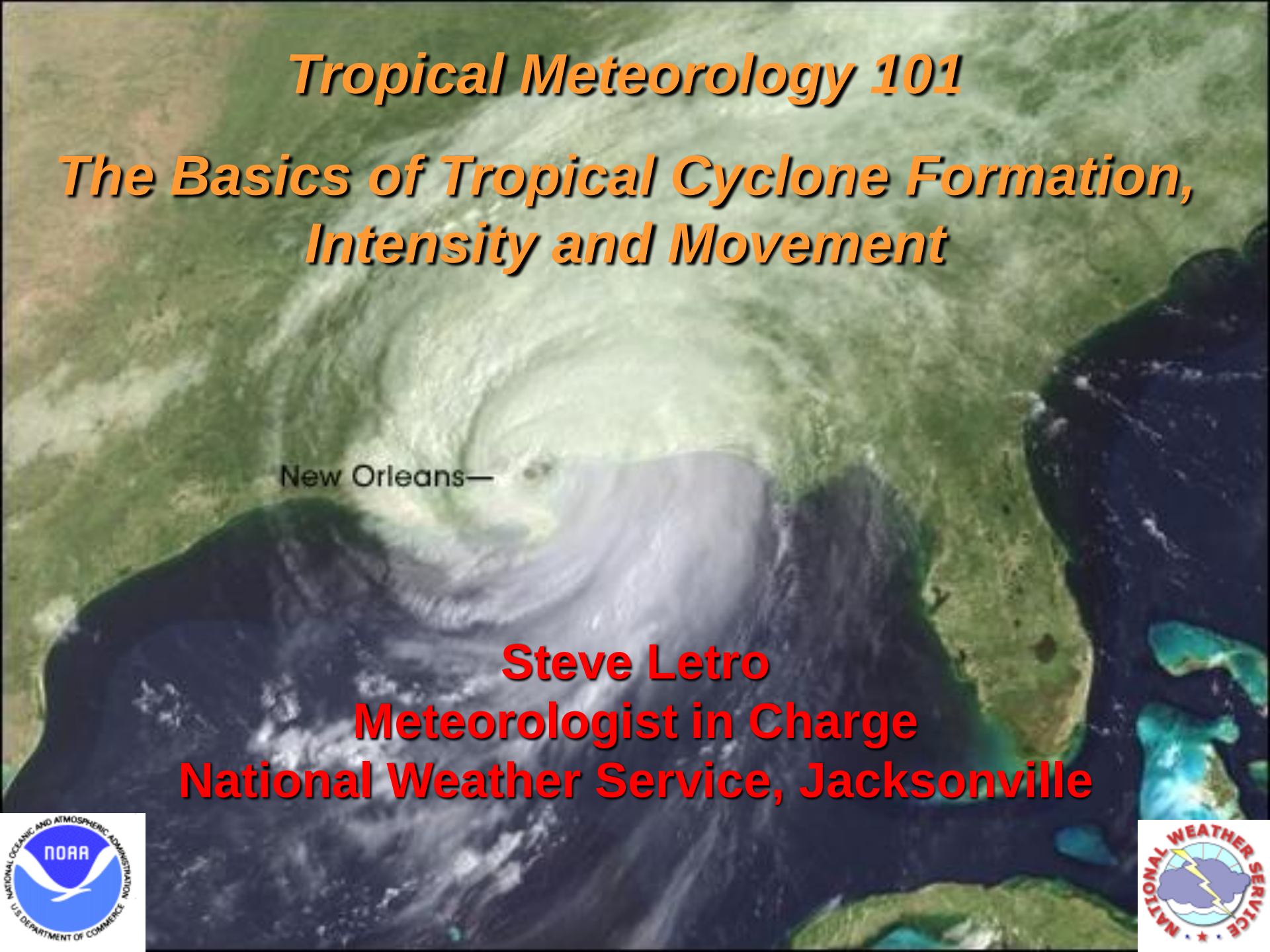
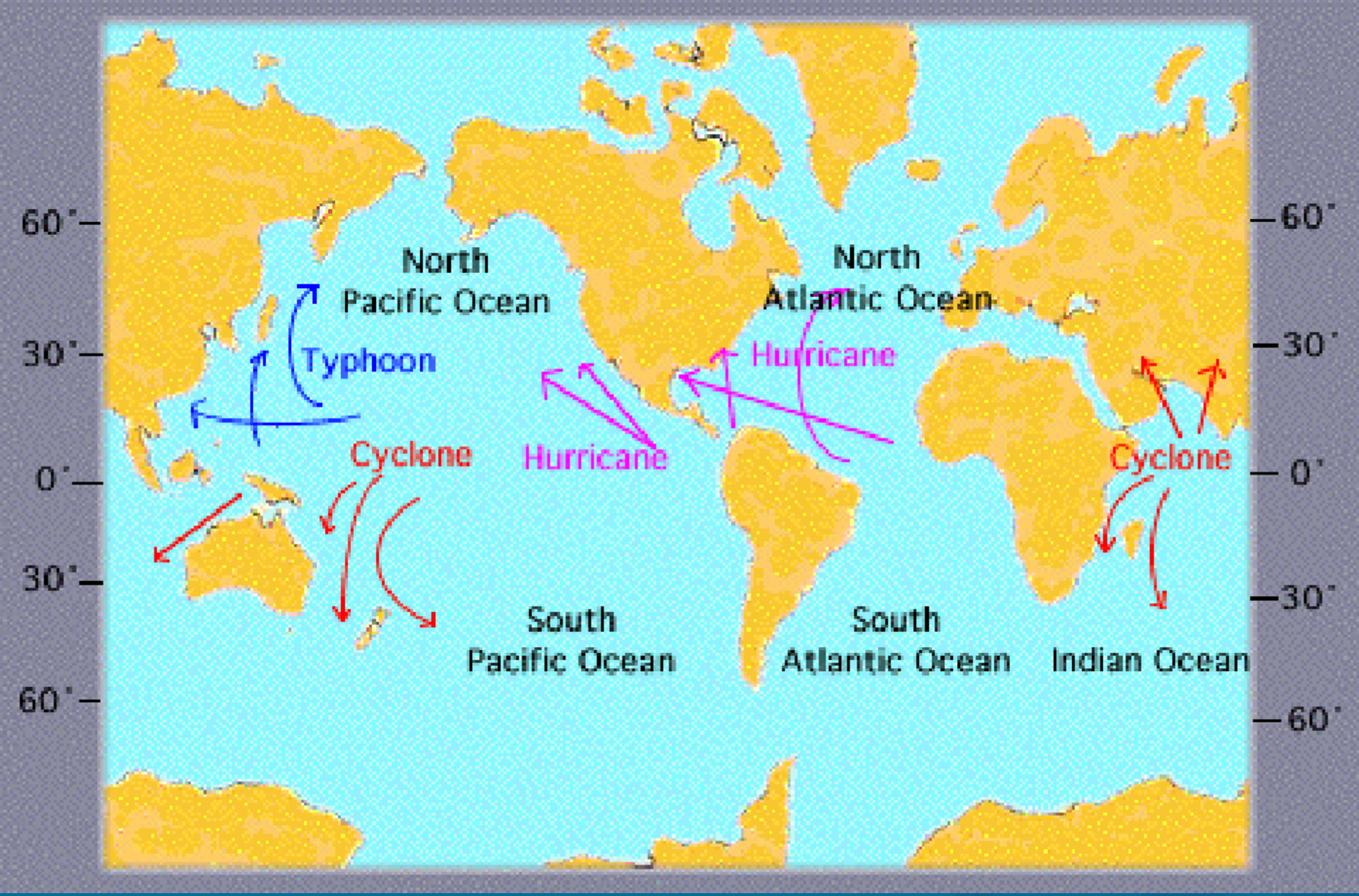
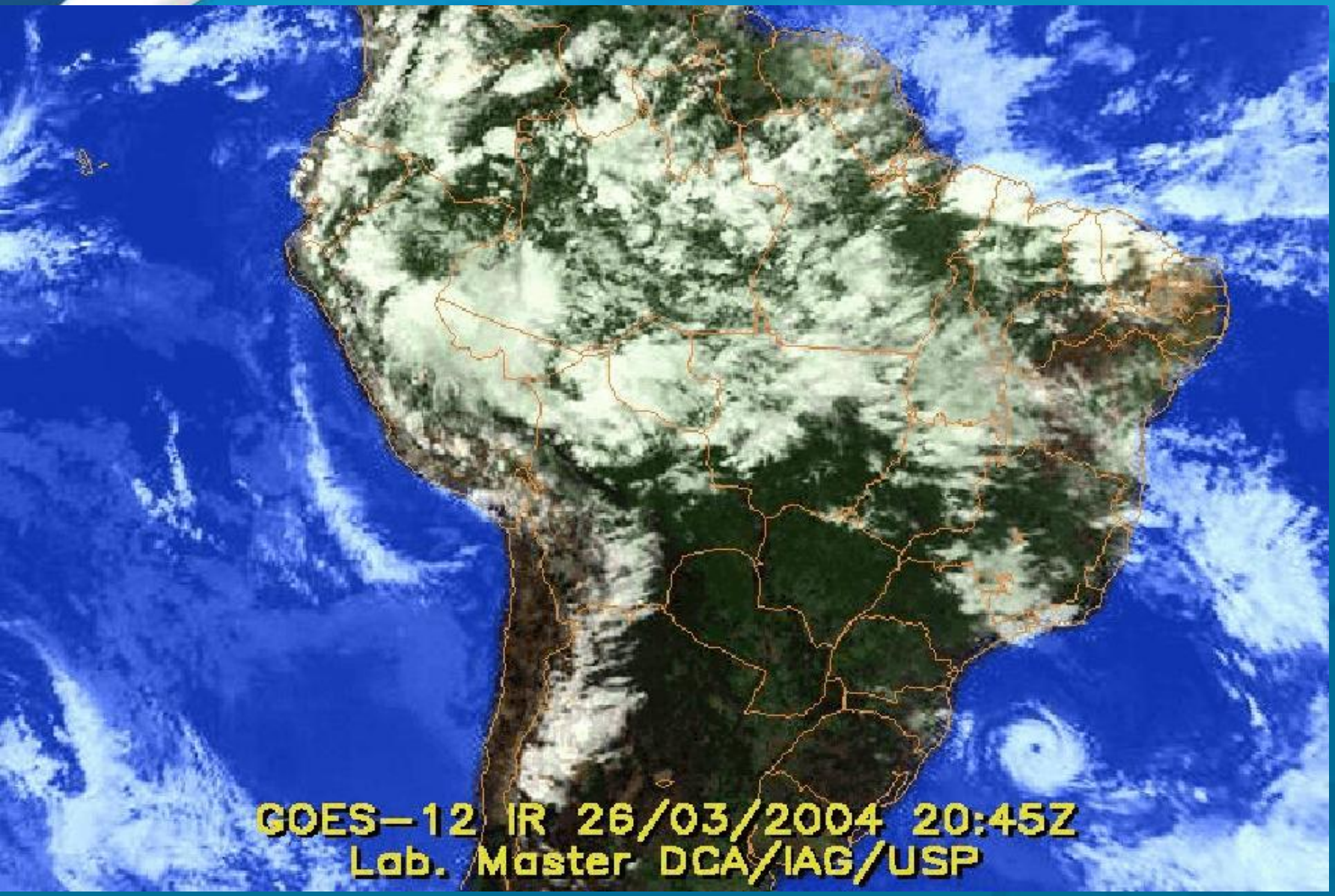
Tropical Meteorology 101

The Basics of Tropical Cyclone Formation, Intensity and Movement



Steve Letro
Meteorologist in Charge
National Weather Service, Jacksonville


60˚
30˚
0˚
30˚
60˚
North
Pacific Ocean
Typhoon
Cyclone
Hurricane
North
Atlantic Ocean
Hurricane
Cyclone
South
Pacific Ocean
South
Atlantic Ocean
Indian Ocean



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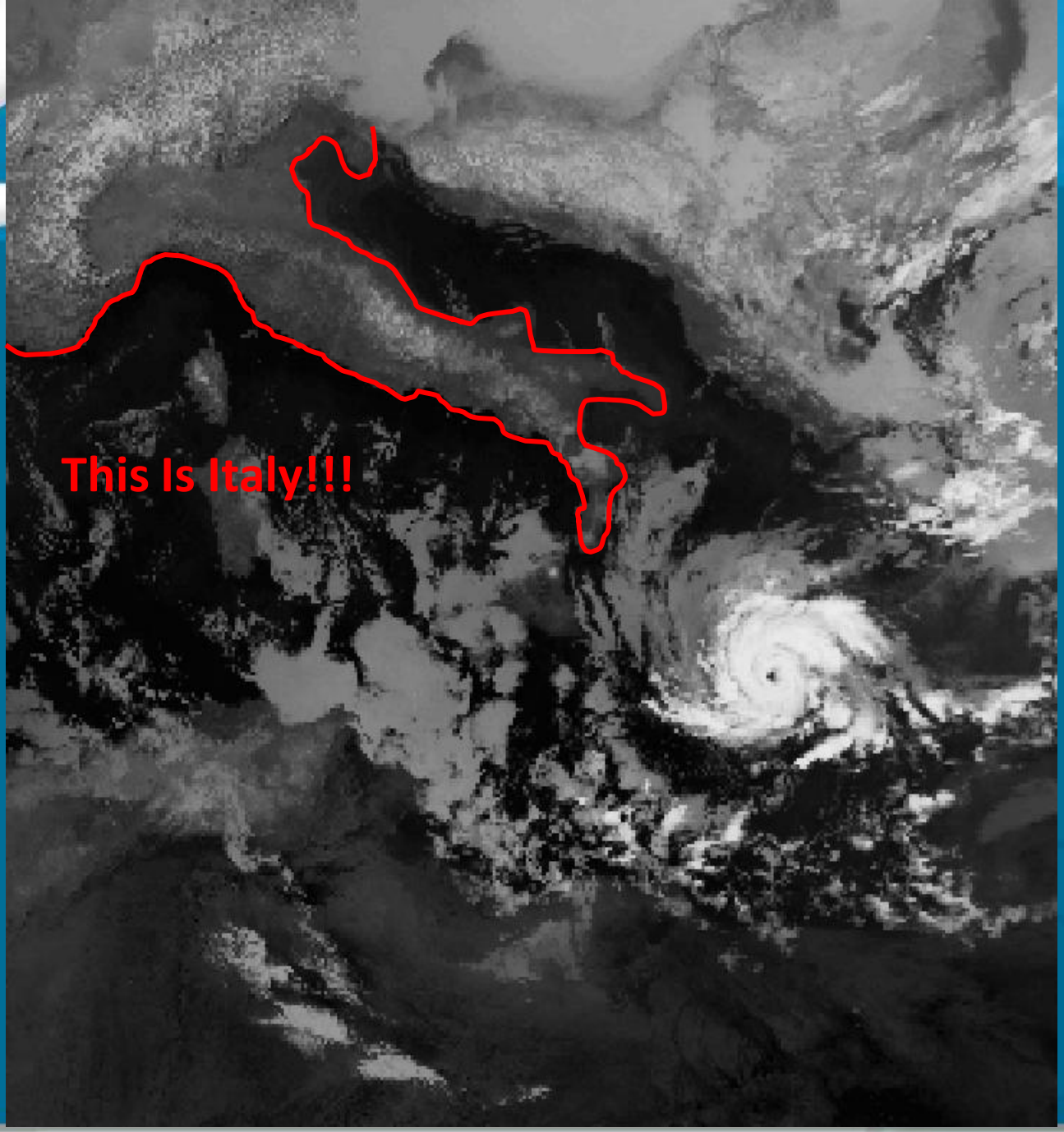
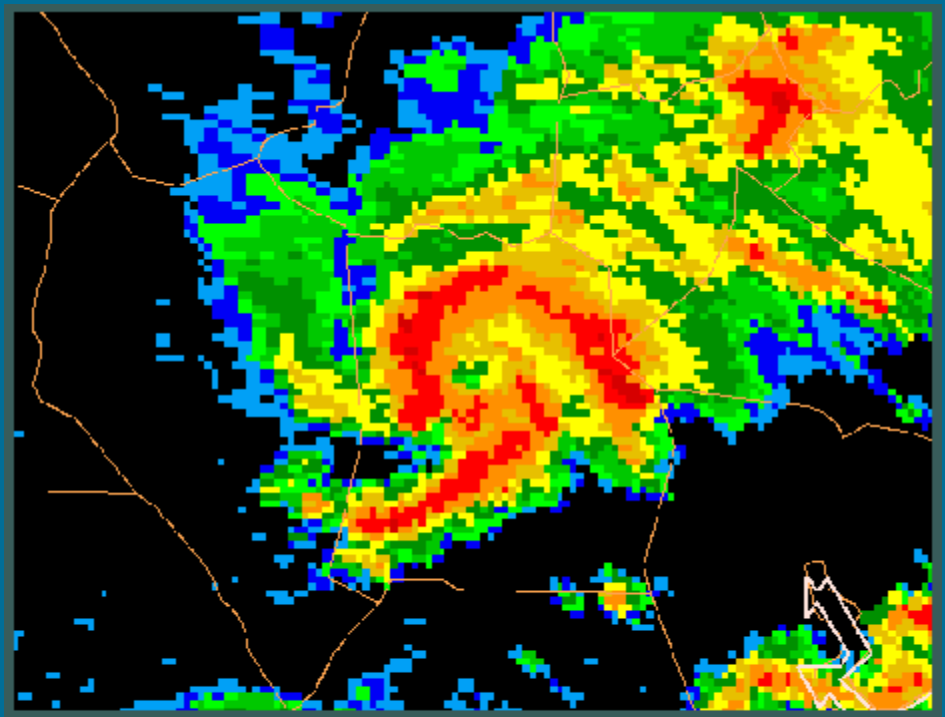


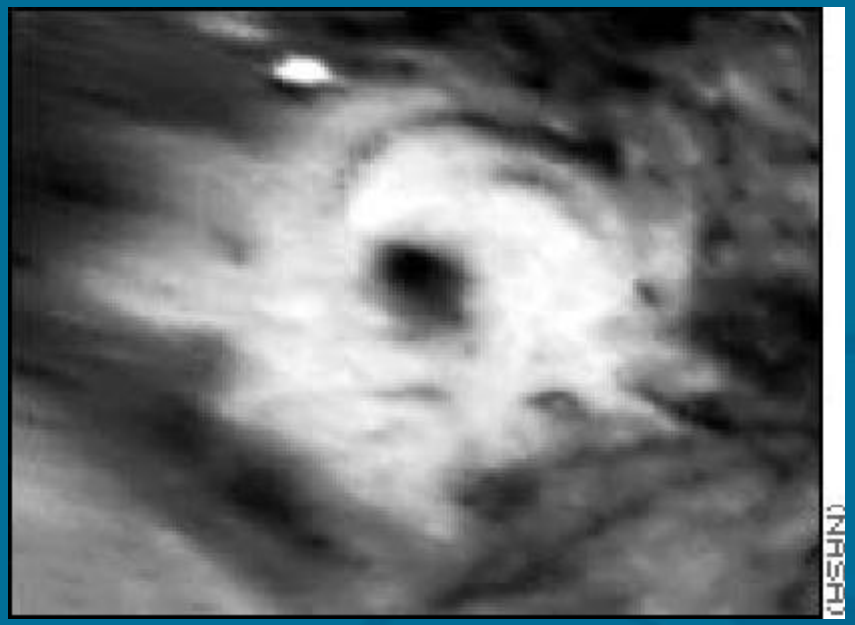
5/21/2008

NATURE ALSO PRODUCES EVEN STRANGER HURRICANE-LIKE STRUCTURES



Hurricane-shaped, tornado-producing supercell over Duplin County, NC

Wilmington NC Base Reflectivity. 0139Z 16 April 1999 (9:39 pm EDT 15 April 1999)



A MARTIAN HURRICANE?

