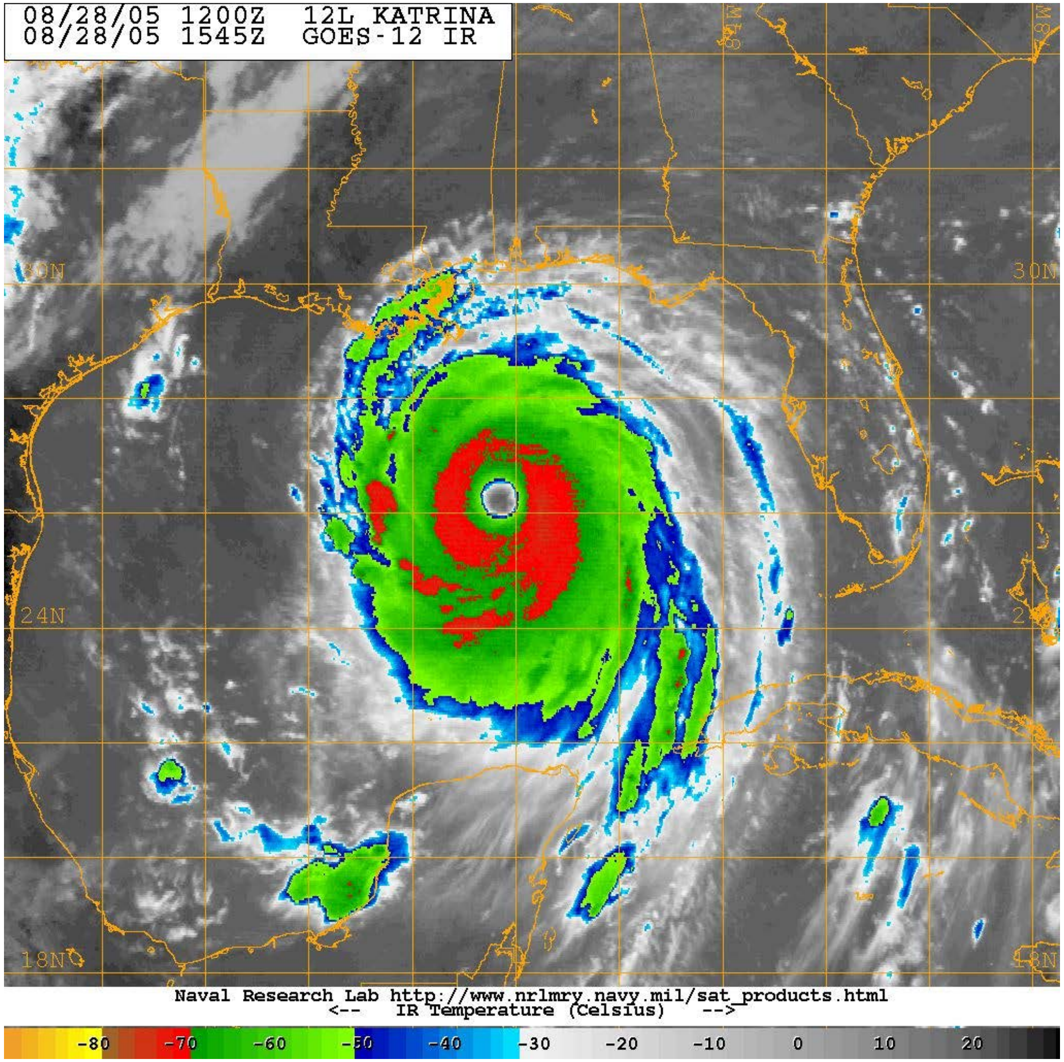
Hurricane

- 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



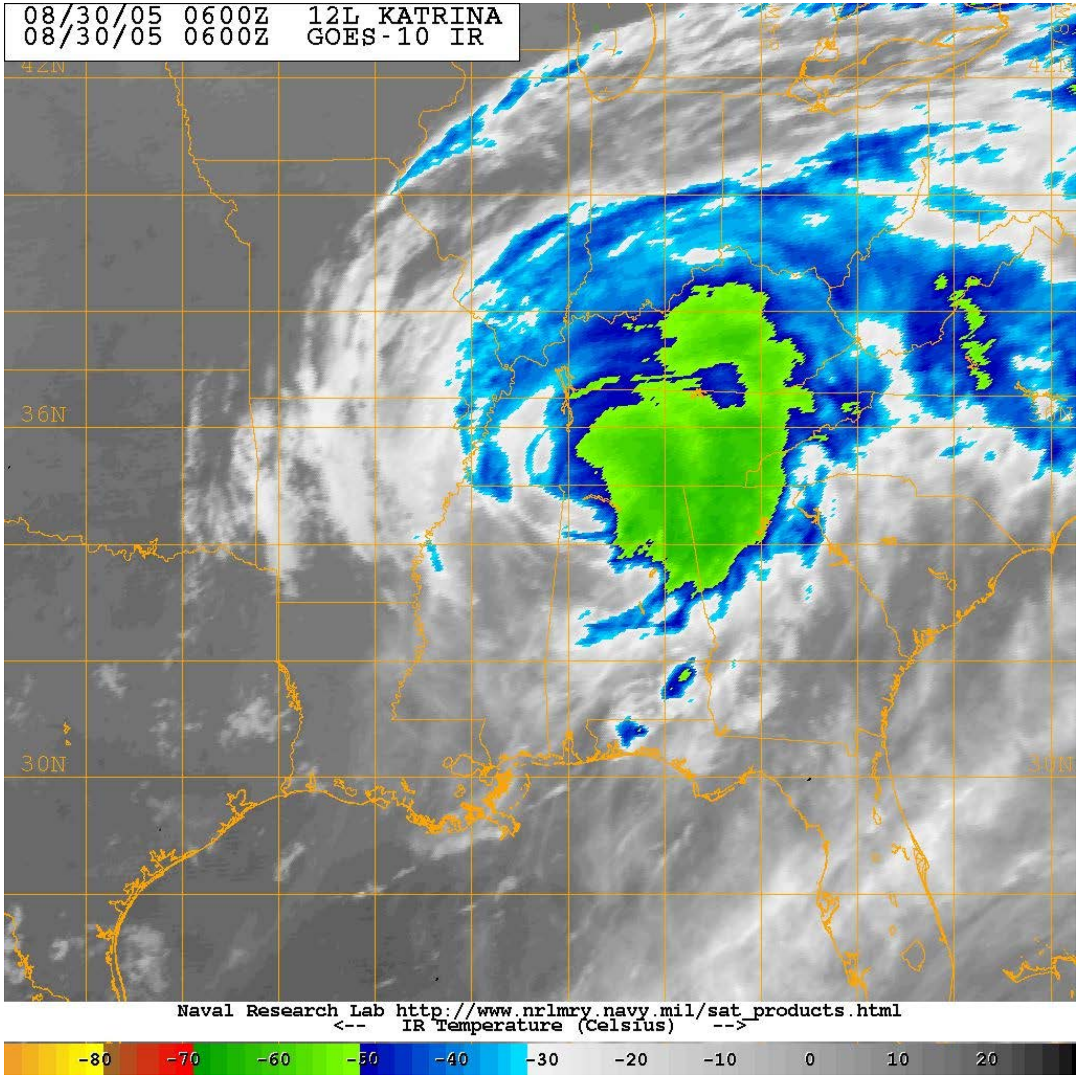
Major Hurricane

- 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

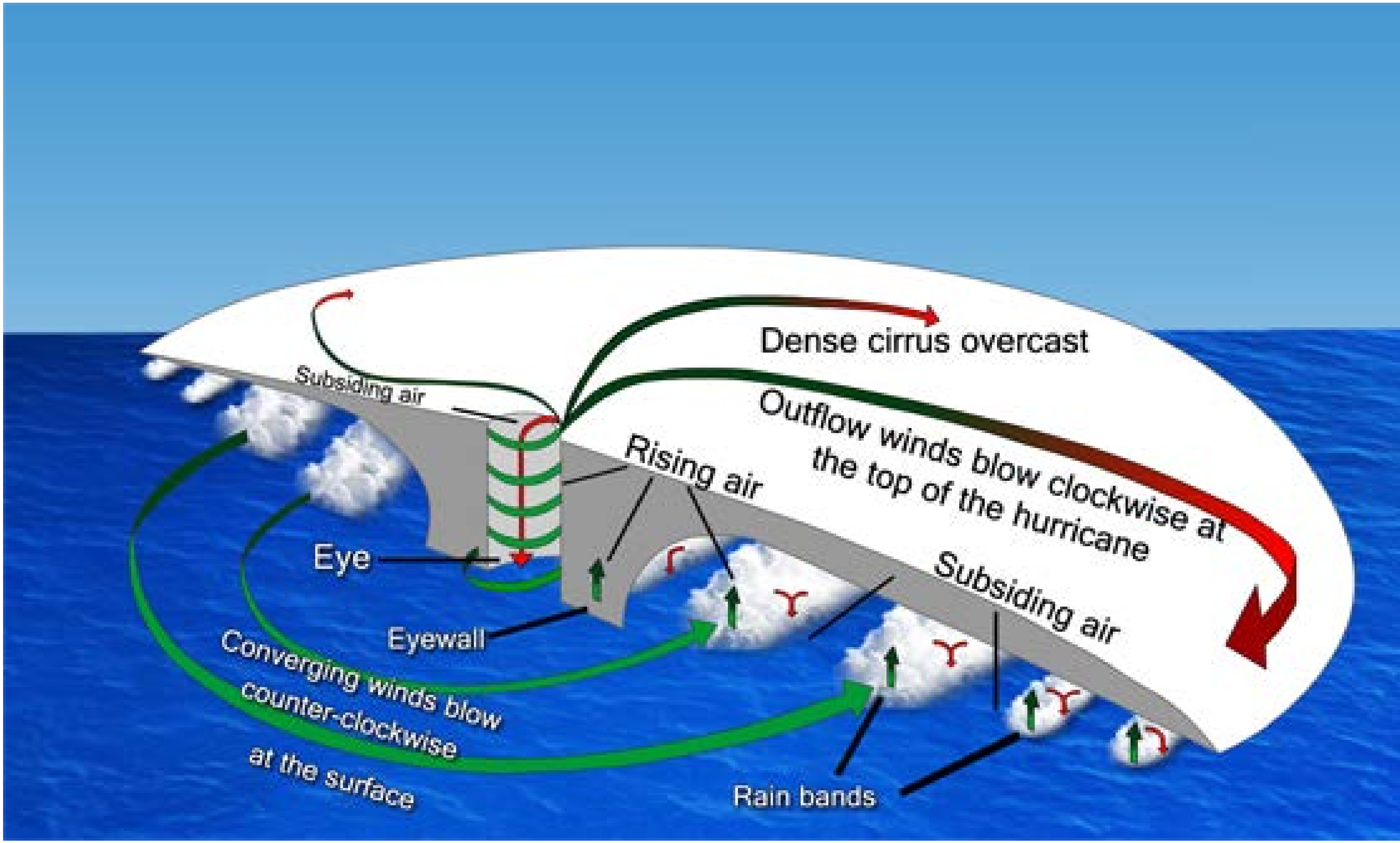


Saffir-Simpson Scale

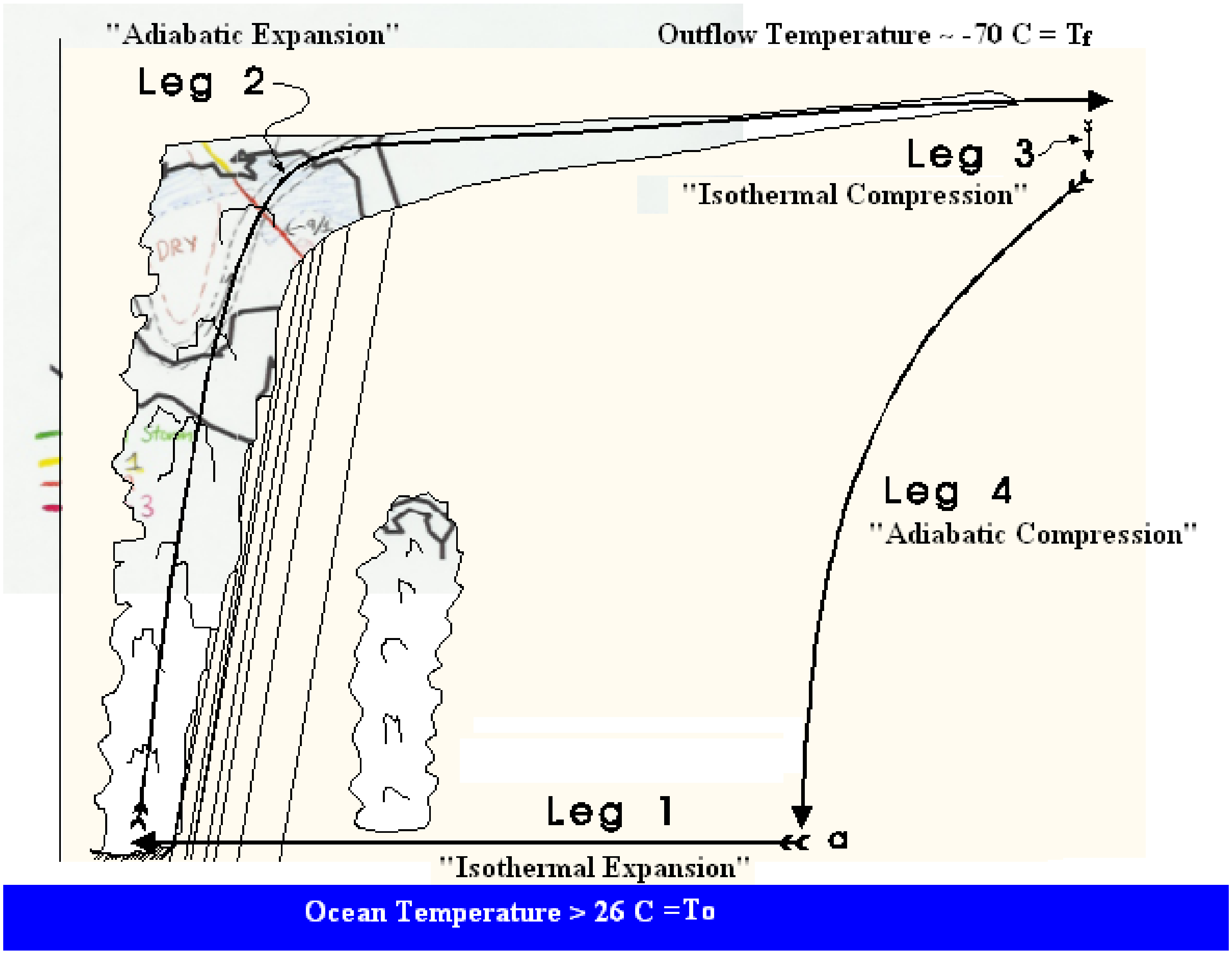
Category	Wind (mph)	Pressure (mb)	Storm Surge (ft)
1	74-95	> 980	4-5
2	96-110	965-979	6-8
3	111-130	945-964	9-12
4	131-155	920-944	13-18