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JUST WHAT IS A "TROPICAL CYCLONE"?

A WEATHER DISTURBANCE WITH WINDS ROTATING AROUND A LOW PRESSURE CENTER… WHICH DERIVES ITS ENERGY FROM THE RELEASE OF LATENT HEAT DURING THE CONDENSATION PROCESS.

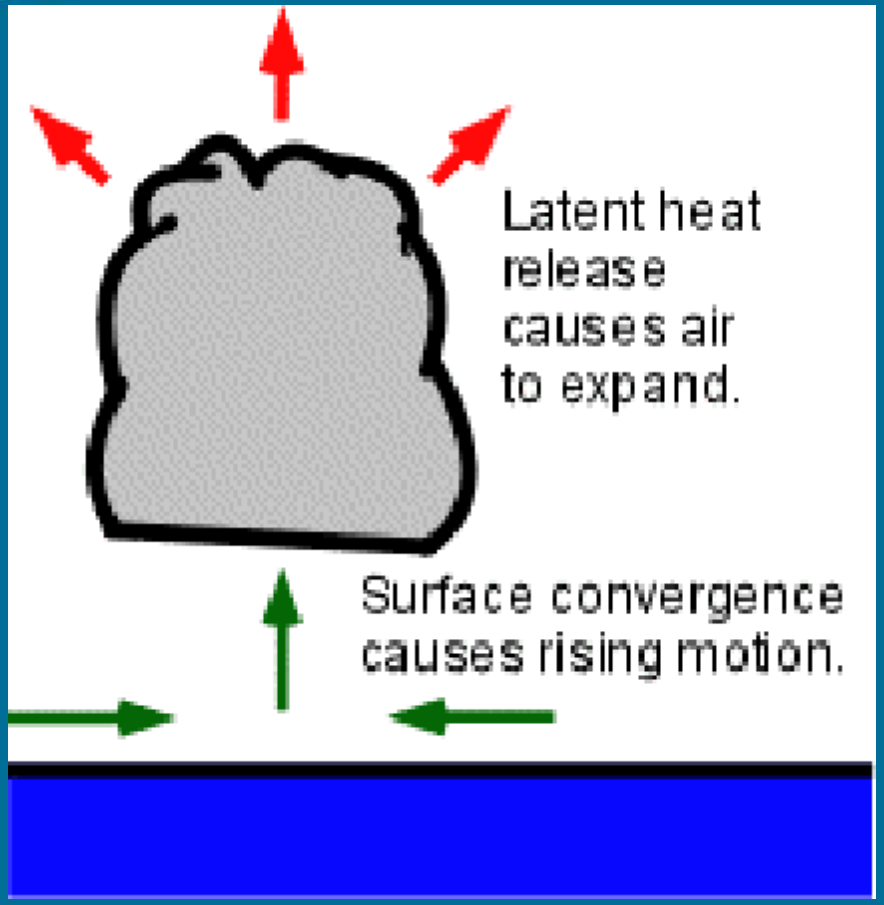
JUST WHAT IS A "TROPICAL CYCLONE"?

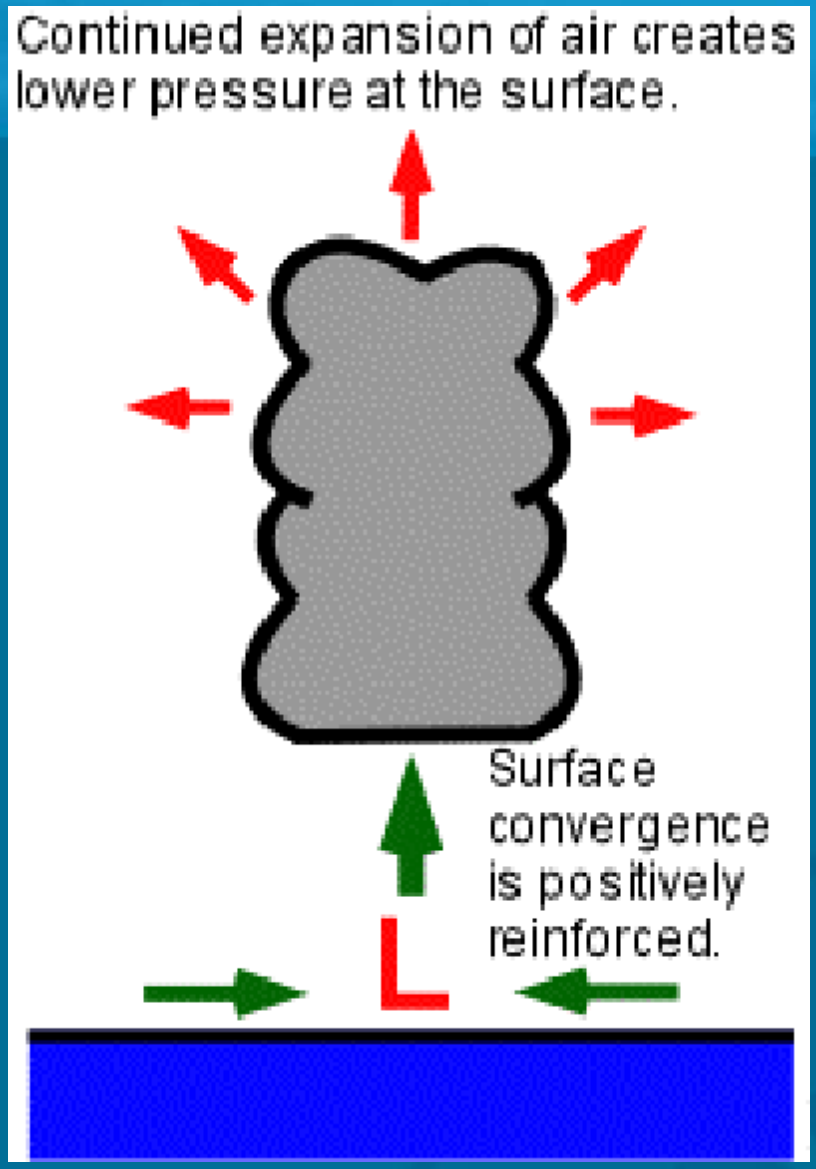
LET'S PUT IT A DIFFERENT WAY…

A TROPICAL CYCLONE FORMS BECAUSE THREE BASIC THINGS HAVE OCCURRED:

1. SOMETHING HAS CAUSED AIR TO BEGIN RISING ON A LARGE SCALE, CAUSING IT TO CONDENSE ITS MOISTURE, RELEASING HEAT.

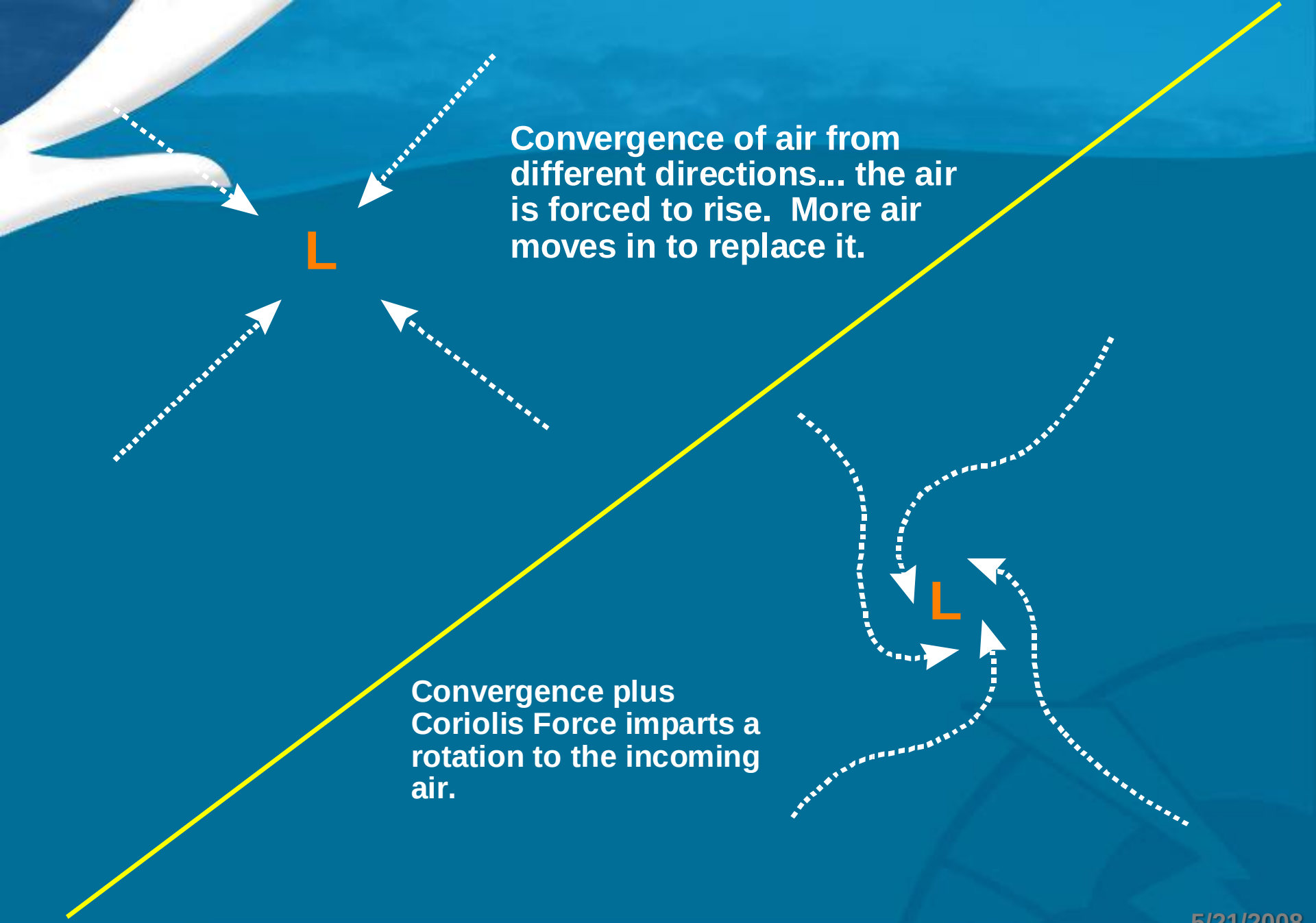
2. AS THE AIR ROSE AND EXPANDED, IT LEFT AN AREA OF LOWER PRESSURE BENEATH IT. AIR THEN BEGAN TO MOVE IN FROM SURROUNDING AREAS TO TAKE ITS PLACE.


Latent heat release causes air to expand.
Surface convergence causes rising motion.


Continued expansion of air creates lower pressure at the surface.
Surface convergence is positively reinforced.

JUST WHAT IS A "TROPICAL CYCLONE"?

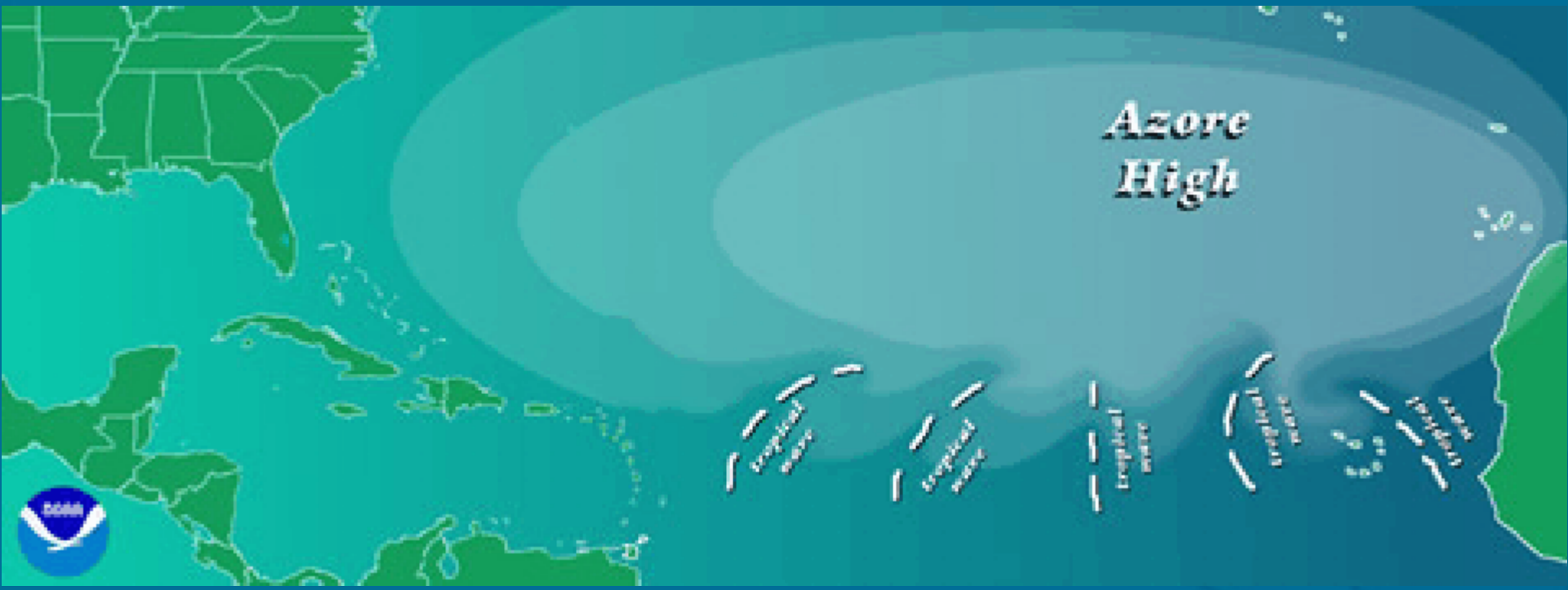
3. AS THE AIR MOVED IN FROM OTHER DIRECTIONS (CONVERGENCE), THE FORCE IMPARTED BY EARTH'S ROTATION (CORIOLIS FORCE) CAUSED IT TO BEGIN TO ROTATE AROUND THE LOW PRESSURE CENTER.


L
Convergence of air from different directions... the air is forced to rise. More air moves in to replace it.
L
Convergence plus Coriolis Force imparts a rotation to the incoming air.

THE MAJOR INGREDIENTS FOR TROPICAL CYCLONE FORMATION:

1. A PRE-EXISTING DISTURBANCE WITH THUNDERSTORMS

TROPICAL WAVES



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TROPICAL WAVES

MOST TROPICAL WAVES HAVE THEIR ORIGIN ALONG THE EQUATORIAL TROUGH IN AFRICA… THOUGH THE EXACT MECHANISM RESPONSIBLE FOR THEIR FORMATION IS OPEN TO SOME DEBATE.

- THESE WAVES EMERGE FROM THE AFRICAN COAST ON AN AVERAGE OF 2-3 PER WEEK DURING HURRICANE SEASON.

- MOST TROPICAL WAVES ARE "STABLE" AND SHOW LITTLE OR NO DEVELOPMENT

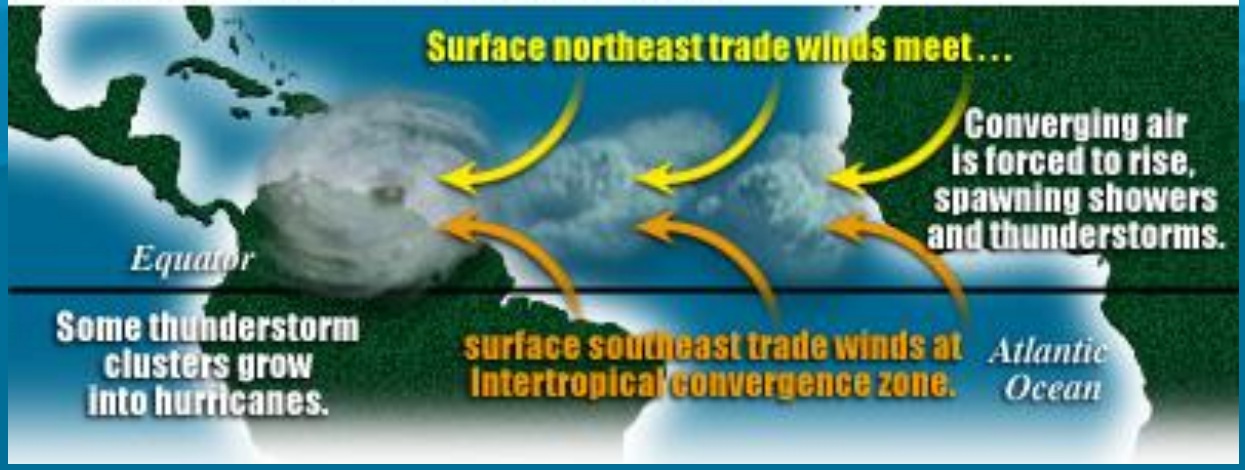
- AT ANY GIVEN TIME DURING HURRICANE SEASON THERE MAY BE SEVERAL OF THESE WAVES ON THE CHARTS. THEY ARE THE MOST COMMON OF THE NORMAL SUMMERTIME MIGRATORY TROPICAL WEATHER DISTURBANCES.

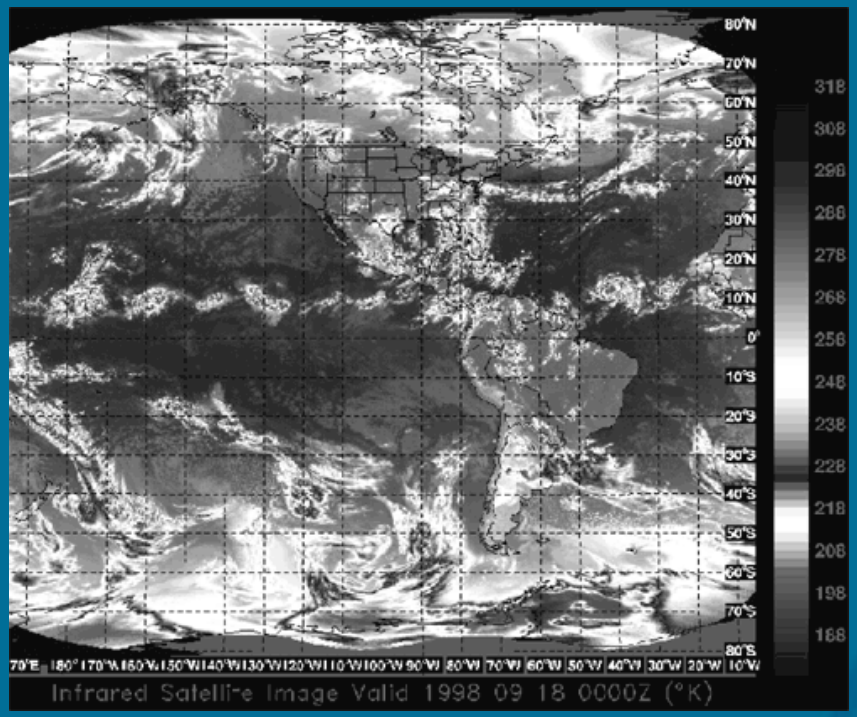
THE EQUATORIAL TROUGH

OR, INTERTROPICAL CONVERGENCE ZONE (ITCZ)

THIS TROUGH IS A NORMAL FEATURE OF THE TROPICS AND IS BELIEVED TO BE A MAJOR FACTOR IN THE GENESIS OF TROPICAL WAVES IN THE EASTERN ATLANTIC/WESTERN AFRICA AREA.