5	>1 55	< 920	> 18

- 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

Mature Tropical Cyclone Structure

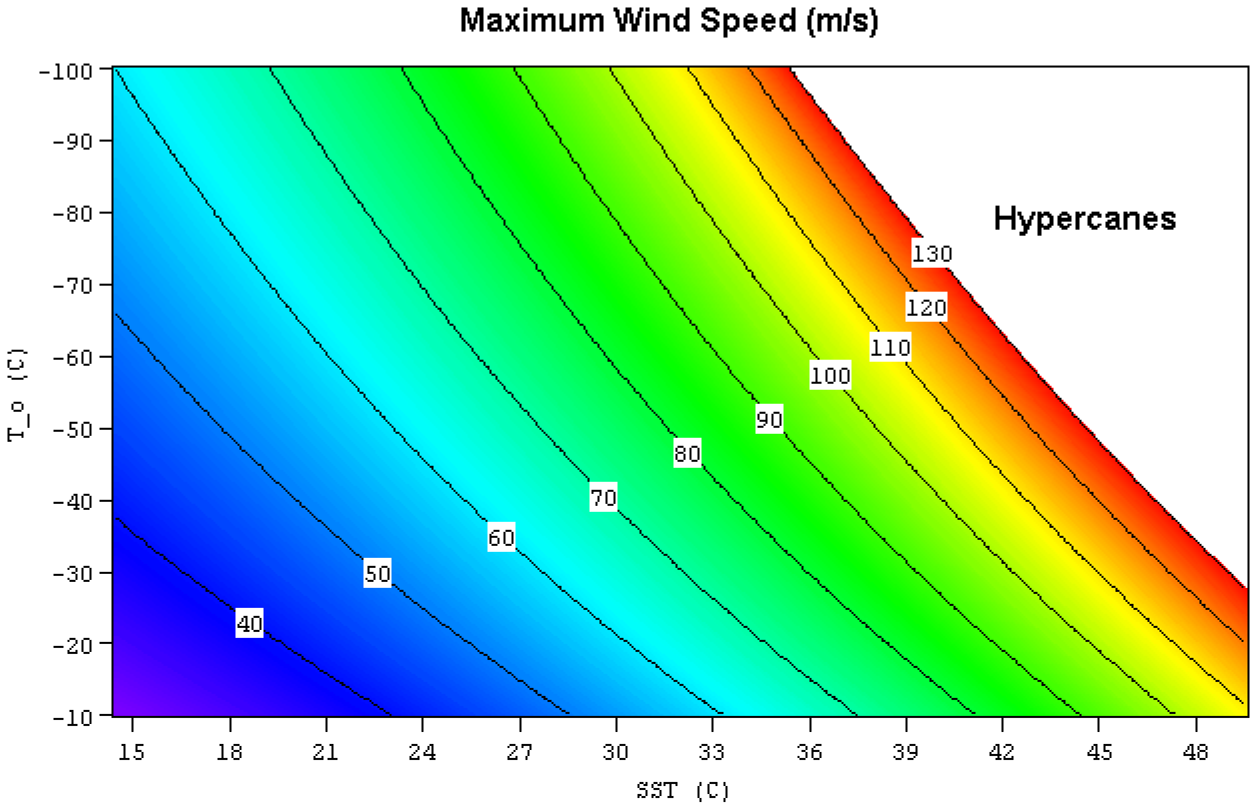


TC as a Carnot Engine



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 (usually wind shear)
2. It can take up to a week or more for a disturbance to organize and strengthen
3. Upwelling of cooler ocean temperature from below the TC (especially if moving slowly)
4. Eyewall replacement cycles