Intertropical convergence zone





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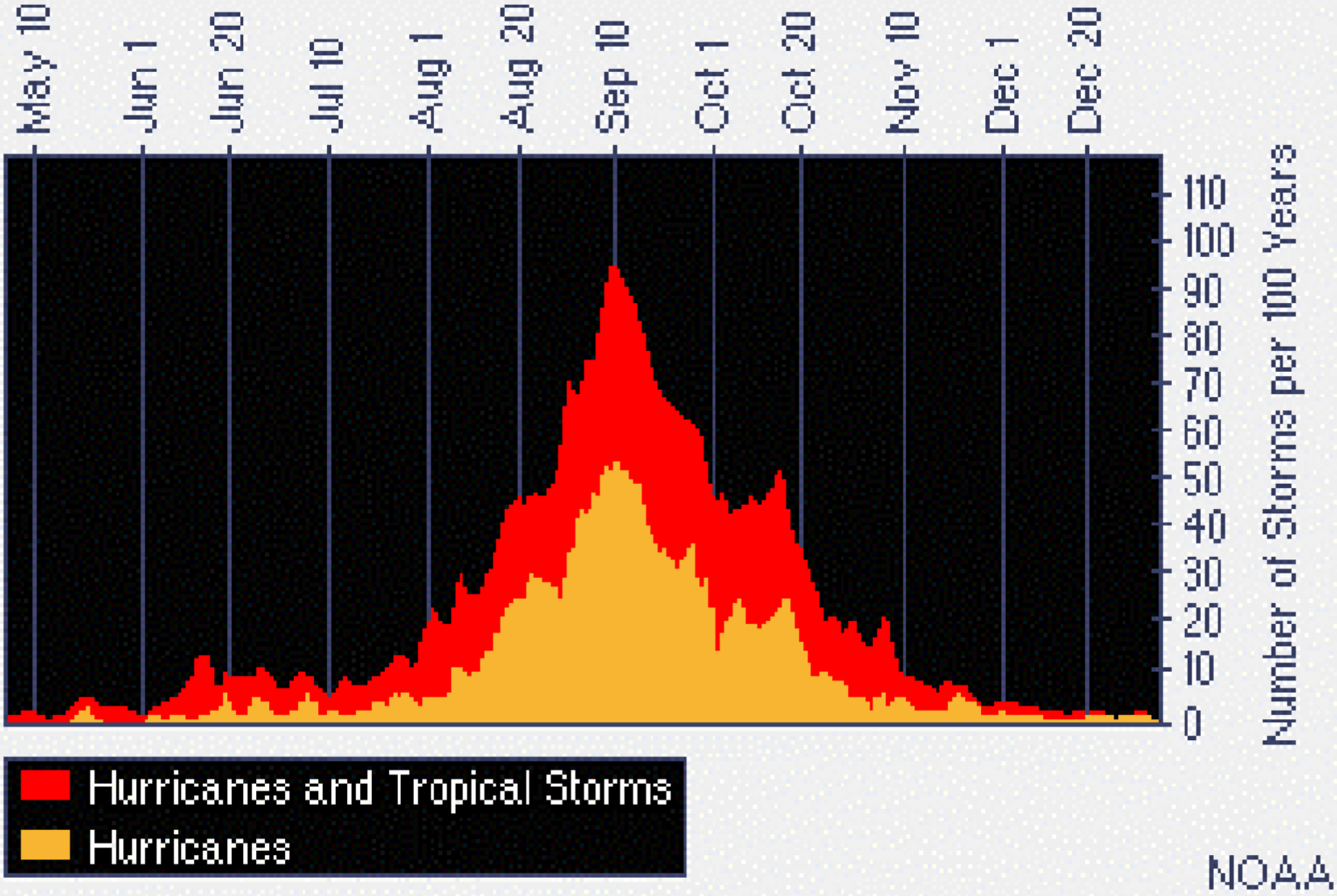
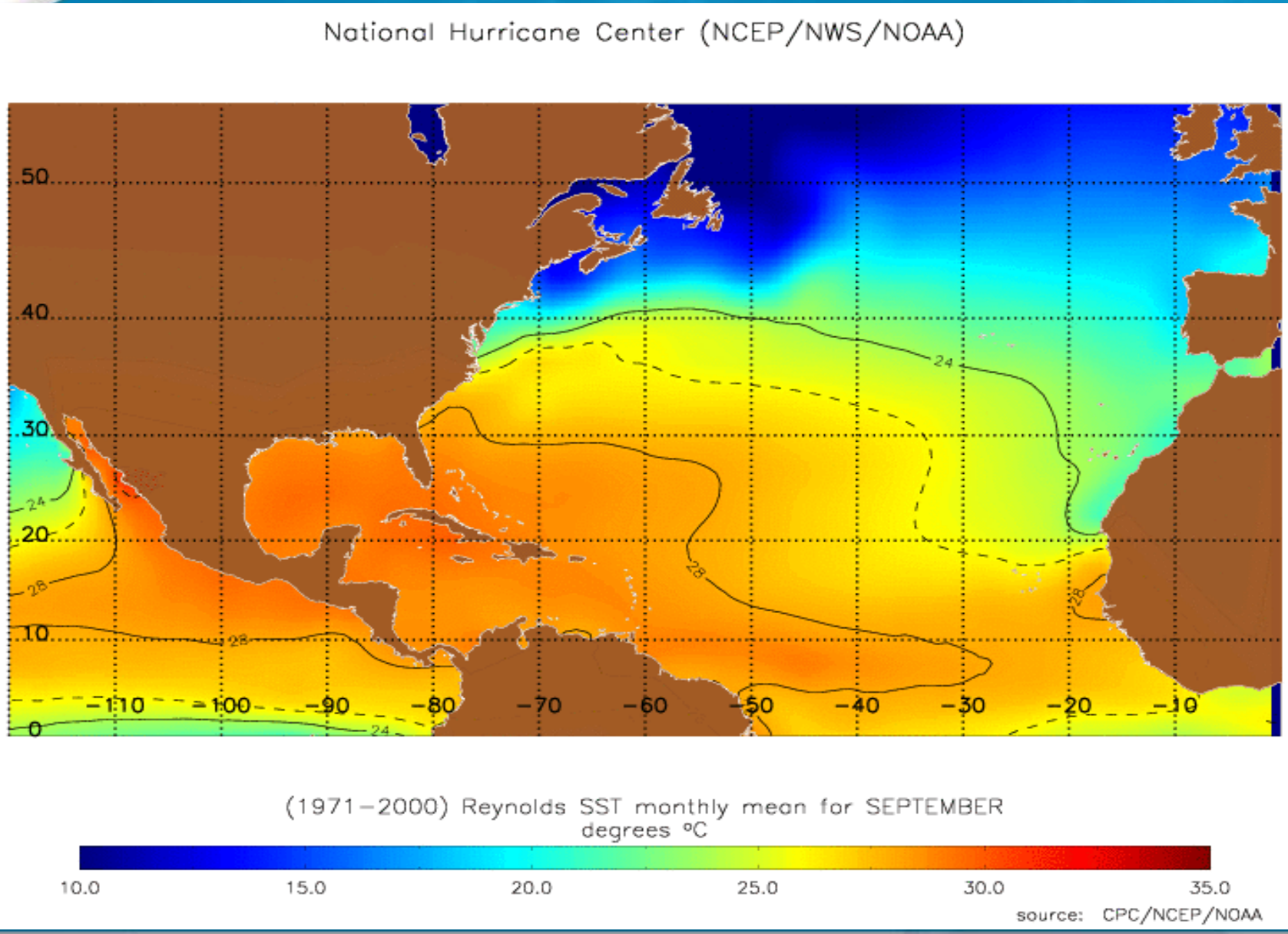
THE NEXT MAJOR INGREDIENT FOR TROPICAL CYCLONE FORMATION:

WARM SEA SURFACE TEMPERATURES (80 DEGREES F OR MORE TO A DEPTH OF AT LEAST ABOUT 150 FEET).

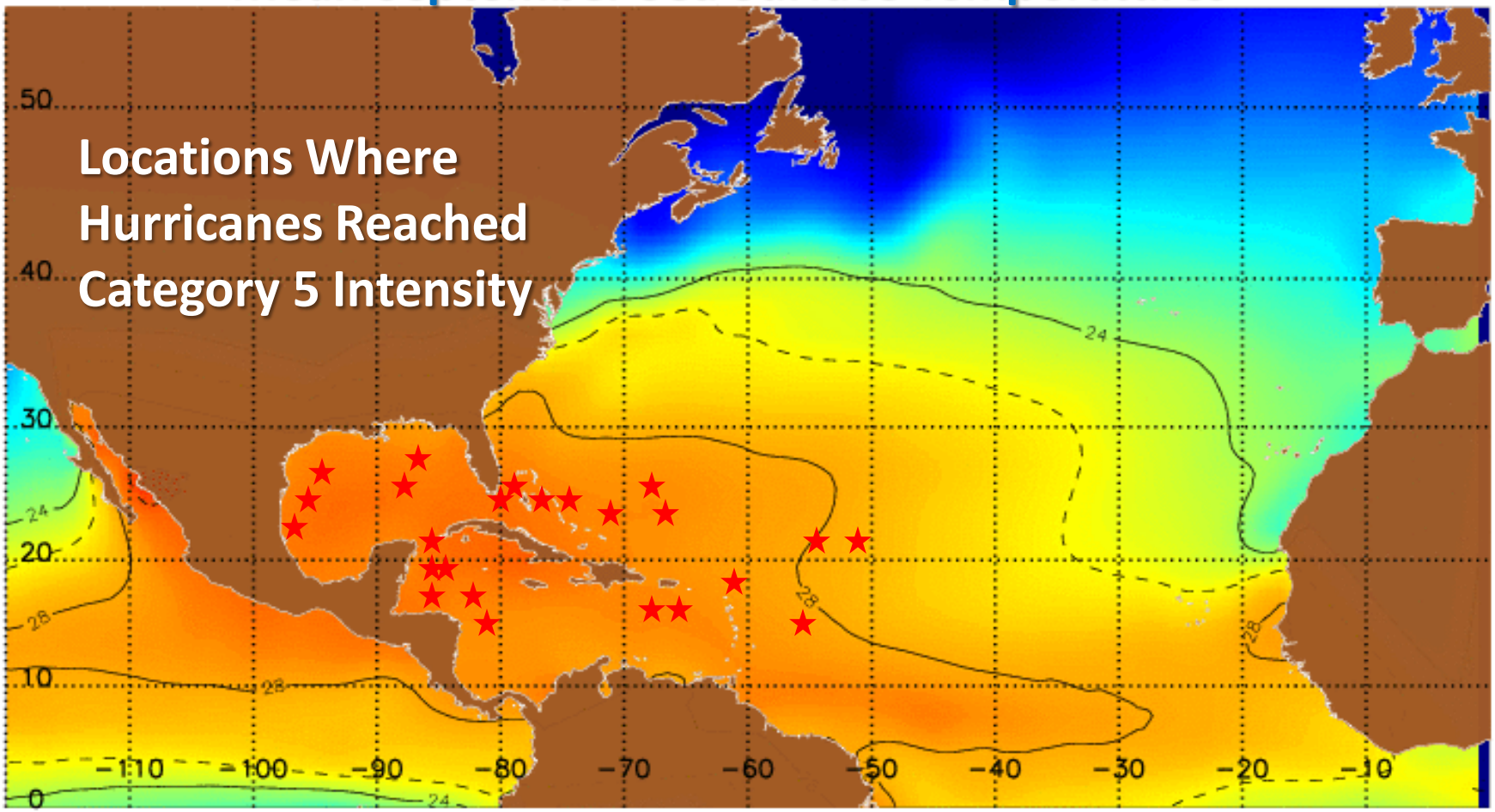

May 10
Jun 1
Jun 20
Jul 10
Aug 1
Aug 20
Sep 10
Oct 1
Oct 20
Nov 10
Dec 1
Dec 20
110
100
90
80
70
60
50
40
30
20
10
0
Number of Storms per 100 Years
Hurricanes and Tropical Storms
Hurricanes
NOAA

Oceanic Heat Content = Hurricane Fuel!



National Hurricane Center (NCEP/NWS/NOAA)

Mean September Sea Surface Temperatures



(1971–2000) Reynolds SST monthly mean for SEPTEMBER
degrees °C

10.0 15.0 20.0 25.0 30.0 35.0

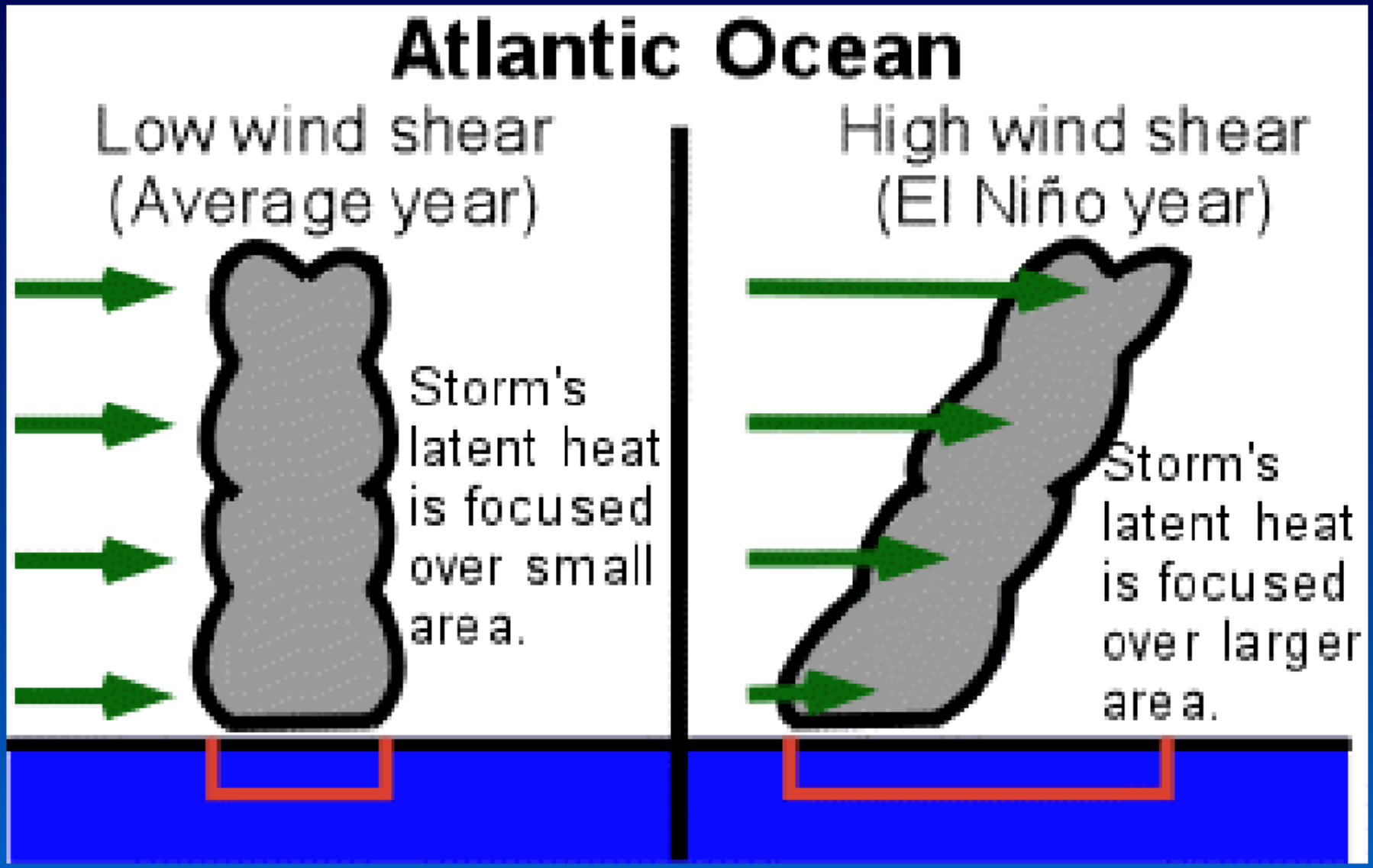
source: CPC/NCEP/NOAA

THE THIRD MAJOR INGREDIENT FOR TROPICAL CYCLONE FORMATION:

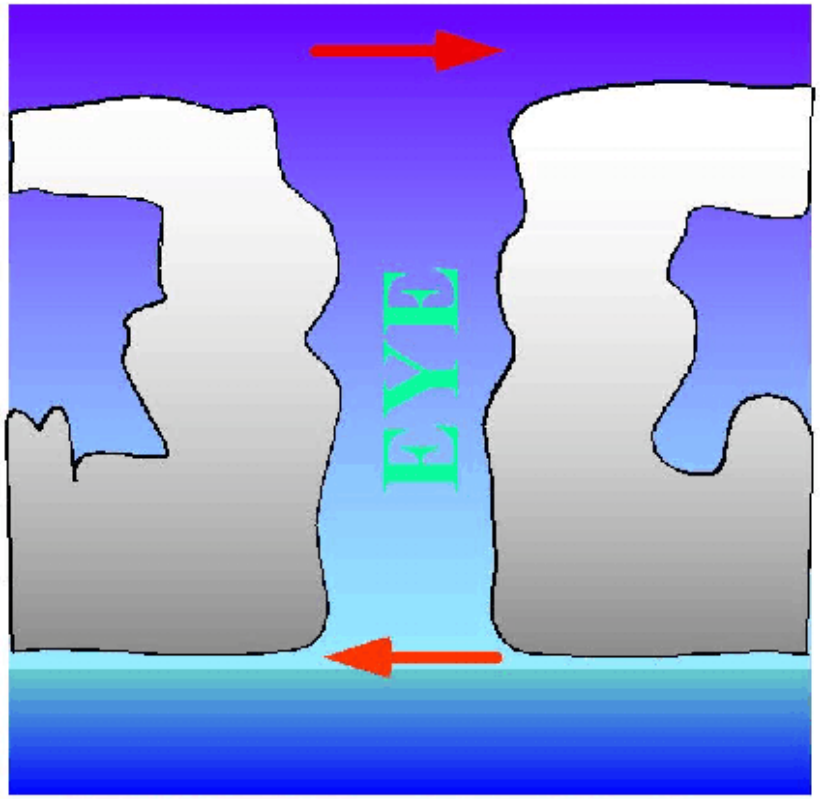
LIGHT VERTICAL WIND SHEAR…NO DRASTIC CHANGES IN DIRECTION OR SPEED WITH HEIGHT…ALLOWING HEAT TO CONCENTRATE IN A VERTICAL COLUMN.