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

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 (adiabatic warming), rest is expelled and slowly sinks away from storm

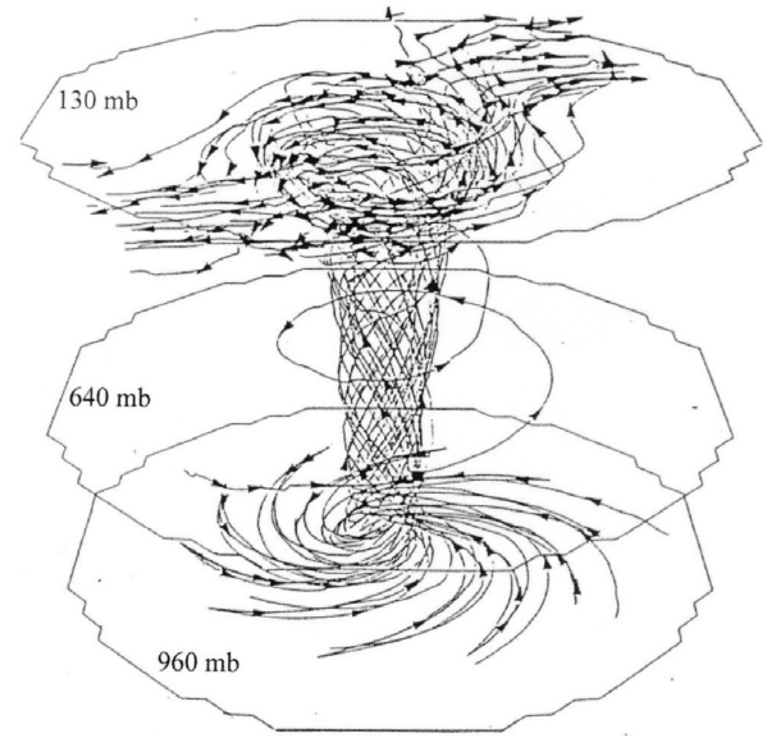
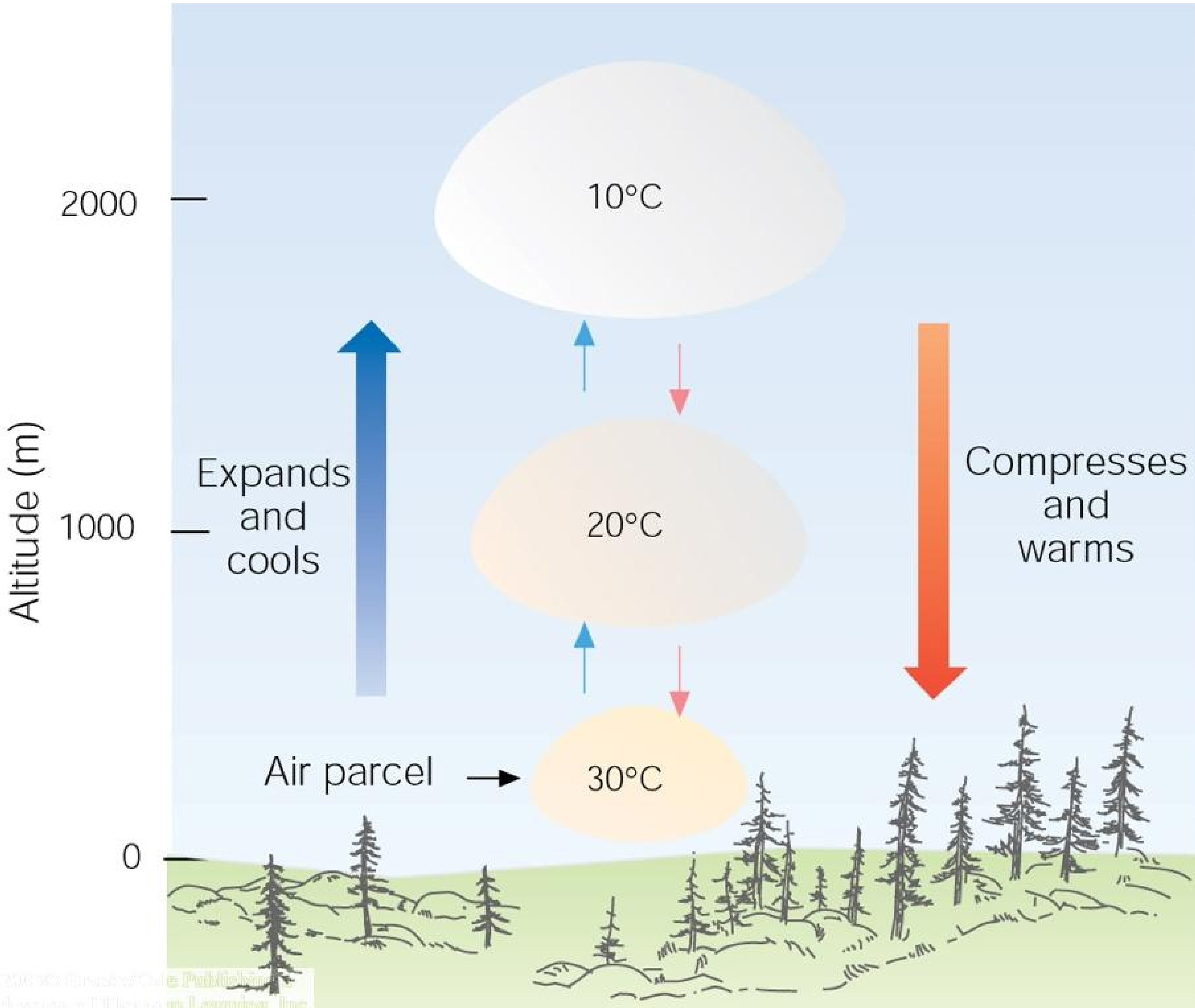
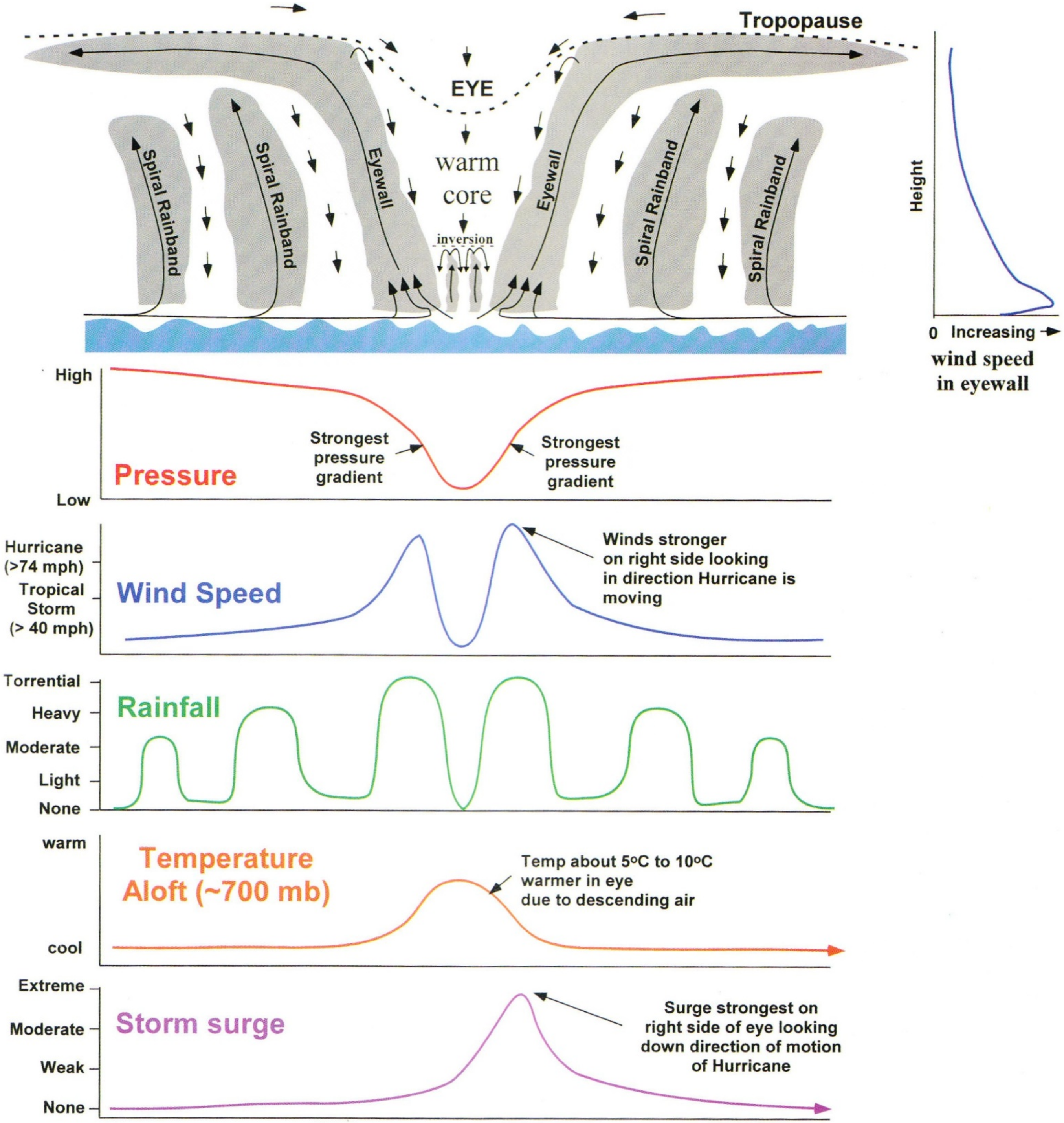