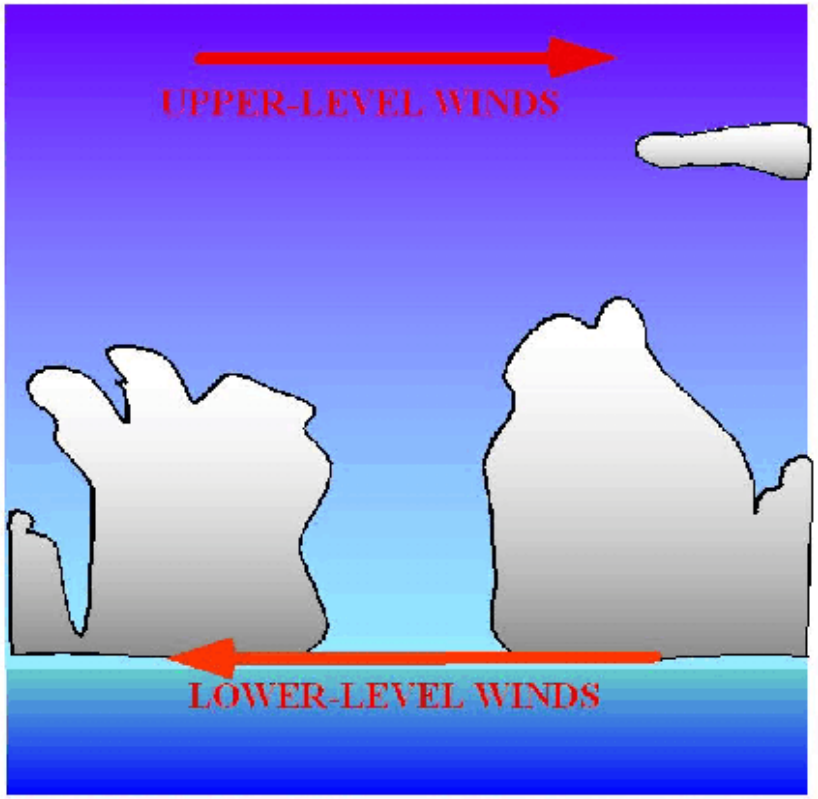
THE MAJOR INGREDIENTS FOR TROPICAL CYCLONE FORMATION:

- 1. A PRE-EXISTING DISTURBANCE
- 2. WARM SEA SURFACE TEMPERATURES
- 3. LIGHT VERTICAL WIND SHEAR
  - Note… The Added Shear Usually Present During Strong El-Nino Years Is A Major Reason The Atlantic Produces Fewer and Weaker Storms Overall During Those Years.


Atlantic Ocean
Low wind shear
(Average year)
Storm's latent heat is focused over small area.
High wind shear
(El Niño year)
Storm's latent heat is focused over larger area.

Effects of Vertical Wind Shear (V_z) on Tropical Cyclones

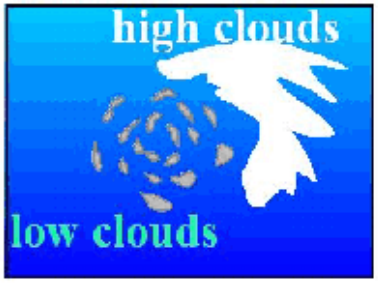




Neal Dorst/Sim Goldenberg
Hurricane Research Division
AOML/NOAA

WEAK SHEAR = FAVORABLE

STRONG SHEAR = *UN*FAVORABLE

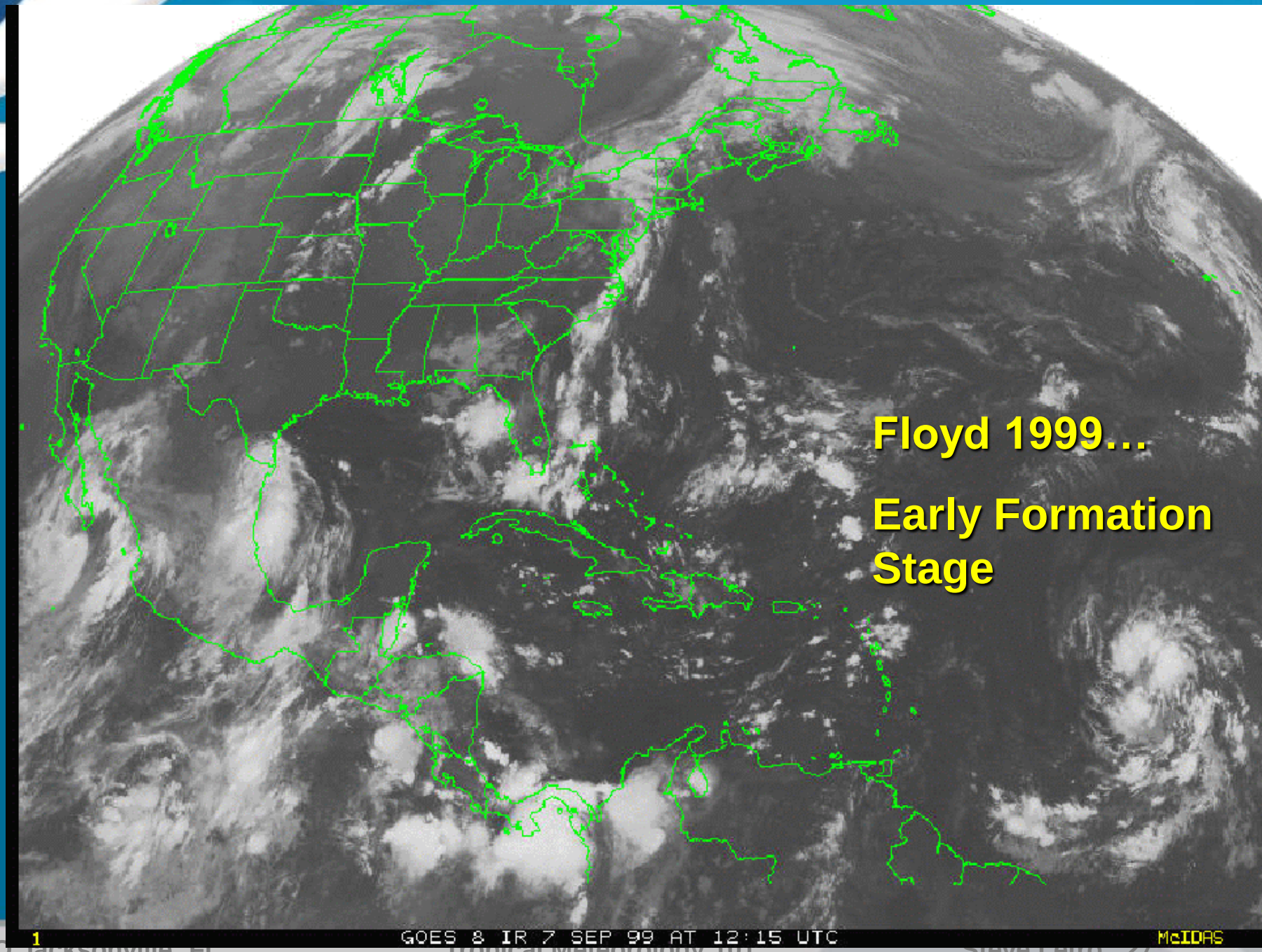


LIFE CYCLE OF A TROPICAL CYCLONE

HURRICANES DON'T JUST "APPEAR"… THEY GO THROUGH WELL DEFINED FORMATIVE, MATURATION AND DECAY PROCESSES.

LIFE CYCLE OF A TROPICAL CYCLONE

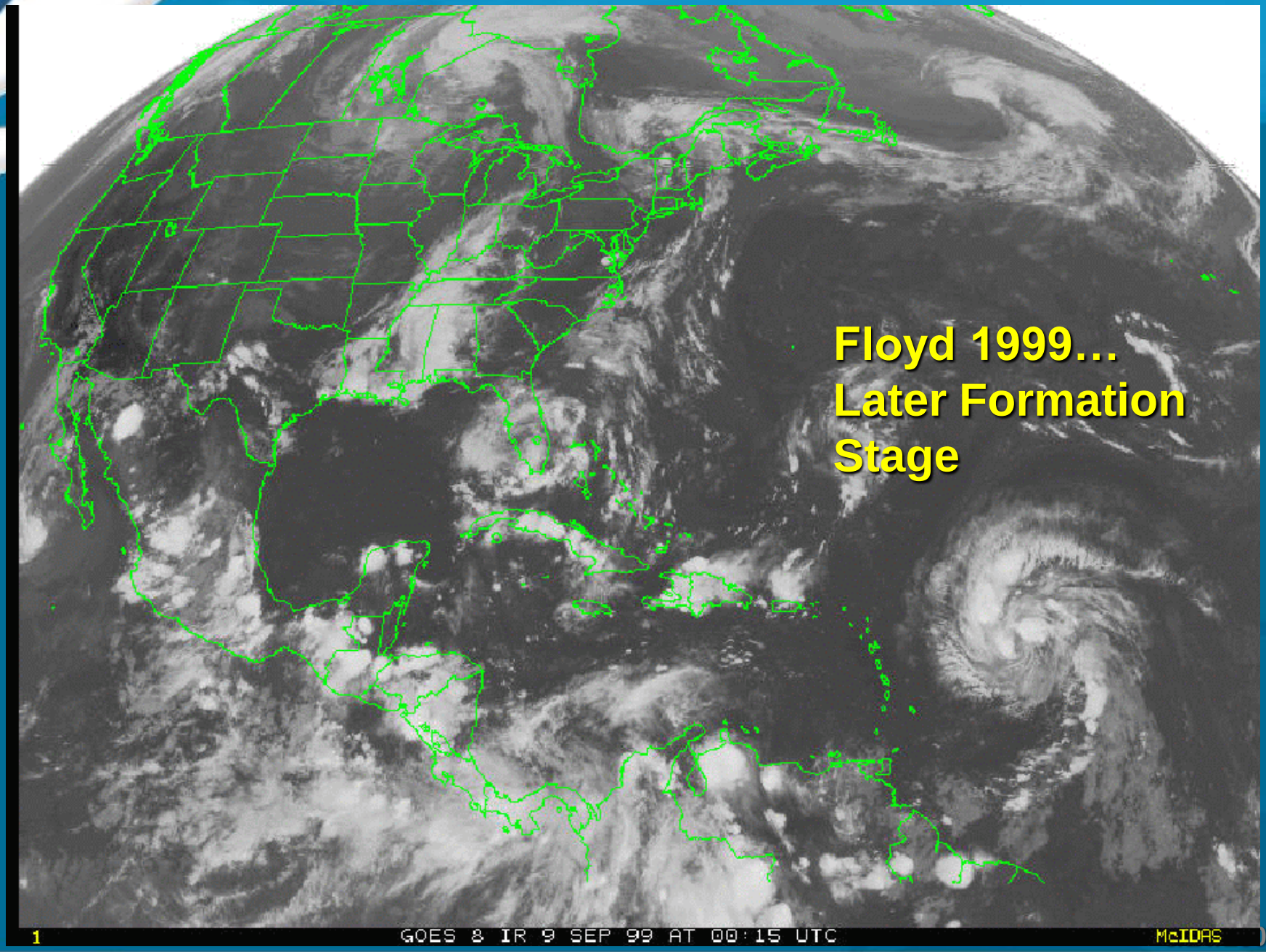
- **FORMATIVE STAGE:**
  - **An existing disturbance acquires a cyclonic circulation (equivalent to "depression" stage).**


Floyd 1999…
Early Formation Stage
1
GOES 8 IR 7 SEP 99 AT 12:15 UTC
McIDAS

LIFE CYCLE OF A TROPICAL CYCLONE

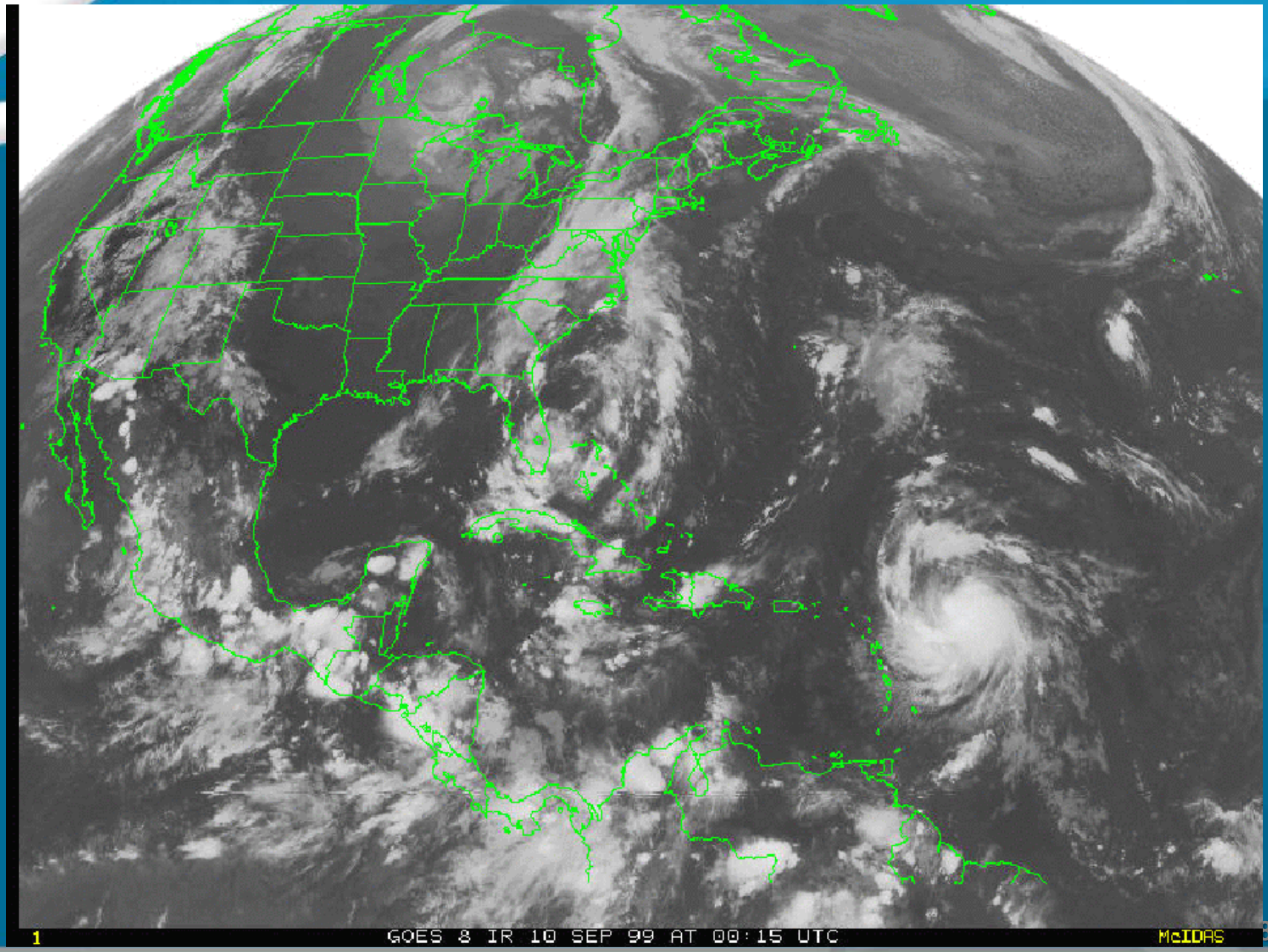
- FORMATIVE STAGE:

The Circulation Becomes Better Organized And Strengthens (Equivalent To "Tropical Storm" Stage.


Floyd 1999…
Later Formation
Stage
1
GOES 8 IR 9 SEP 99 AT 00:15 UTC
McIDAS

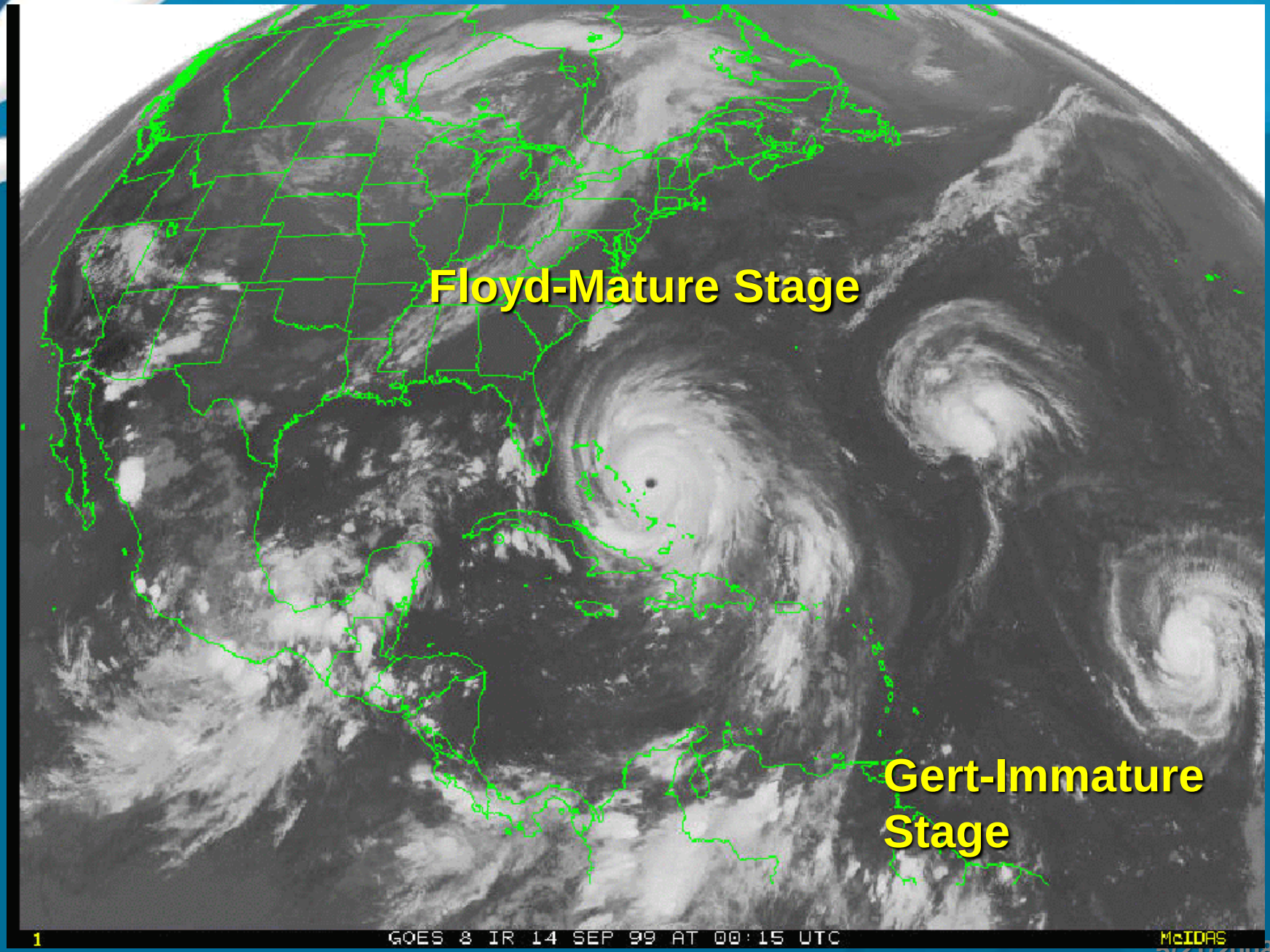
LIFE CYCLE OF A TROPICAL CYCLONE

- **Maturation Stage:**
  - **Winds increase to hurricane force and initial eye/eyewall development begins (“minimal hurricane” stage).**


1
GOES 8 IR 10 SEP 99 AT 00:15 UTC
McIDAS

LIFE CYCLE OF A TROPICAL CYCLONE

- **Maturation Stage:**
  - **Storm reaches maximum organization and wind strength. Core may undergo several eyewall replacement cycles. Wind field may begin to expand (often latitude-dependent)**