Figure 23.7 Trajectories of air parcels as they move through a numerically modeled hurricane. A full trajectory covers a period of eight days and each arrow head along a trajectory denotes a nine-hour interval. (From Anthes, R.A., Trout, J. W., and S. S. Ostlund. 1971. Three-dimensional particle trajectories 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.)

Adiabatic Heating and Cooling



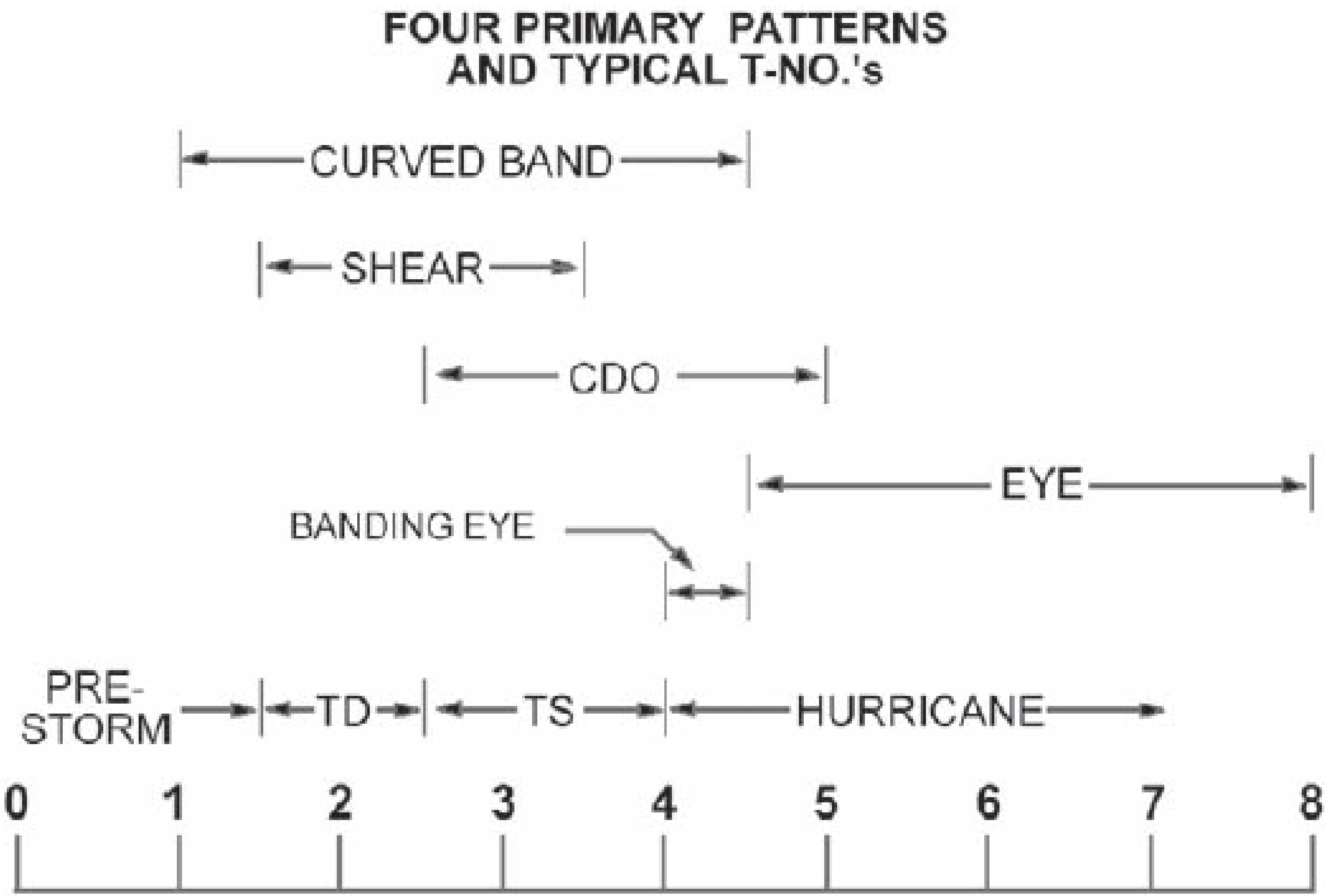

Tropopause
EYE
warm
core
inversion
Eyewall
Eyewall
Spiral Rainband
Spiral Rainband
Spiral Rainband
Spiral Rainband
Height
0 Increasing
wind speed
in eyewall
High
Low
Pressure
Strongest pressure gradient
Strongest pressure gradient
Hurricane (>74 mph)
Tropical Storm (> 40 mph)
Wind Speed
Winds stronger on right side looking in direction Hurricane is moving
Torrential
Heavy
Moderate
Light
None
Rainfall
warm
cool
Temperature Aloft (~700 mb)
Temp about 5oC to 10oC warmer in eye due to descending air
Extreme
Moderate
Weak
None
Storm surge
Surge strongest on right side of eye looking down direction of motion of Hurricane

Determining TC Intensity from Satellites

1. Statistical Methods (Dvorak Technique)
   - Use cloud pattern to estimate intensity based on consistent cloud patterns of TC
2. Satellite-Derived Wind Speeds (VIS and IR)
   - Estimate wind speed from recent cloud movements
3. Passive Microwave Imagery (PMI)
   - AMSU intensity estimates

Dvorak Technique

- Estimates intensity (maximum surface wind) in terms of a numerical scale that ranges from T0 to T8 in steps of 0.5
- Originally used Visible imagery, then subsequently for IR-BD 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" in the actual imagery
- Scene types:
  - Curved Band Pattern
  - Shear Pattern
  - Central Dense Overcast (CDO) / Embedded Center Pattern
  - Eye Pattern or Banding Eye Pattern


FOUR PRIMARY PATTERNS
AND TYPICAL T-NO.'s
CURVED BAND
SHEAR
CDO
EYE
BANDING EYE
PRE-
STORM
TD
TS
HURRICANE
0
1
2
3
4
5
6
7
8