Floyd-Mature Stage
Gert-Immature Stage
1
GOES 8 IR 14 SEP 99 AT 00:15 UTC
McIDAS

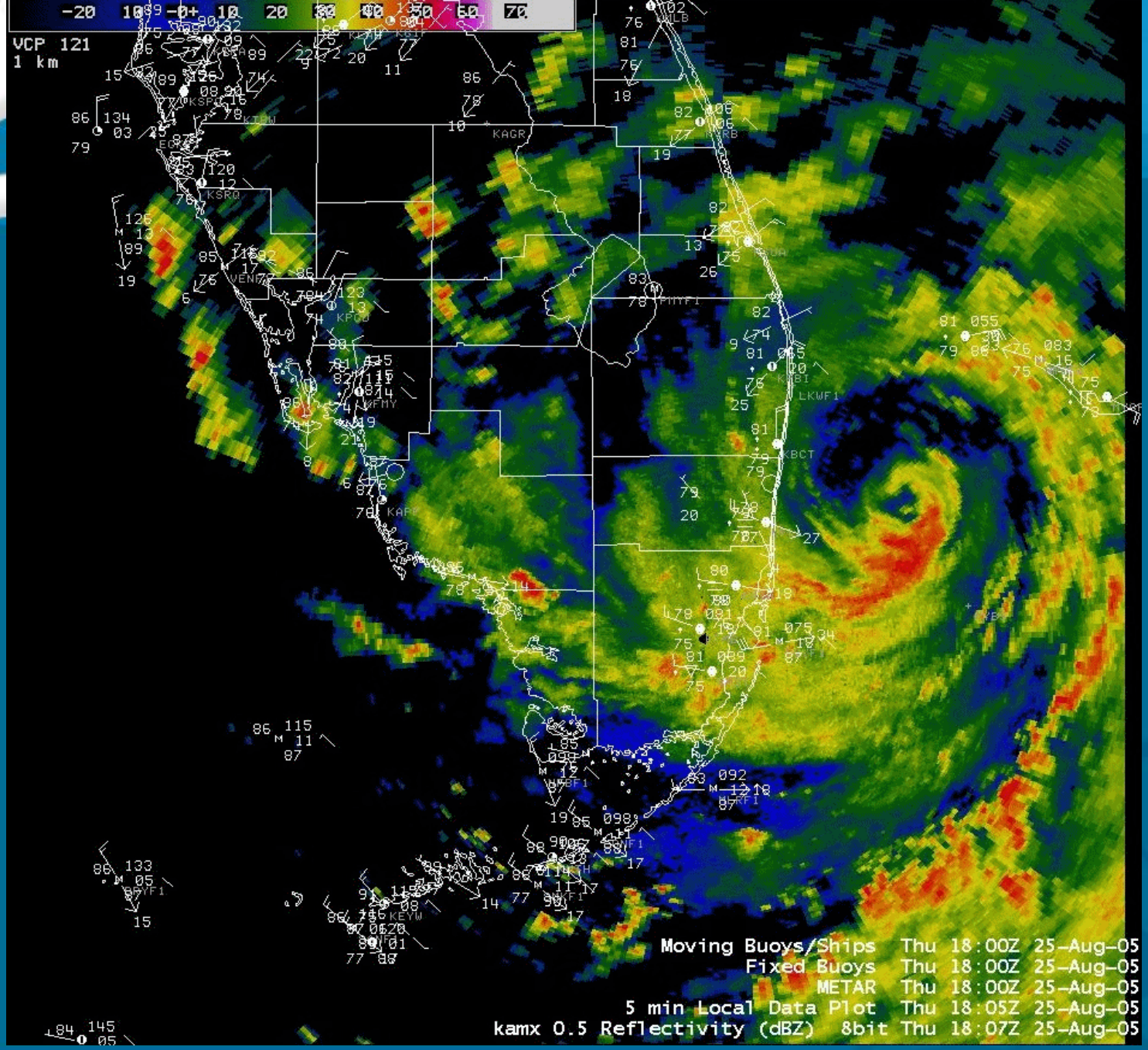
LIFE CYCLE OF A TROPICAL CYCLONE

- **Decaying or Transformation Stage**
  - **Storm Falls Victim To Cold Air Or Water, Or May Become Extratropical (Non-tropical Energy Source).**
  - **Storm Moves Over Land and Fills (*usually!)***

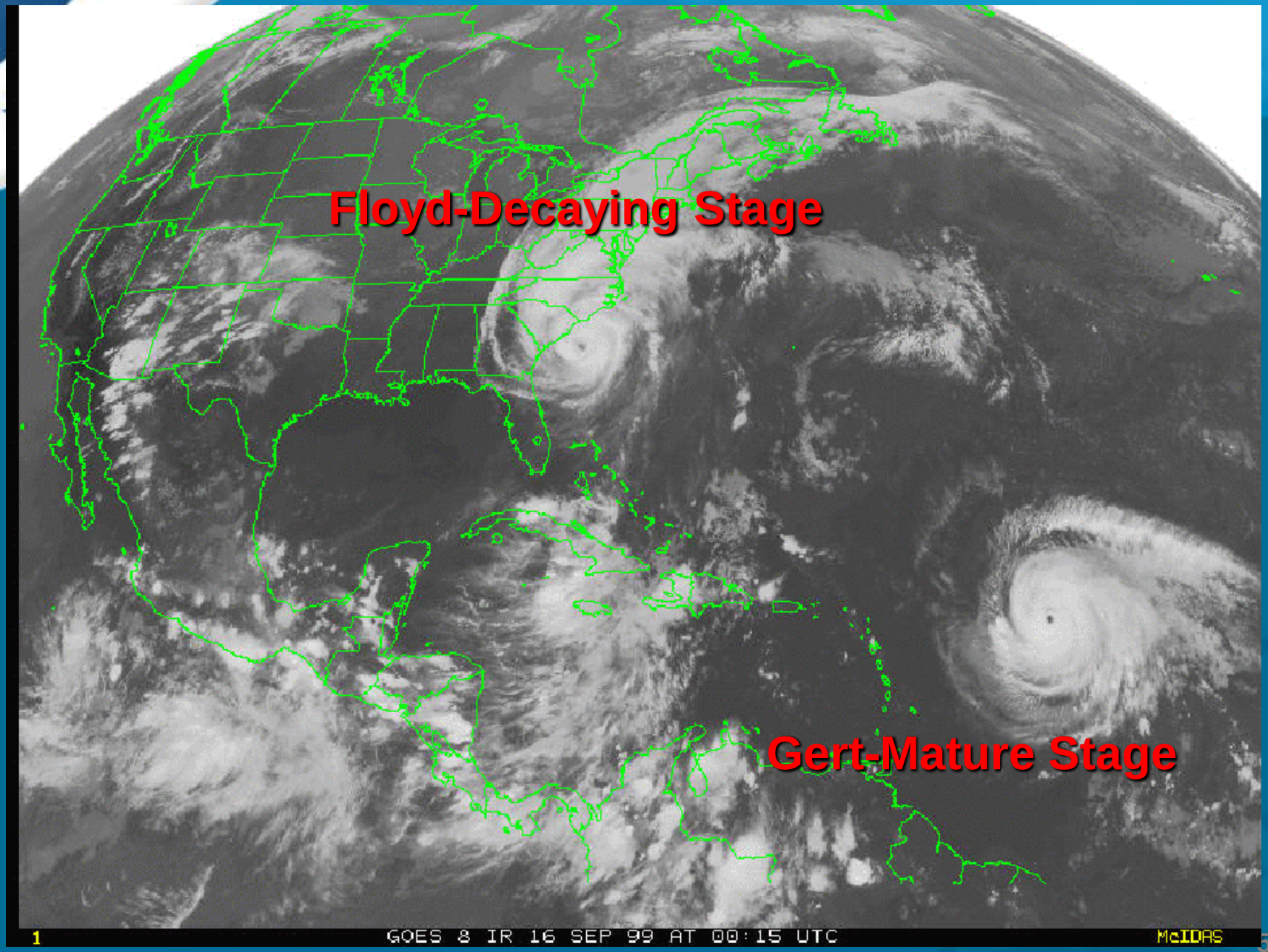
An Anomaly…

"Conventional Wisdom" States That Hurricanes Weaken When The Center Moves Over Land…

…But Consider The Case Of Katrina Moving Across South Florida…


-20 10 -0+ 10 20 30 40 50 60 70
VCP 121
1 km
Moving Buoys/Ships Thu 18:00Z 25-Aug-05
Fixed Buoys Thu 18:00Z 25-Aug-05
METAR Thu 18:00Z 25-Aug-05
5 min Local Data Plot Thu 18:05Z 25-Aug-05
kamx 0.5 Reflectivity (dBZ) 8bit Thu 18:07Z 25-Aug-05

5/21/2008


Floyd-Decaying Stage
Gert-Mature Stage
1
GOES 8 IR 16 SEP 99 AT 00:15 UTC
McIDAS

Factors Affecting Development

General "Rules of Thumb"

A Tropical Cyclone Will Normally Maintain or Increase It's Intensity As Long As:

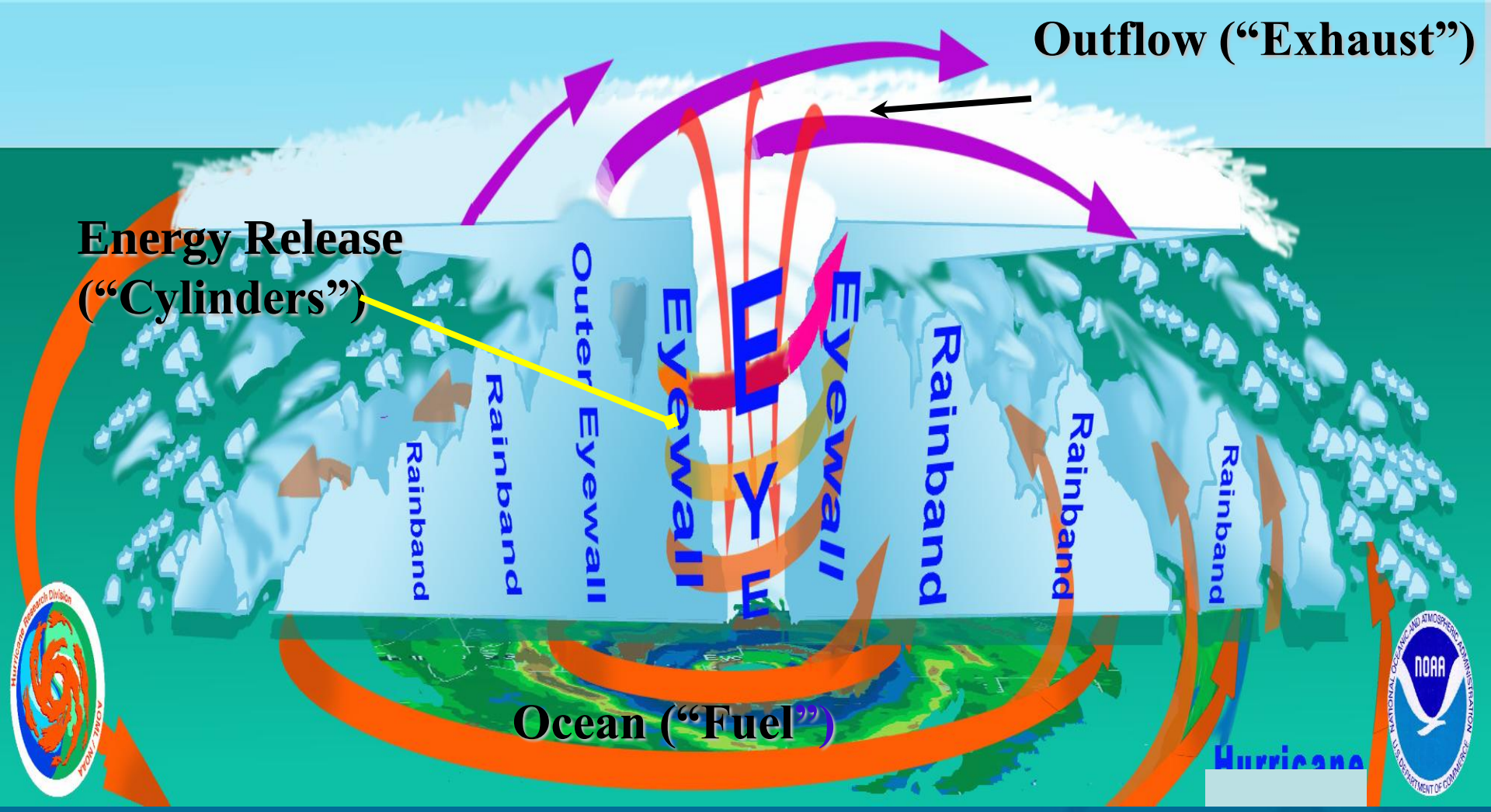
- **Environmental Winds Around The Storm Remain Light, Reducing Wind Shear And Allowing Convective Columns To Grow.**
- **A Steady Supply Of Energy Is Available In The Form Of Evaporation From Warm Ocean Surface.**
- **There Are No Cold Or Dry Air Intrusions To Inhibit The Convective Processes.**

Factors Affecting Development

A Tropical Cyclone Will Normally Maintain or Increase It's Intensity As Long As:

- Warm Moist Air Can Continually Be Fed Into The Circulation Without Interference (Inflow).
- A Compensating Amount Of Mass Can Be Removed From The Upper Levels Of The Storm (Outflow) Allowing Convection To Continue And Pressures To Remain Low.
- The Amount Of Intensification That Occurs Is Highly Dependent On The Efficiency Of These Inflow And Outflow Processes!

Nature's Great Heat Engine… The Hurricane



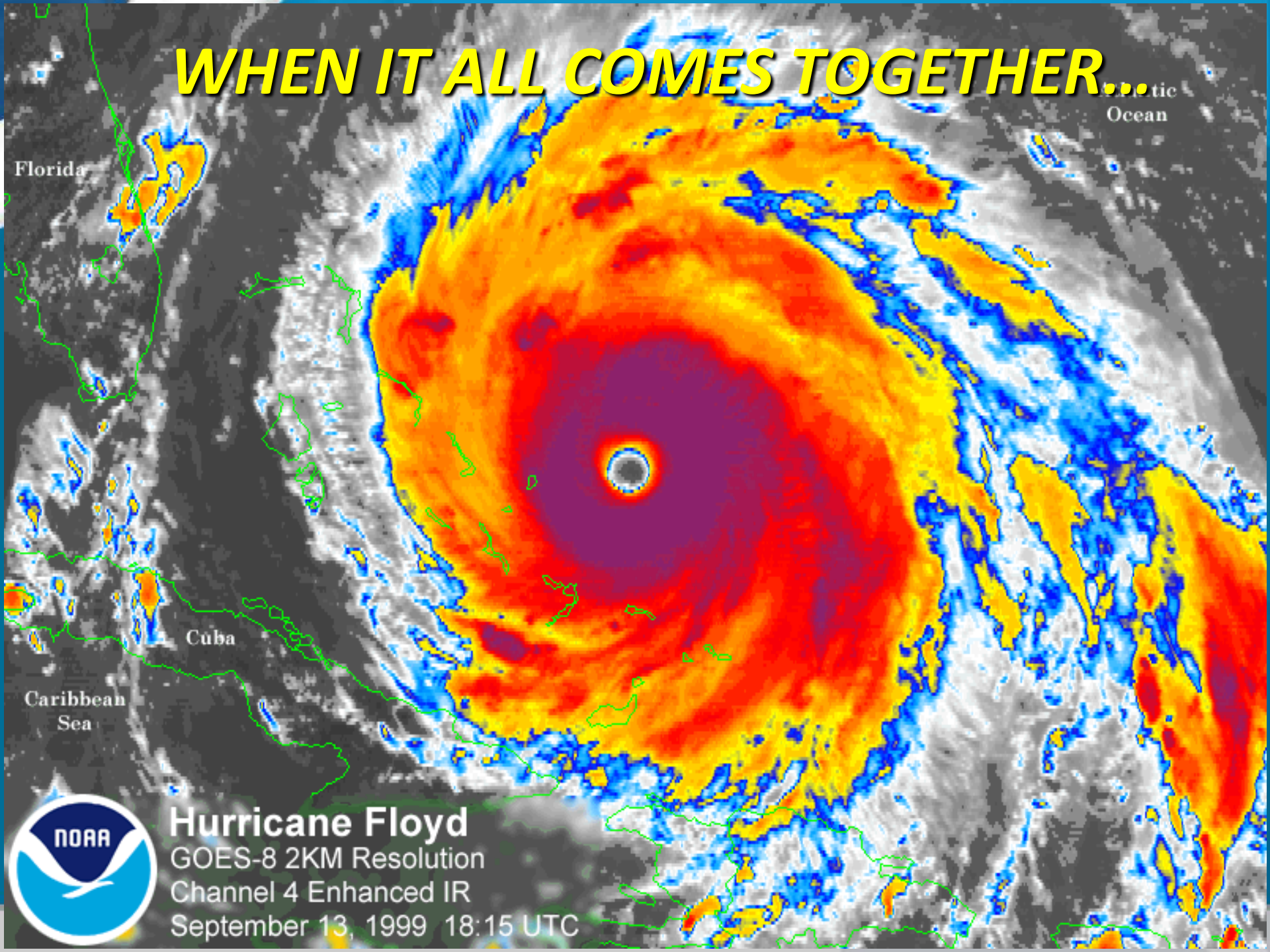
"Fuel" (heat) Is Processed Into Energy In The "Cylinders" (Eyewall & Rainbands) And The Spent Fuel Is Expelled As "Exhaust"

5/21/2008

If Any Of The Three Main Parts Of The Engine…

1. *Availability of Fuel*
2. *Ability To Process The Fuel Into Energy*
3. *Ability to Exhaust The Waste*

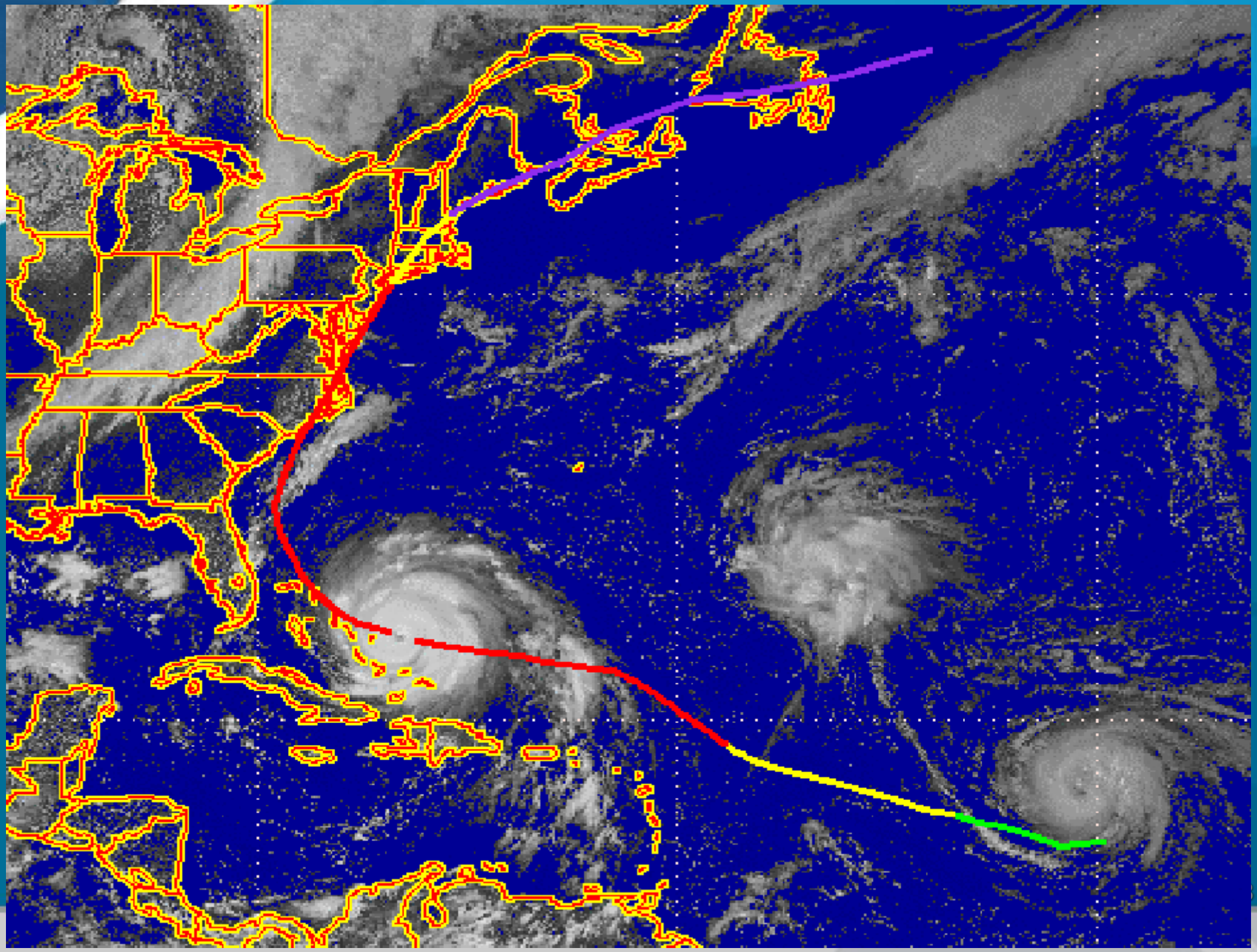
… Are Interfered With… The Engine Cannot Function Efficiently