T #

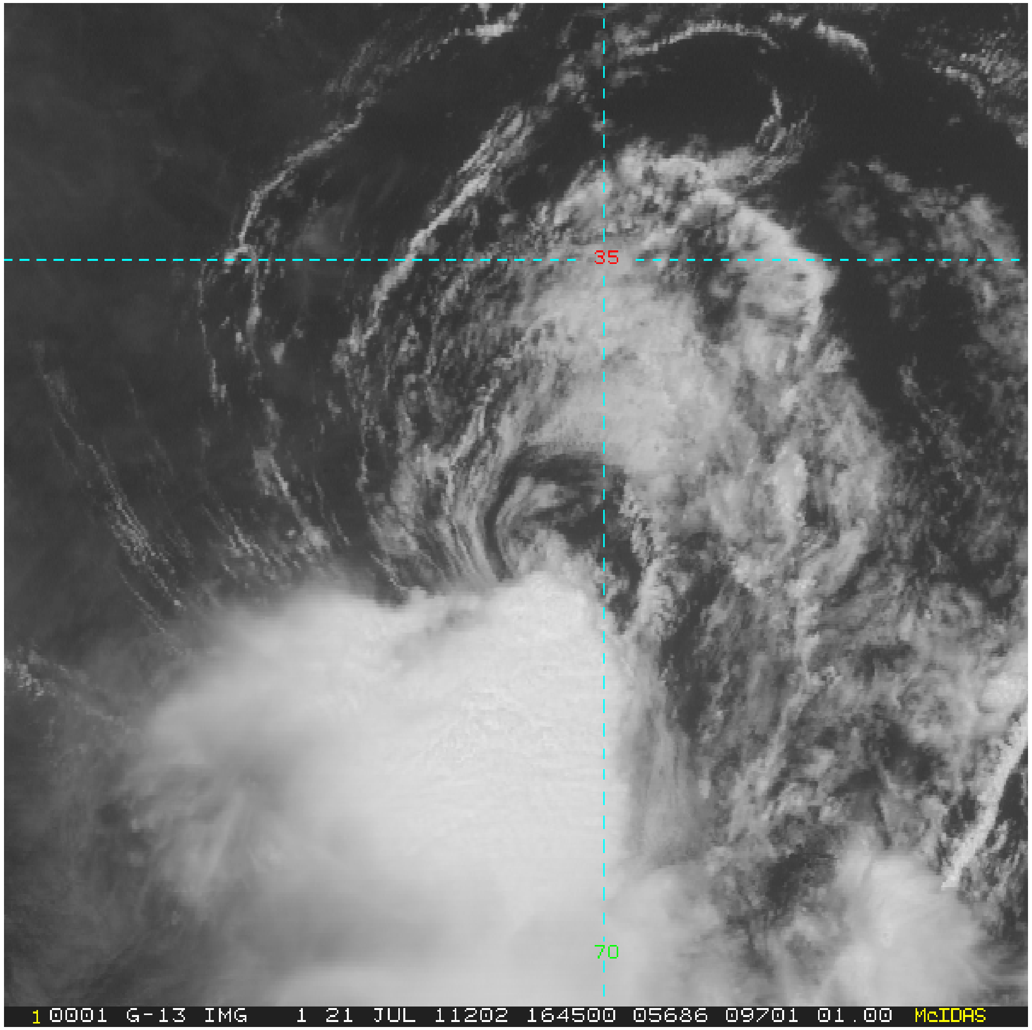
Dvorak T-Number and Corresponding Intensity[3]

T-Number	Winds			Category	Min. Pressure (millibars)	
	(knots)	(mph)	(km/h)	(SSHS)	Atlantic	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.

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 (tilted), or sheared apart

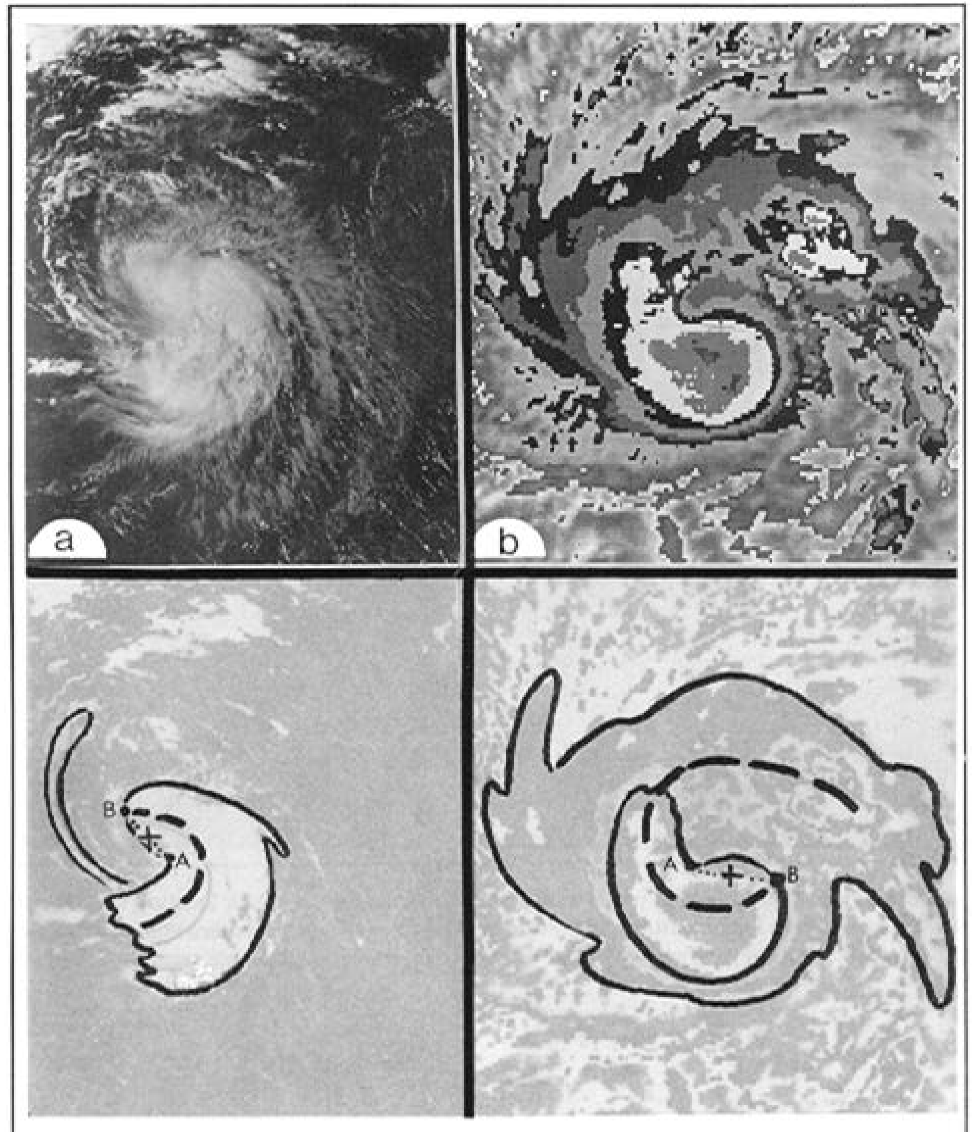


BD Enhancement Curve

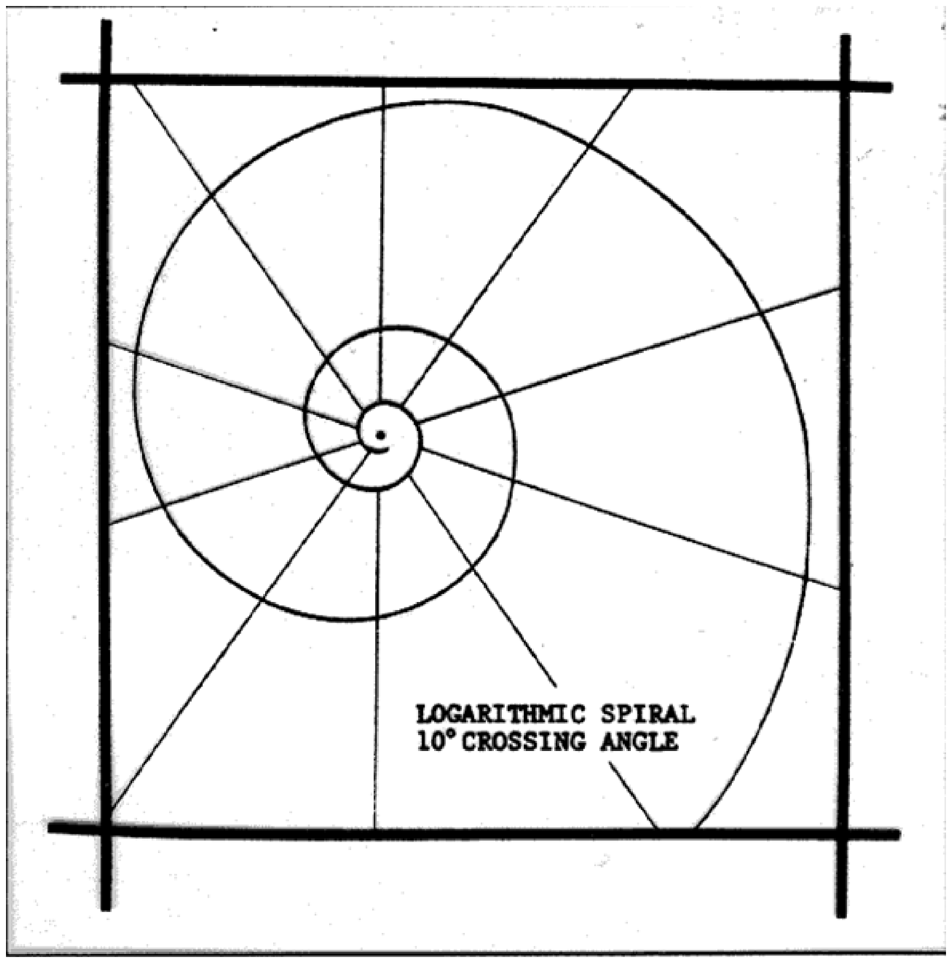
Segment Number	Color Range	Temperature Range (^oC)	Name
2	0-255	>9.0	Warm Medium Gray (WMG)
3	109-202	9.0 to -30	Off White (OW)
4	60-60	-31 to -41	Dark Gray (DG)
5	110-110	-42 to -53	Medium Gray (MG)
6	160-160	-54 to -63	Light Gray (LG)
7	0-0	-64 to -69	Black (B)
8	255-255	-70 to -75	White (W)
9	135-135	-76 to -80	Cold Medium Gray (CMG)
10	85-85	<-80	Cold Dark Gray (CDG)

Curved Band Pattern

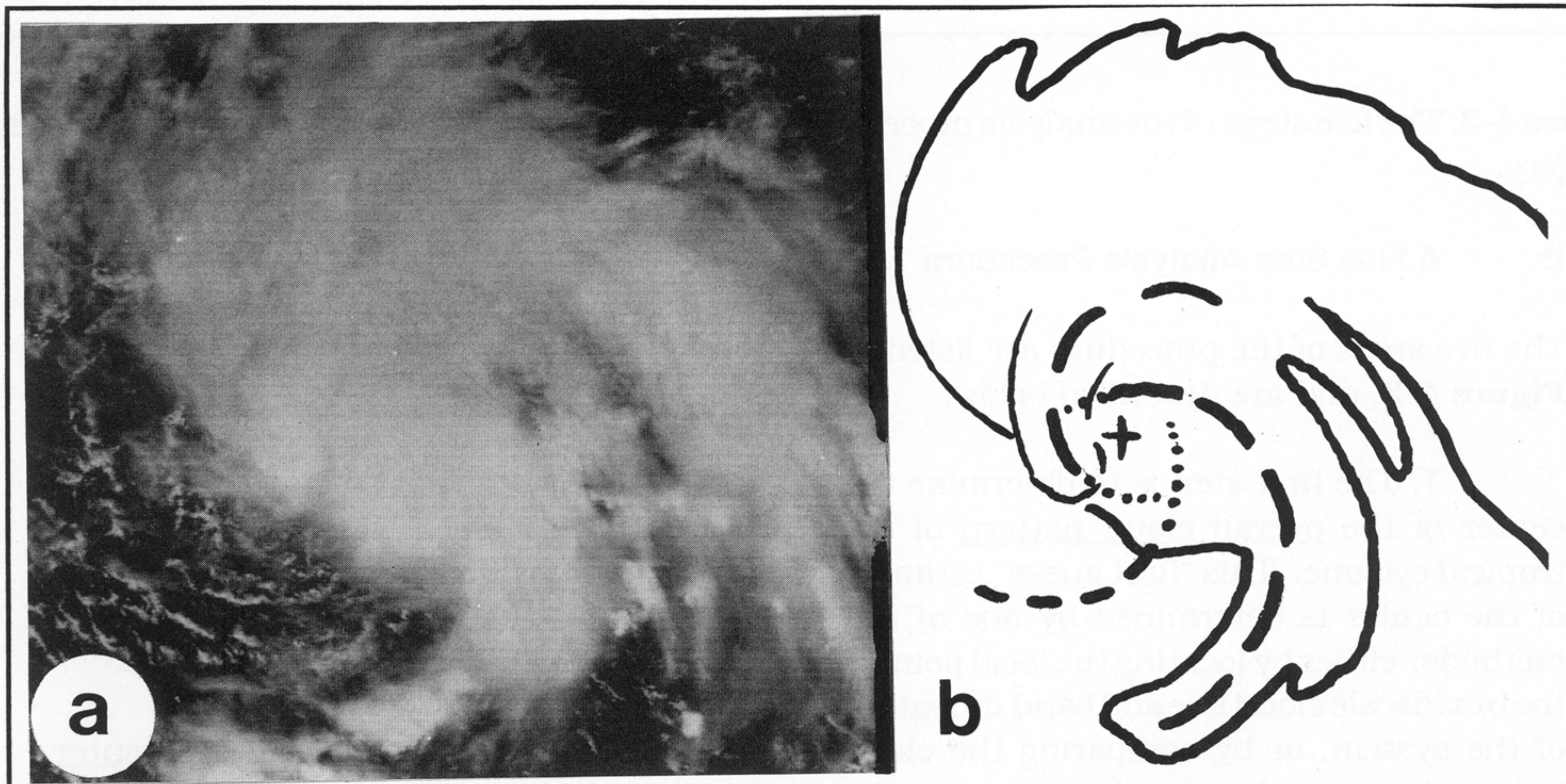
- In this stage, the more completely the rainbands are wrapped around the system, the greater the TC vorticity and intensity.