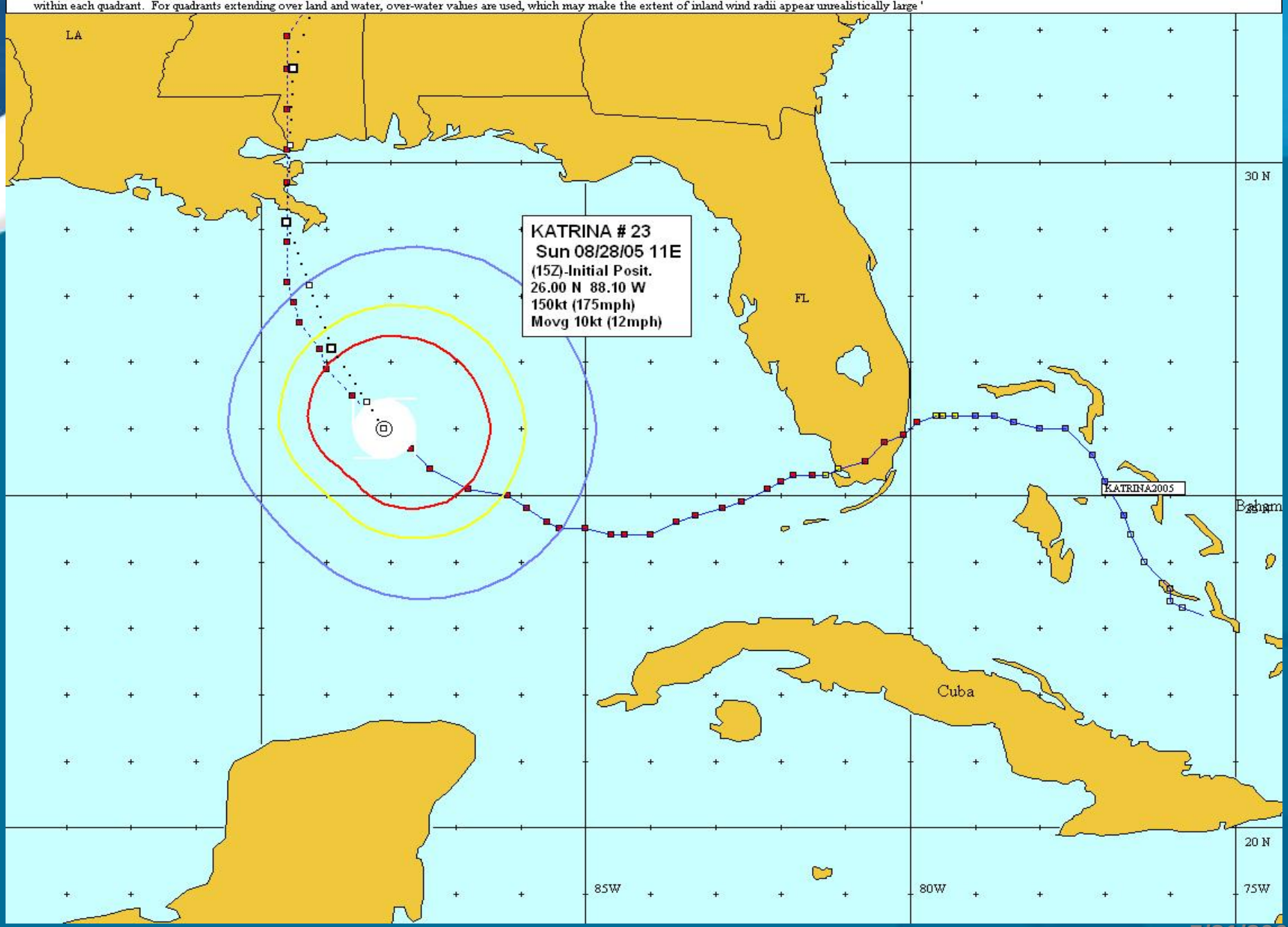

WHEN IT ALL COMES TOGETHER...
Florida
Ocean
Cuba
Caribbean Sea
NOAA
Hurricane Floyd
GOES-8 2KM Resolution
Channel 4 Enhanced IR
September 13, 1999 18:15 UTC

TROPICAL CYCLONE INTENSITY

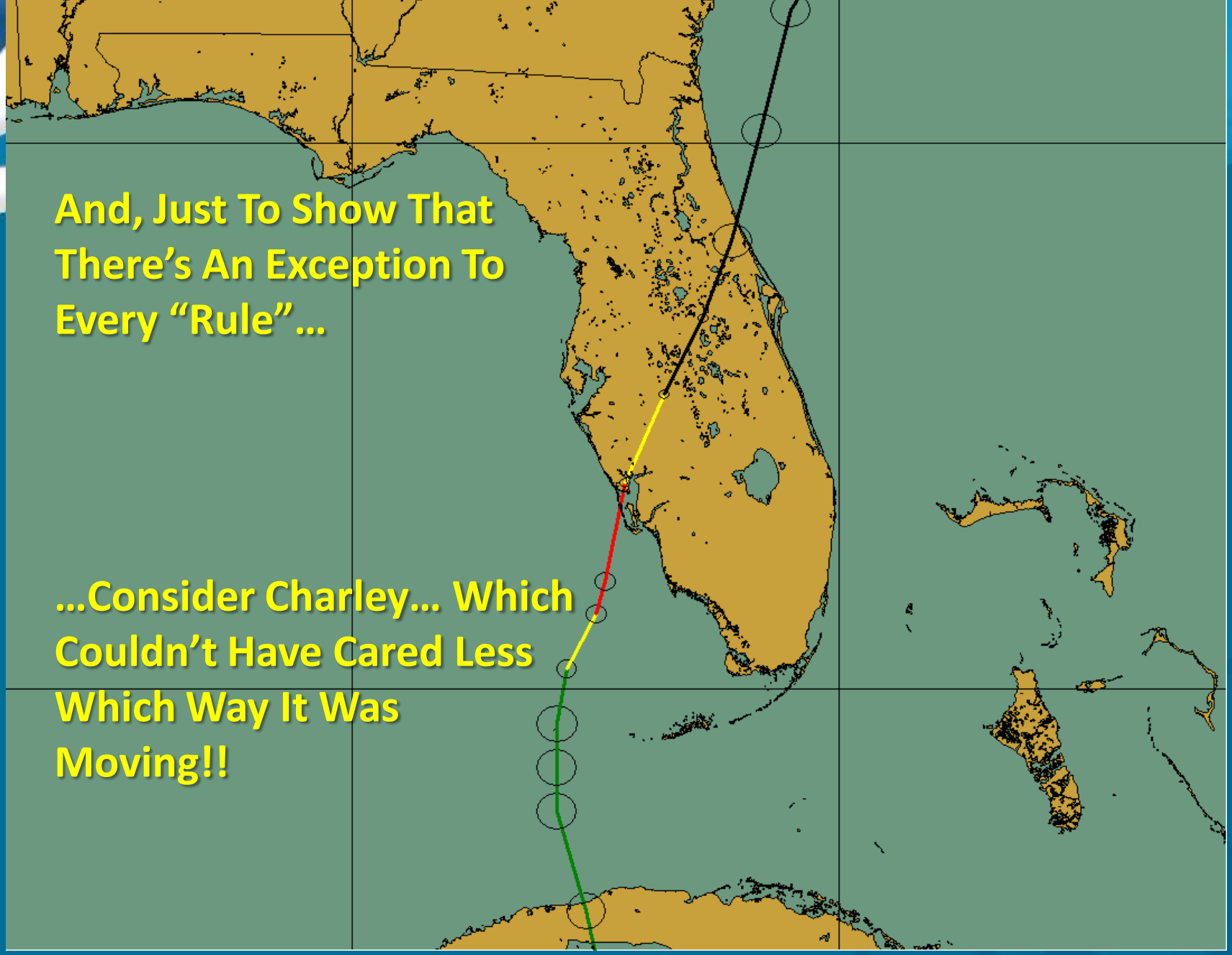
FORECAST CONSIDERATIONS

- It Is Normal For Hurricanes To Undergo Multiple Intensification Cycles Due To:
  - Internal Oscillations (Eyewall Replacements Cycle- Stay Tuned For Michelle Mainelli's Discussion Of These Features In Tropical Meteorology 201.)
  - Short Term, Small Scale Environmental Changes
- As A Very General Rule Of Thumb, Hurricanes Reach Their Greatest Intensity Near Or Before Their Recurvature Point.
- Once They Begin To Recurve, They Are Usually Headed Northward Into Cooler Water And Less Favorable Atmospheric Conditions (Higher Shear).




within each quadrant. For quadrants extending over land and water, over-water values are used, which may make the extent of inland wind radii appear unrealistically large '
LA
KATRINA # 23
Sun 08/28/05 11E
(15Z)-Initial Posit.
26.00 N 88.10 W
150kt (175mph)
Movg 10kt (12mph)
FL
30 N
KATRINA2005
Cuba
20 N
85W
80W
75W

5/21/2008

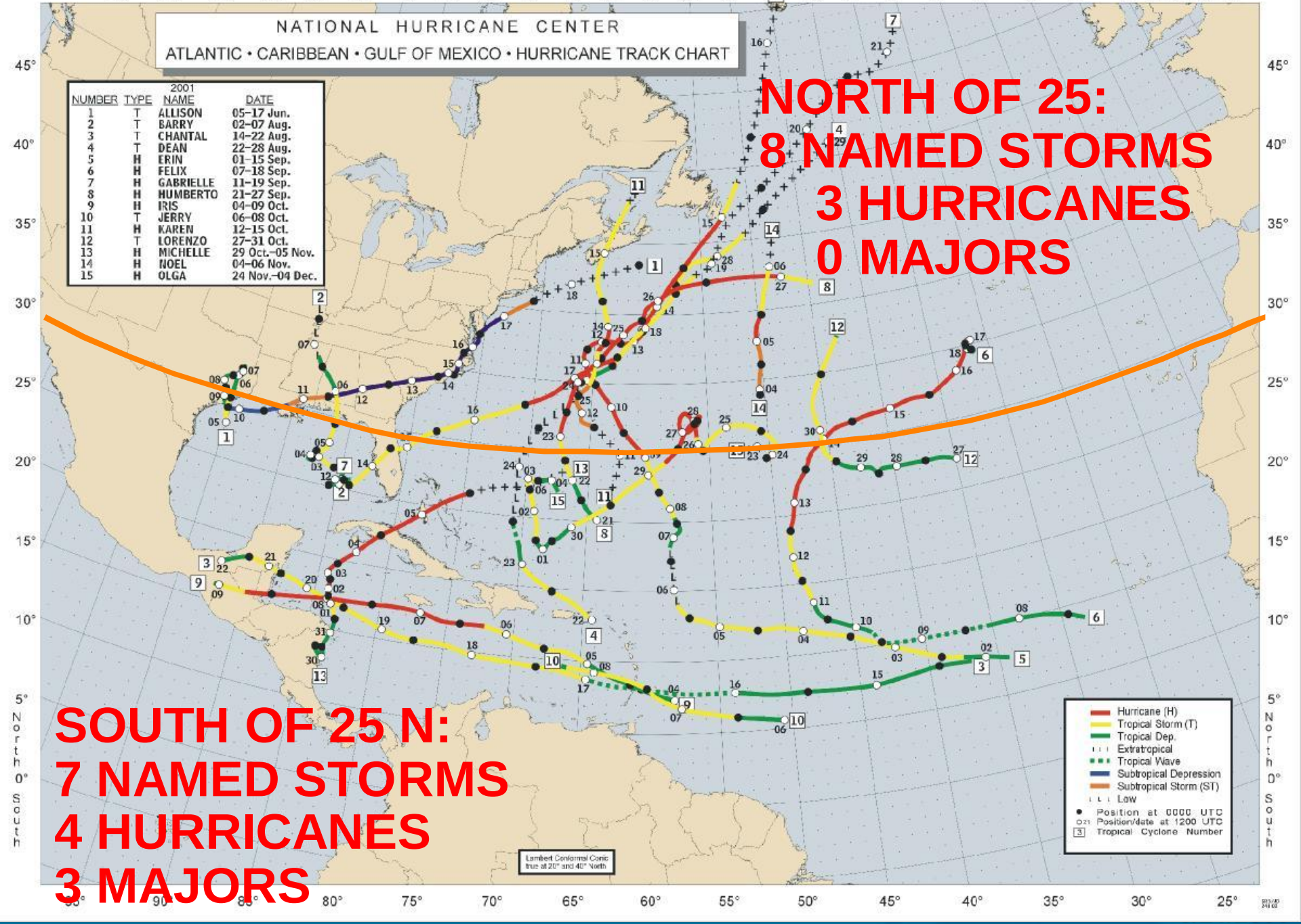

And, Just To Show That There's An Exception To Every "Rule"…
…Consider Charley… Which Couldn't Have Cared Less Which Way It Was Moving!!

5/21/2008

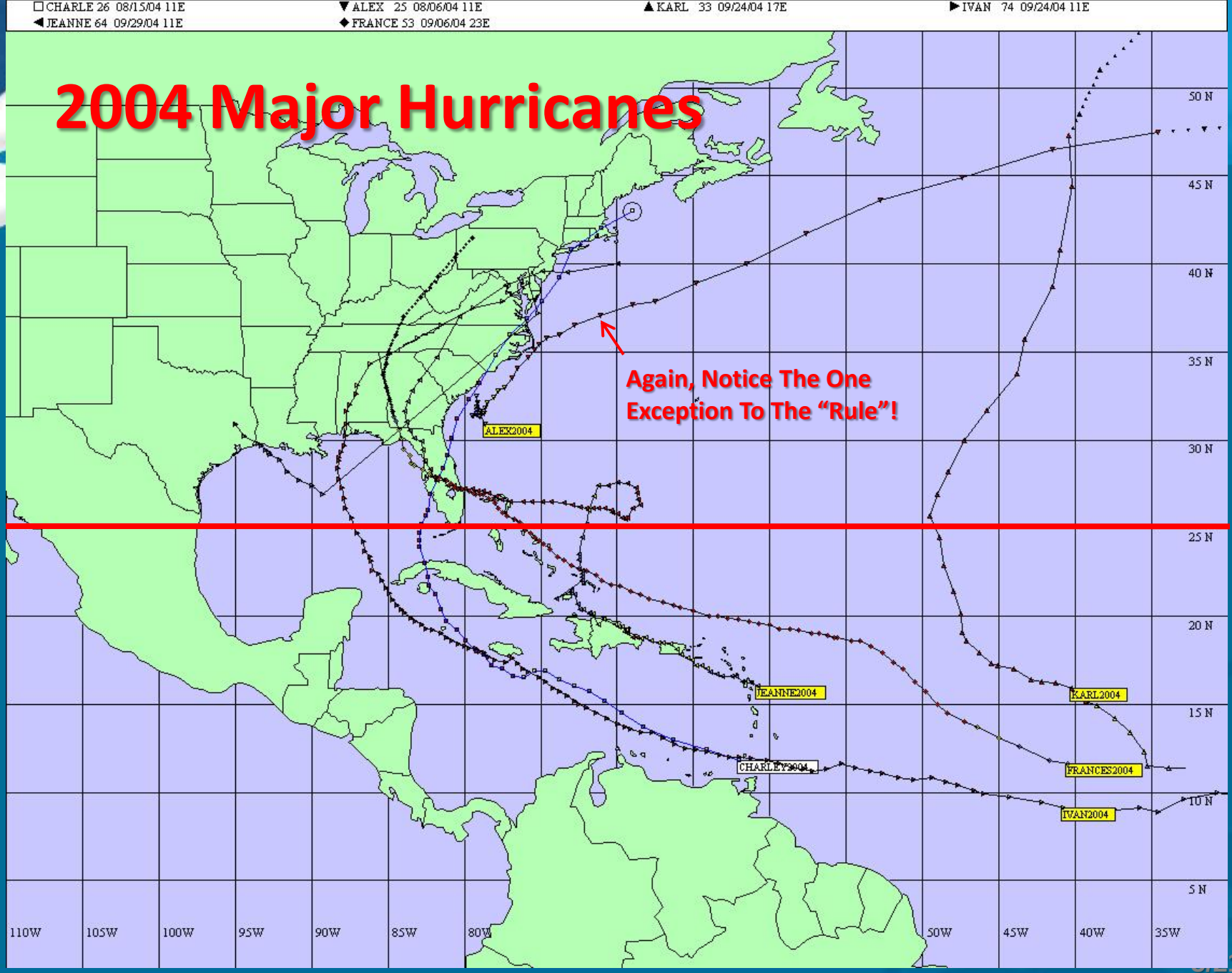
TROPICAL CYCLONE INTENSITY

FORECAST "Rule Of Thumb"…

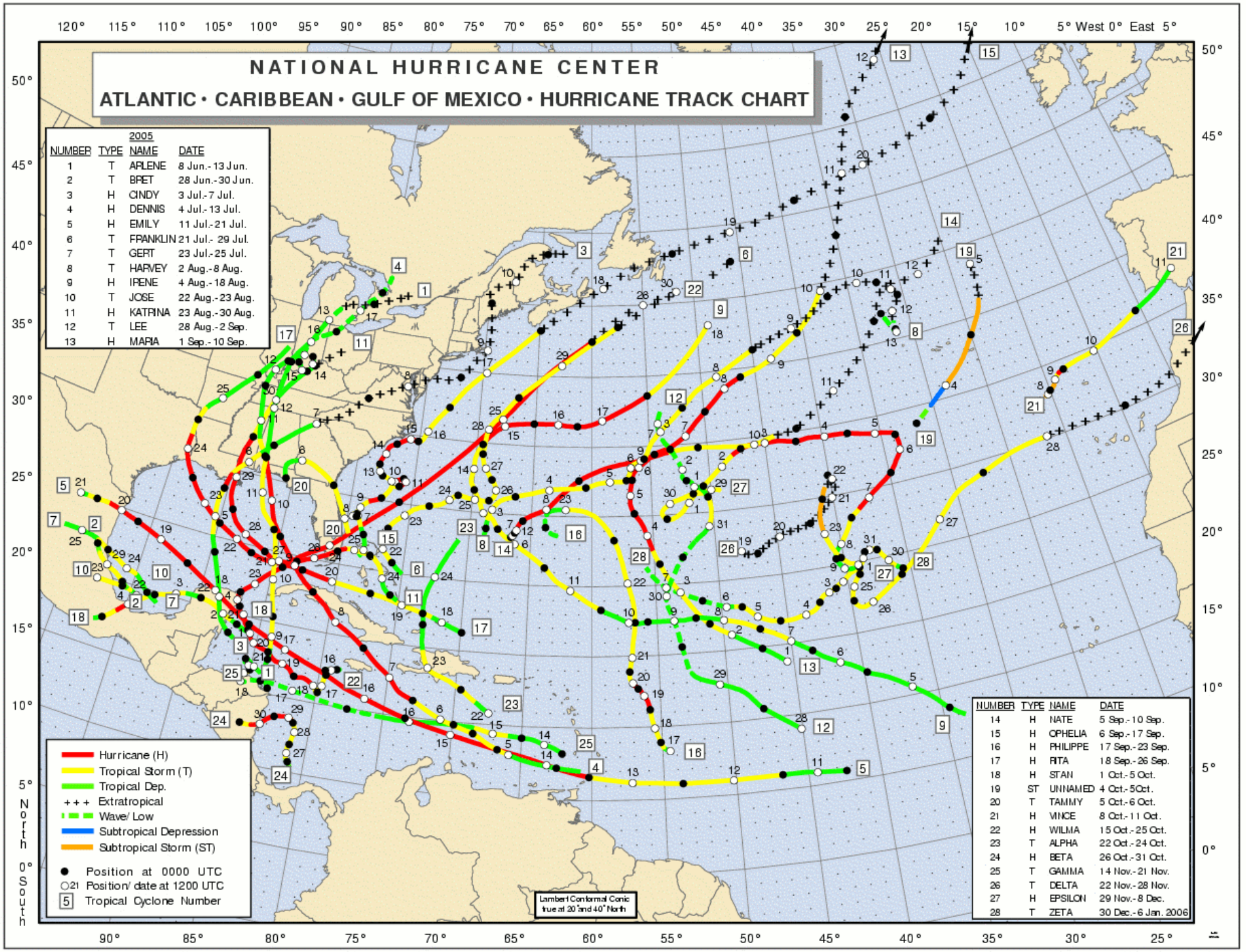
- Tropical Cyclones Forming North Of Latitude 25 Will Not Usually Attain Great Intensity. Exception: Gulf Of Mexico Storms (Due To Presence Of Higher Oceanic Heat Content).

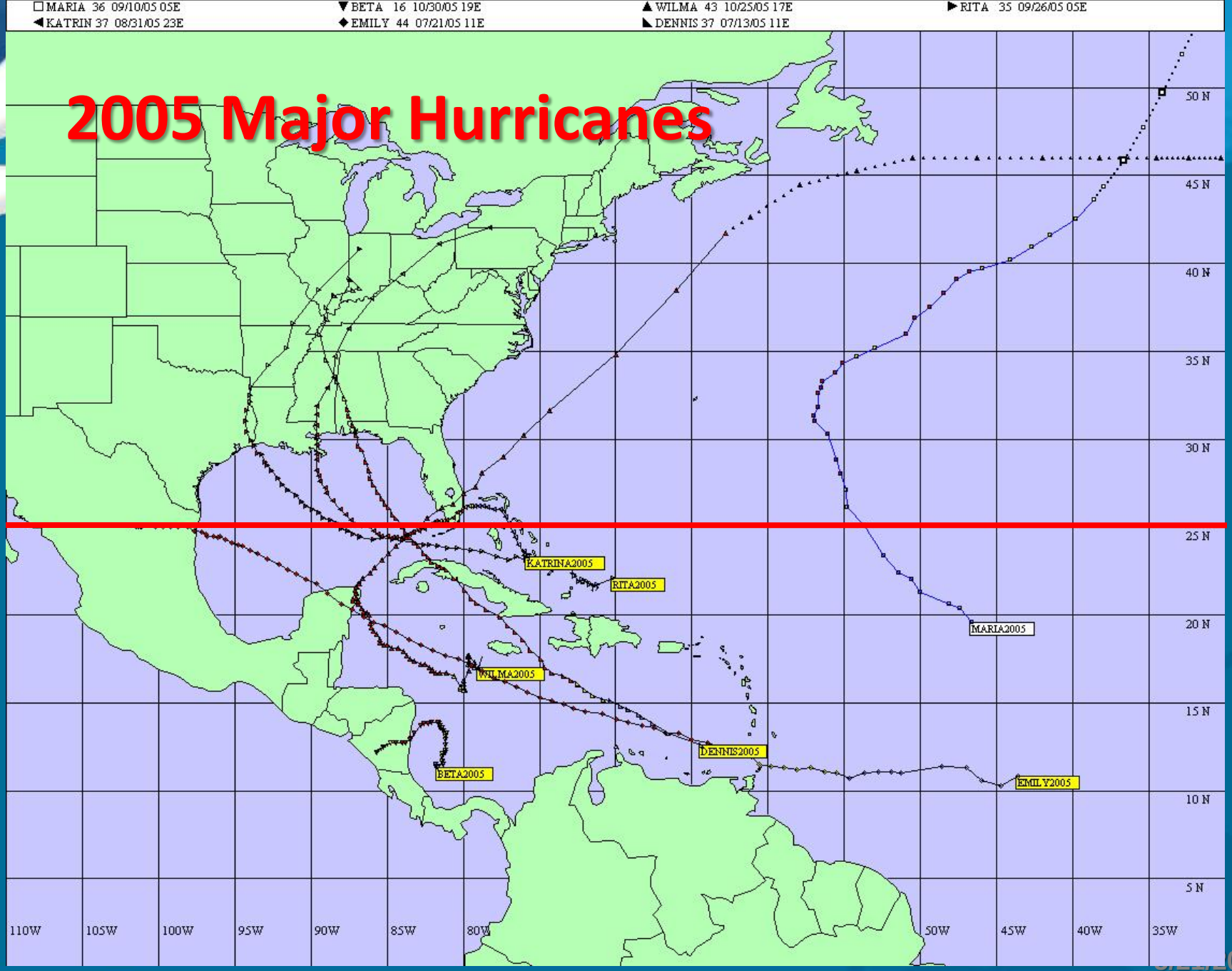

NATIONAL HURRICANE CENTER
ATLANTIC • CARIBBEAN • GULF OF MEXICO • HURRICANE TRACK CHART
2001
NUMBER TYPE NAME DATE
1 T ALLISON 05–17 Jun.
2 T BARRY 02–07 Aug.
3 T CHANTAL 14–22 Aug.
4 T DEAN 22–28 Aug.
5 H ERIN 01–15 Sep.
6 H FELIX 07–18 Sep.
7 H GABRIELLE 11–19 Sep.
8 H HUMBERTO 21–27 Sep.
9 H IRIS 04–09 Oct.
10 T JERRY 06–08 Oct.
11 H KAREN 12–15 Oct.
12 T LORENZO 27–31 Oct.
13 H MICHELLE 29 Oct.–05 Nov.
14 H NOEL 04–06 Nov.
15 H OLGA 24 Nov.–04 Dec.
NORTH OF 25:
8 NAMED STORMS
3 HURRICANES
0 MAJORS
SOUTH OF 25 N:
7 NAMED STORMS
4 HURRICANES
3 MAJORS
Hurricane (H)
Tropical Storm (T)
Tropical Dep.
Extratropical
Tropical Wave
Subtropical Depression
Subtropical Storm (ST)
Low
Position at 0000 UTC
Position/date at 1200 UTC
Tropical Cyclone Number
Lambert Conformal Conic
true at 20° and 40° North
45°
40°
35°
30°
25°
20°
15°
10°
5°
0°
5° North
0° South
90°
85°
80°
75°
70°
65°
60°
55°
50°
45°
40°
35°
30°
25°

2004 Major Hurricanes



Again, Notice The One Exception To The "Rule"!


NATIONAL HURRICANE CENTER
ATLANTIC • CARIBBEAN • GULF OF MEXICO • HURRICANE TRACK CHART
2005
NUMBER TYPE NAME DATE
1 T ARLENE 8 Jun.-13 Jun.
2 T BRET 28 Jun.-30 Jun.
3 H CINDY 3 Jul.-7 Jul.
4 H DENNIS 4 Jul.-13 Jul.
5 H EMILY 11 Jul.-21 Jul.
6 T FRANKLIN 21 Jul.- 29 Jul.
7 T GERT 23 Jul.-25 Jul.
8 T HARVEY 2 Aug.-8 Aug.
9 H IRENE 4 Aug.-18 Aug.
10 T JOSE 22 Aug.-23 Aug.
11 H KATRINA 23 Aug.-30 Aug.
12 T LEE 28 Aug.-2 Sep.
13 H MARIA 1 Sep.-10 Sep.
NUMBER TYPE NAME DATE
14 H NATE 5 Sep.-10 Sep.
15 H OPHELIA 6 Sep.-17 Sep.
16 H PHILIPPE 17 Sep.-23 Sep.
17 H RITA 18 Sep.-26 Sep.
18 H STAN 1 Oct.-5 Oct.
19 ST UNNAMED 4 Oct.-5Oct.
20 T TAMMY 5 Oct.-6 Oct.
21 H VINCE 8 Oct.-11 Oct.
22 H WILMA 15 Oct.-25 Oct.
23 T ALPHA 22 Oct.-24 Oct.
24 H BETA 26 Oct.-31 Oct.
25 T GAMMA 14 Nov.-21 Nov.
26 T DELTA 22 Nov.-28 Nov.
27 H EPSILON 29 Nov.-8 Dec.
28 T ZETA 30 Dec.-6 Jan. 2006
Hurricane (H)
Tropical Storm (T)
Tropical Dep.
Extratropical
Wave/ Low
Subtropical Depression
Subtropical Storm (ST)
Position at 0000 UTC
21 Position/ date at 1200 UTC
5 Tropical Cyclone Number
Lambert Conformal Conic
true at 20°and 40° North
120° 115° 110° 105° 100° 95° 90° 85° 80° 75° 70° 65° 60° 55° 50° 45° 40° 35° 30° 25° 20° 15° 10° 5° West 0° East 5°
50° 45° 40° 35° 30° 25° 20° 15° 10° 5° North 0° South
90° 85° 80° 75° 70° 65° 60° 55° 50° 45° 40° 35° 30° 25°

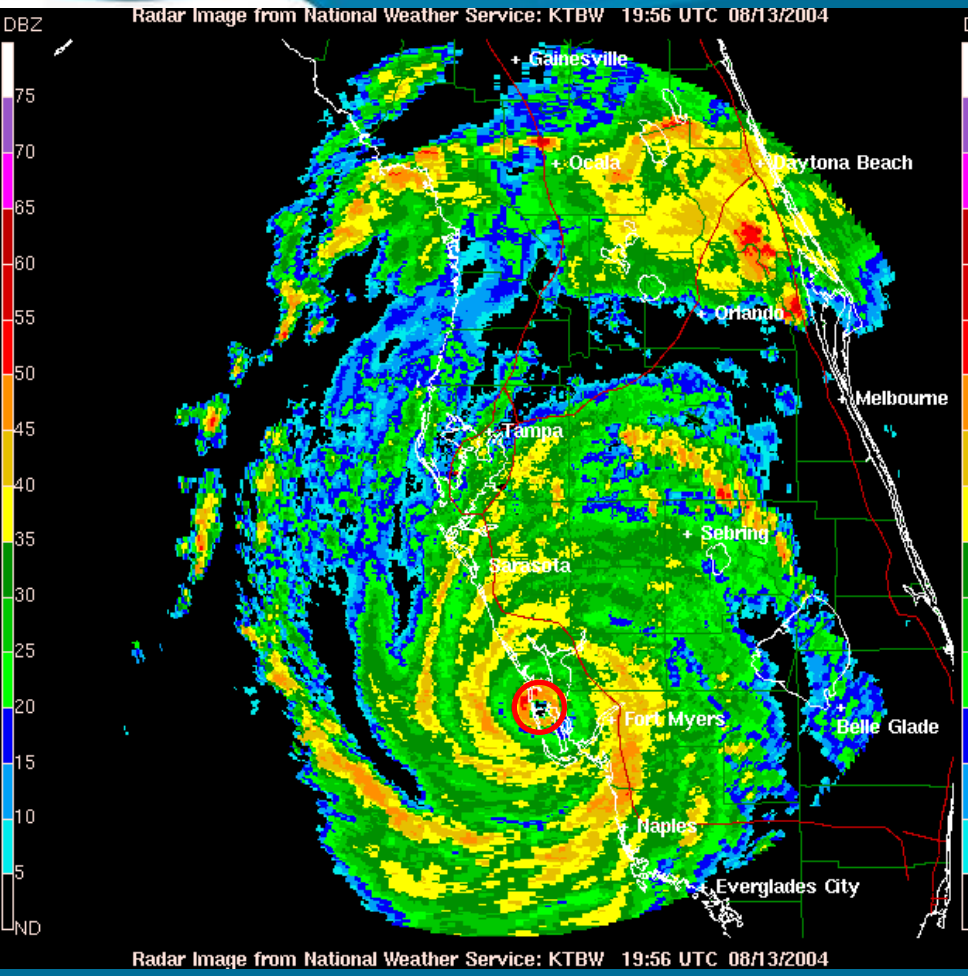

MARIA 36 09/10/05 05E
KATRIN 37 08/31/05 23E
BETA 16 10/30/05 19E
EMILY 44 07/21/05 11E
WILMA 43 10/25/05 17E
DENNIS 37 07/13/05 11E
RITA 35 09/26/05 05E
2005 Major Hurricanes
KATRINA2005
RITA2005
MARIA2005
WILMA2005
DENNIS2005
BETA2005
EMILY2005
50 N
45 N
40 N
35 N
30 N
25 N
20 N
15 N
10 N
5 N
110W
105W
100W
95W
90W
85W
80W
50W
45W
40W
35W

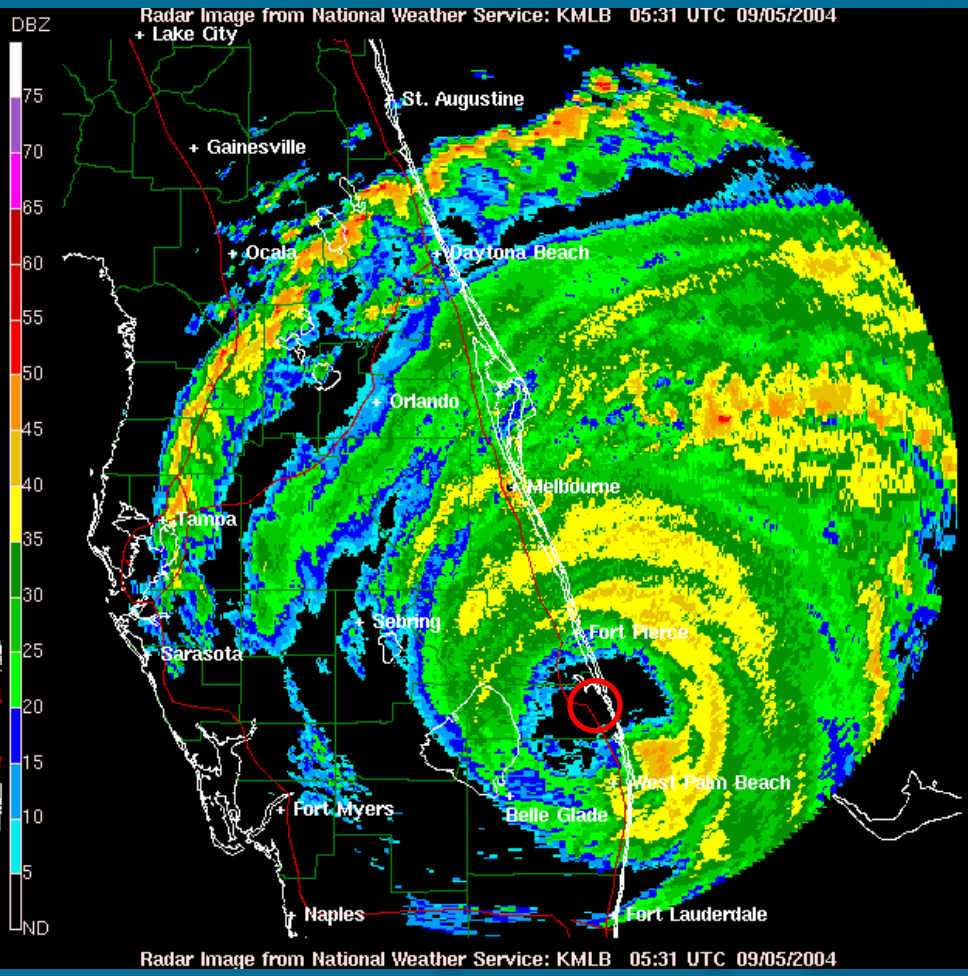
TROPICAL CYCLONE SIZE

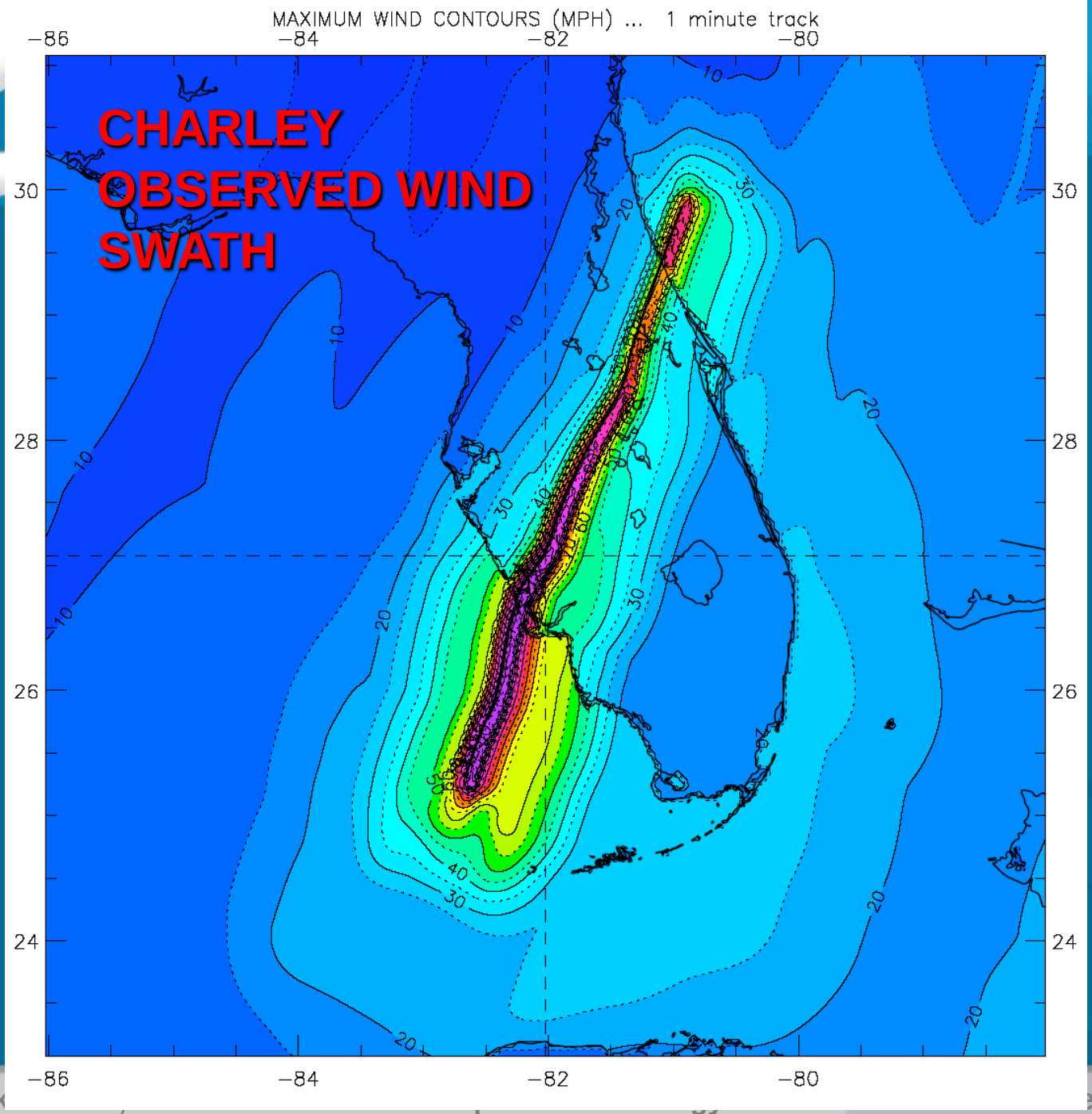
All Storms Are NOT Created Equal!