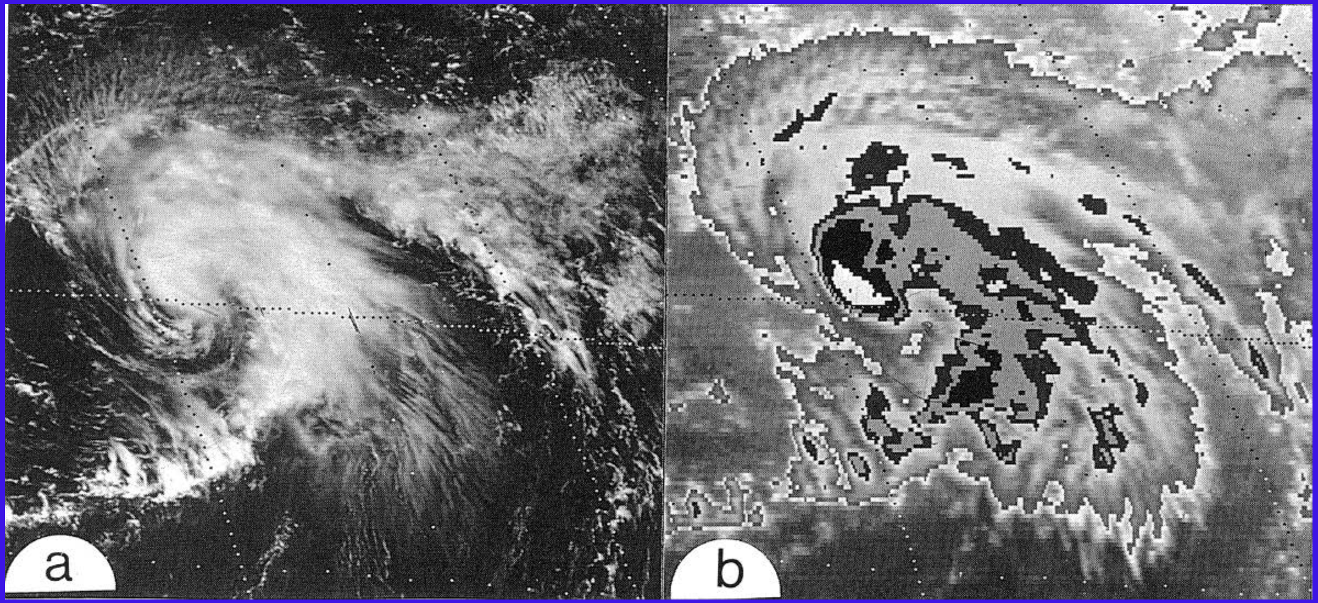
Dvorak Log10 Spiral Template

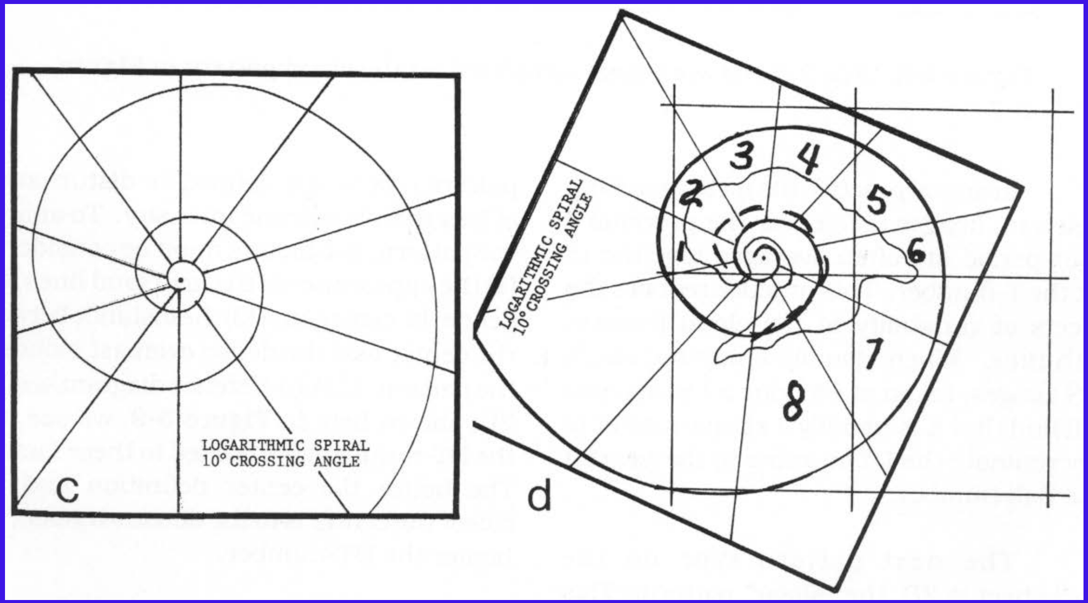


Identifying Curvature of Spiral Band



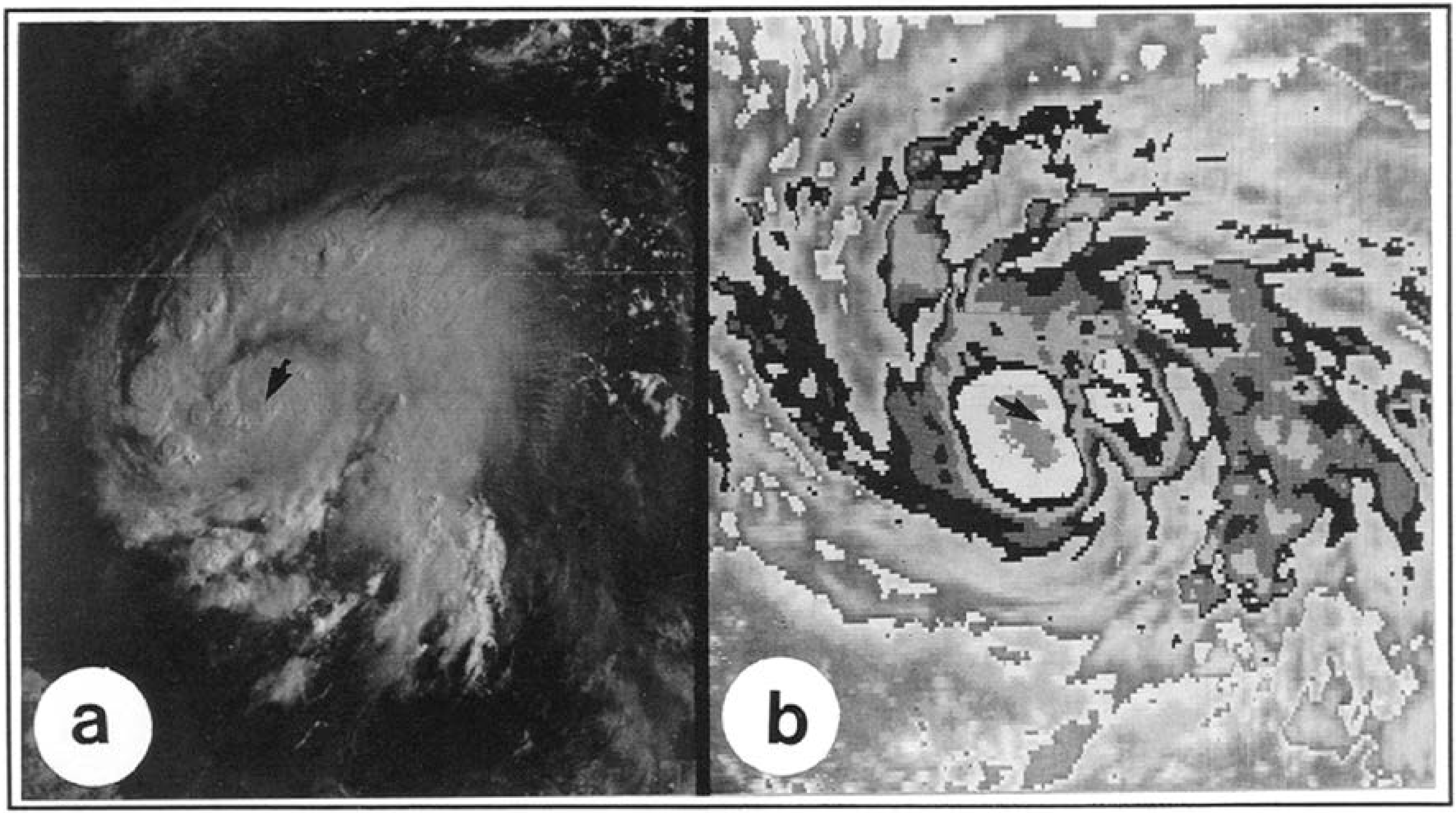
Measuring Curved Bands





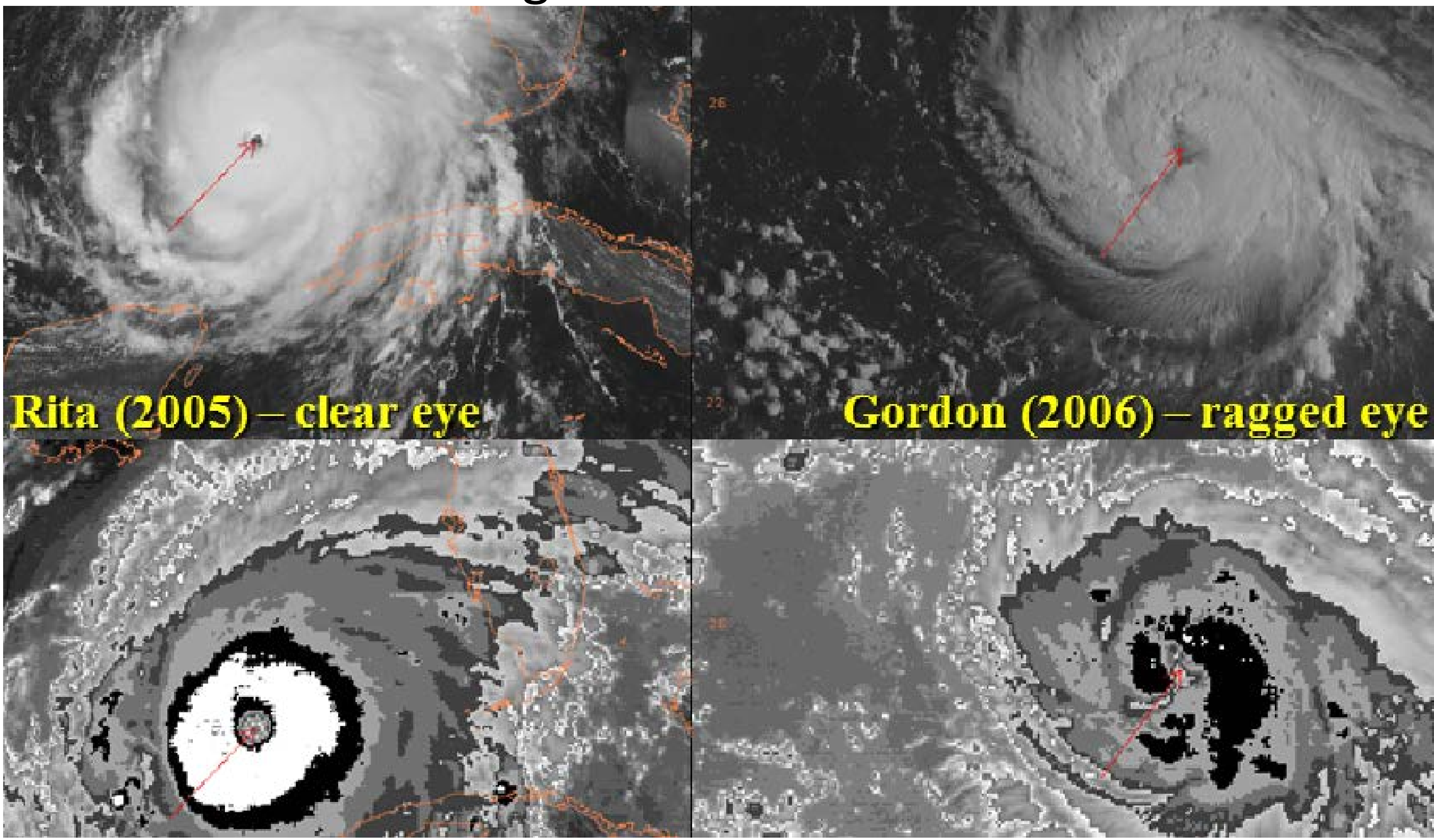
0.8 Banding - DT=3.5

CDO / Embedded Center Pattern



Eye Pattern

- Identifies temperature contrast between the warm eye and cold surrounding convection.



Step 2C - Eye Patterns

Infrared Technique

Is the 24 hour old FT > 2.0? If not, go to step 2A or step 4.

Surrounding BD Color	CMG	W	B	LG	MG	DG	OW
Narrowest width (deg)	≥0.5	≥0.5	≥0.5	≥0.4	≥0.4	≥0.3	≥0.3
Eye Number (E#)	6.5	6.0	5.5	5.0	4.5	4.5	4.0

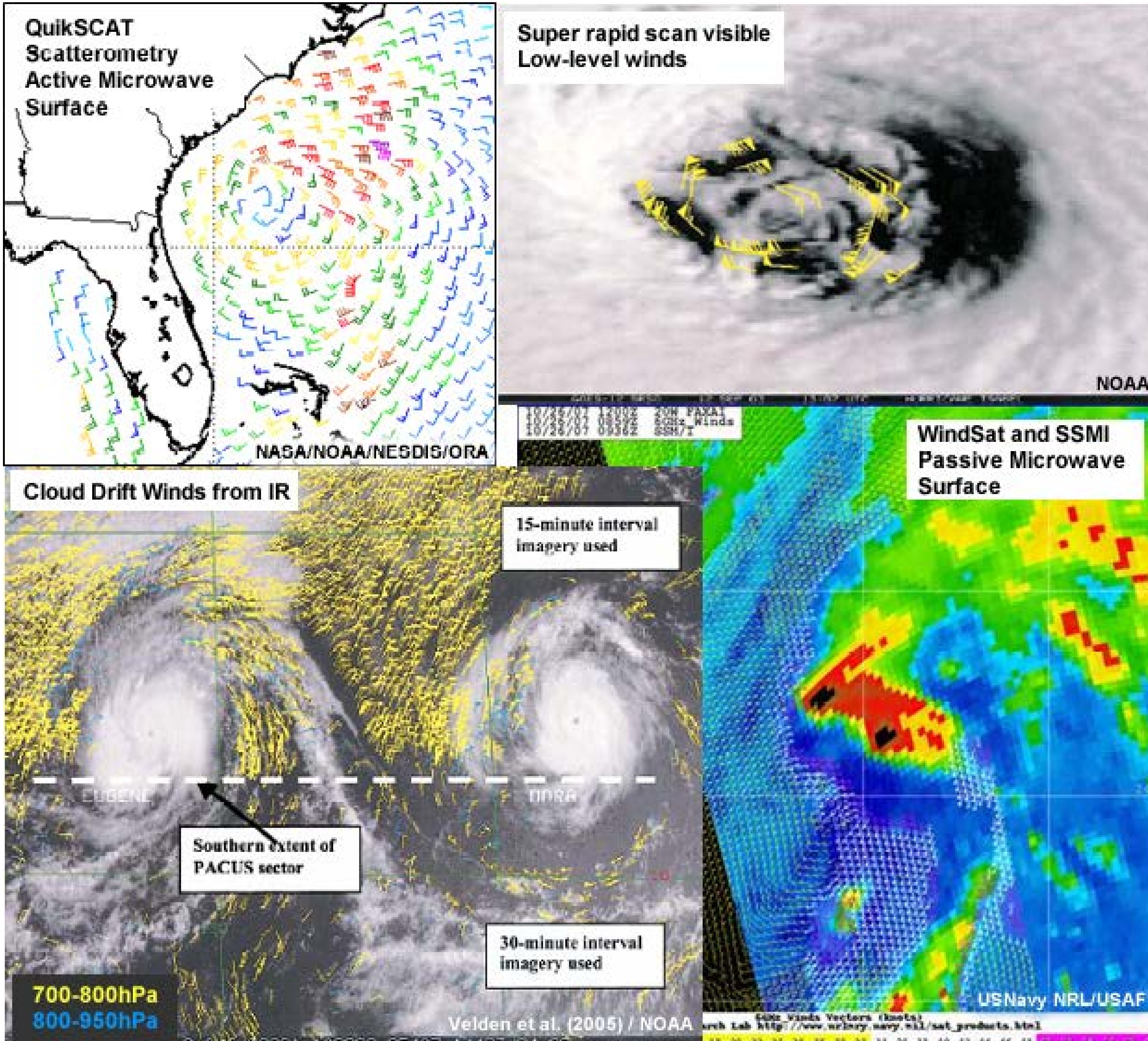
Eye Adjustment:

Eye Temperature

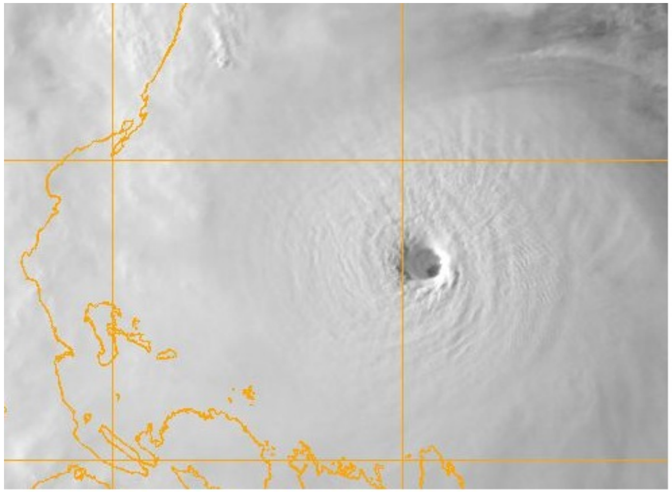
Surr. BD Color	WMG	OW	DG	MG	LG	B	W
OW	0	-0.5					
DG	0	0	-0.5				
MG	0	0	-0.5	-0.5			
LG	+0.5	0	0	-0.5	-0.5		
B	+1.0	+0.5	0	0	-0.5	-0.5	
W	+1.0	+0.5	+0.5	0	0	-1.0	-1.0
CMG	+1.0	+0.5	+0.5	0	0	-0.5	-1.0

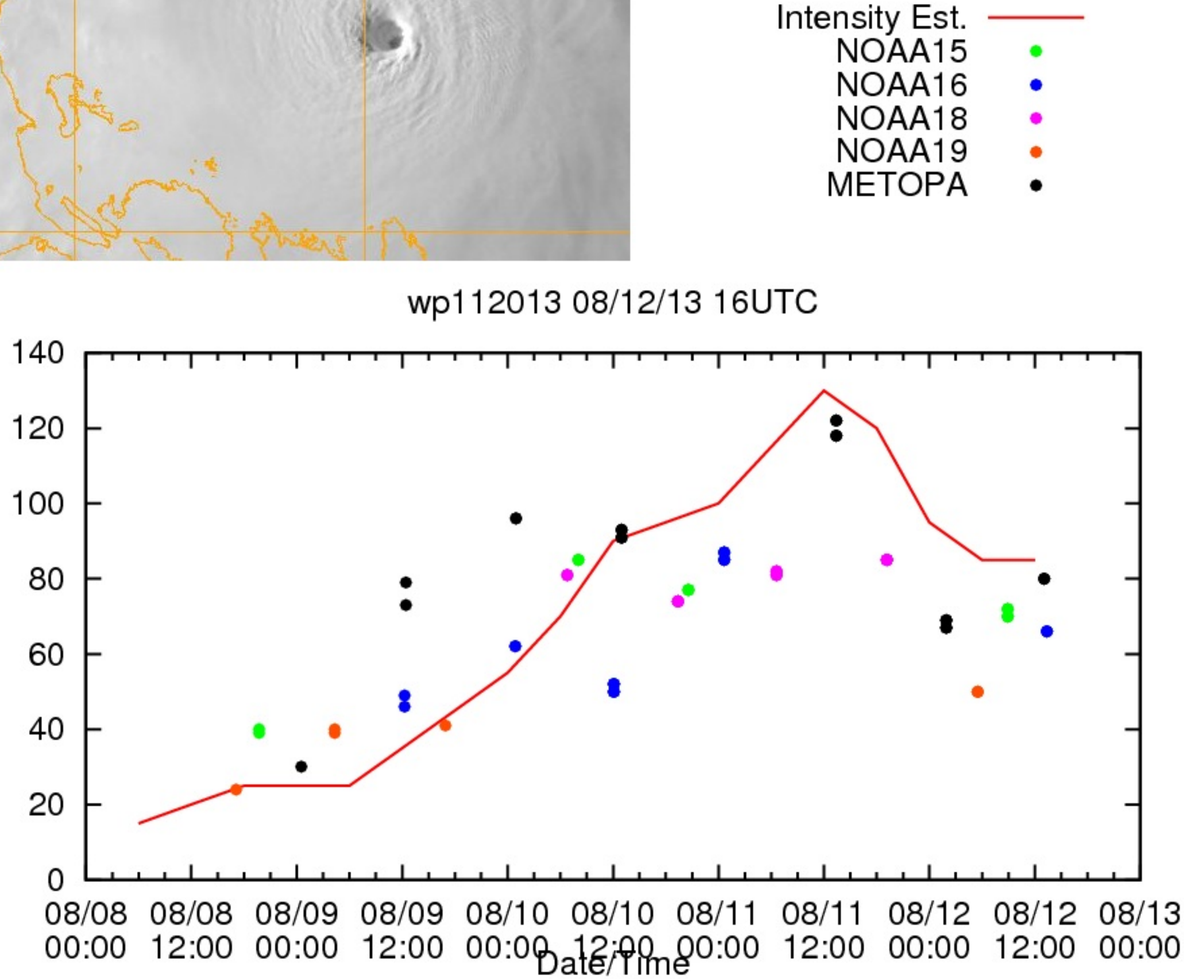
Satellite-Derived Winds

- Works best in moderate-wind and low-precipitation environments
- Not as reliable 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 infrequent
- GOES satellites can also be used by monitoring cloud movement patterns


QuikSCAT
Scatterometry
Active Microwave
Surface
NASA/NOAA/NESDIS/ORA
Super rapid scan visible
Low-level winds
NOAA
WindSat and SSMI
Passive Microwave
Surface
USNavy NRL/USAF
Cloud Drift Winds from IR
15-minute interval
imagery used
Southern extent of
PACUS sector
30-minute interval
imagery used
700-800hPa
800-950hPa
Velden et al. (2005) / NOAA

PMI - AMSU Intensity Estimates





Review Questions

1. Name one of the 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.