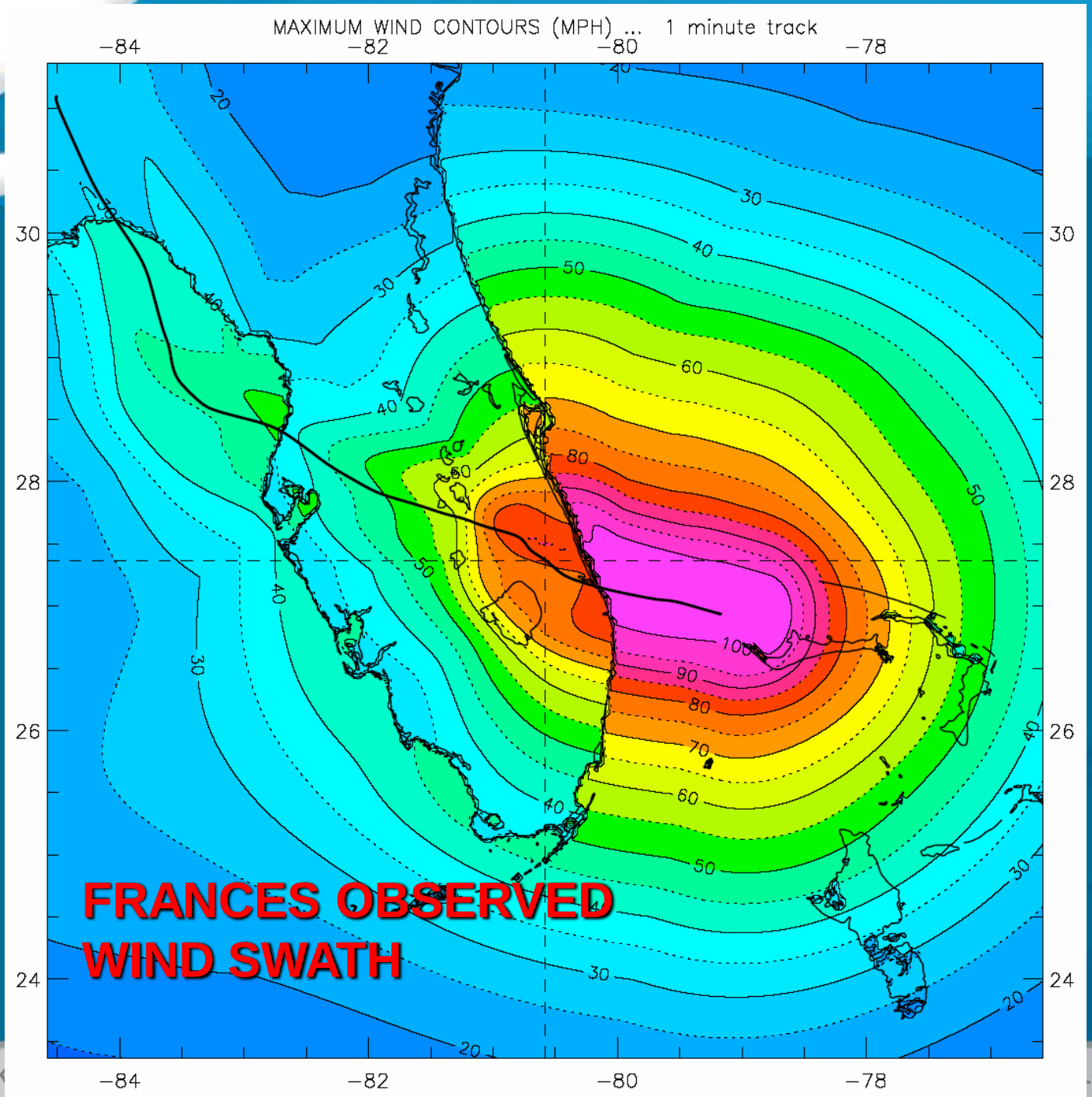
- **THOUGH OFTEN OVERLOOKED, THE EXTENT OF THE HURRICANE WINDFIELD HAS A DIRECT EFFECT ON THE AREA TO BE IMPACTED… AND ALSO ON THE PLACEMENT OF WATCHES AND WARNINGS!**

Charley/Frances Core Sizes






MAXIMUM WIND CONTOURS (MPH) ... 1 minute track
CHARLEY
OBSERVED WIND
SWATH
−86
−84
−82
−80
30
28
26
24


MAXIMUM WIND CONTOURS (MPH) ... 1 minute track
−84
−82
−80
−78
30
28
26
24
FRANCES OBSERVED
WIND SWATH

TROPICAL CYCLONE SIZE

All Storms Are NOT Created Equal!

- **There Are Really No Hard And Fast Rules Regarding The Size Of Any Individual Tropical Cyclone**

- **While There Are Some Very General "Rules Of Thumb" Regarding Hurricane Size ... Almost All Have Very Some Very Notable Exceptions!**

TROPICAL CYCLONE SIZE

Forecast "Rules of Thumb"

- The Hurricane "Envelope" Tends To Expand In The Later Mature Stage.
- Because Of This...In General... Cape Verde Type Hurricanes Seem To Have The Best Chance Of Attaining Both Great Size ***And*** Strength.
- This Is Due To The Opportunity To Go Through Most Of Their Life Cycle Over Very Warm Water Before Striking Land.
- It Is Also Common, though, To See Cape Verde Storms Remain Weak, Or Even Die Out Completely Over Warm Water Due To Hostile Atmospheric Conditions.

TROPICAL CYCLONE SIZE

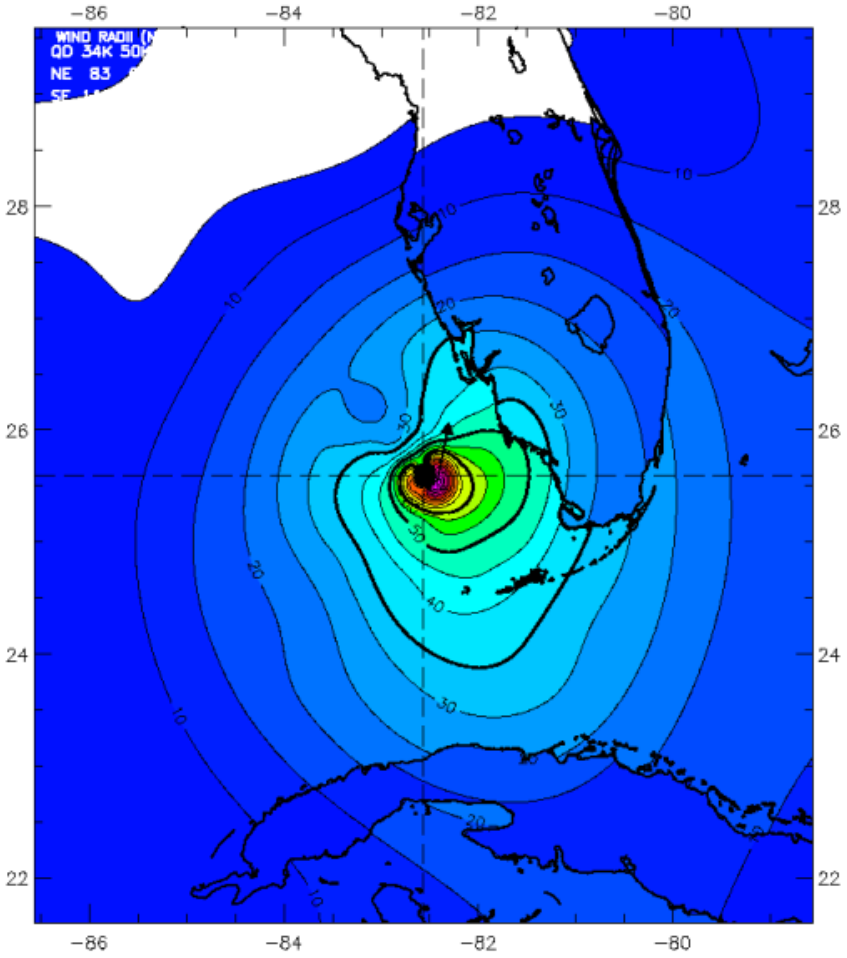
ALL STORMS ARE *NOT* CREATED EQUAL!

- Windfields Are Not Usually Uniform Around A Storm's Circulation.
- Wind Strength And Areal Extent Are Usually Greater On The Right Side Of The Storm With Respect To Direction Of Motion.
- Proximity To Land Can Enhance This Non-Uniformity In The Windfield… Common In "Paralleling" Storms

Hurricane Charley 1630 UTC 13 Aug 2004

Max 1–min sustained surface winds (kt) for marine exposure

Analysis based on MOORED_BUOY from 1220 – 1220 z; GPSSONDE_SFC from 1219 – 1701 z;
SHIP from 1220 – 1220 z; TOWER_LD_TO from 0000 – 0000 z;
AFRES_FLT adj. to surface from mean height 3168 m from 1219 – 1219 z;
GPSSONDE_WL150 from 1219 – 1219 z; GPSSONDE_MBL from 1219 – 1701 z;
DRIFTING_BUOY from 1300 – 1300 z; GOES from 1302 – 1302 z; CMAN from 1230 – 1230 z;
1630 z position interpolated from 1522 Vortex; mslp = 964.0 mb



Observed Max. Surface Wind: 118 kts, 8 nm SE of center based on 1658 z AFRES_FLT sfc measurement
Analyzed Max. Wind: 114 kts, 9 nm SE of center
Experimental research product of:

NOAA / AOML / Hurricane Research Division

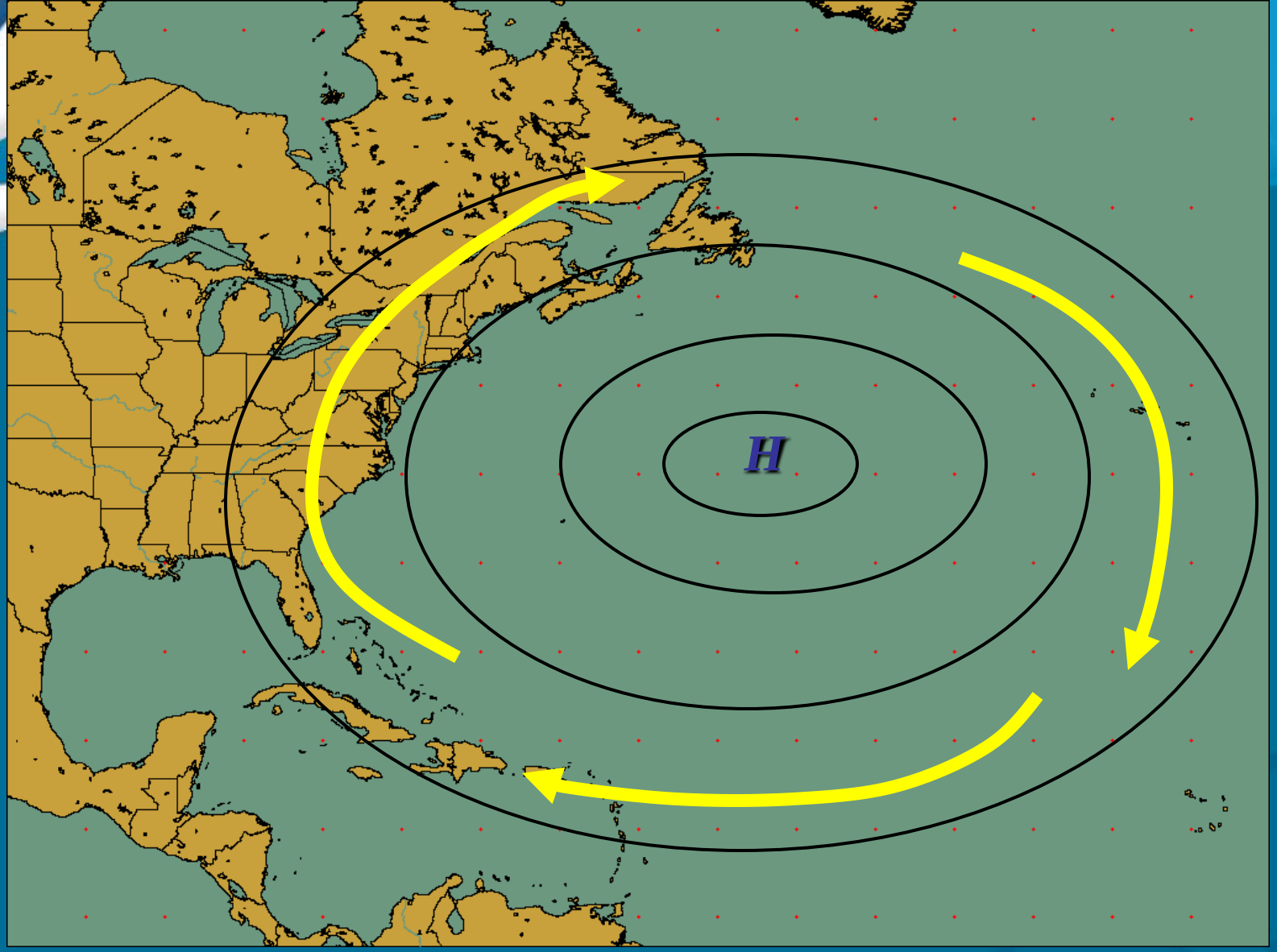
5/21/2008

TROPICAL CYCLONE MOTION

- In General, Tropical Cyclones Move According To The Direction And Strength Of The Air Currents They Are Embedded In.

- Where Those Currents Are Strongest And Most Persistent, Motion Is Relatively Predictable. Example: Latitudes <20 Degrees Or >40 Degrees.

- Where Those Currents Are Weak Or Changing, Motion Is Erratic, And Forecasts Show Less Reliability.



THE SUMMERTIME ATLANTIC (BERMUDA) HIGH PRESSURE SYSTEM IS A CRITICAL FACTOR IN DETERMINING TROPICAL CYCLONE MOTION!

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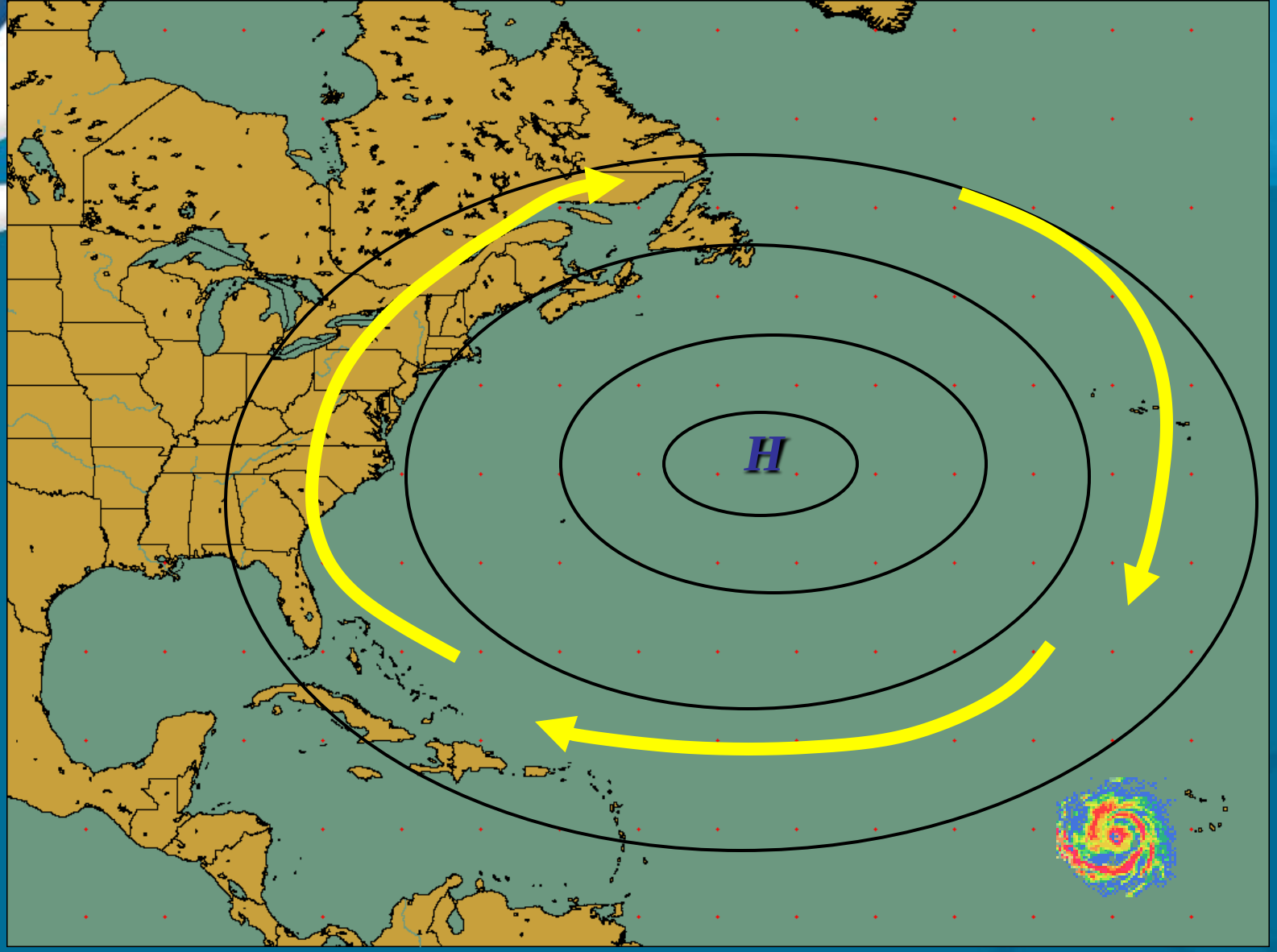
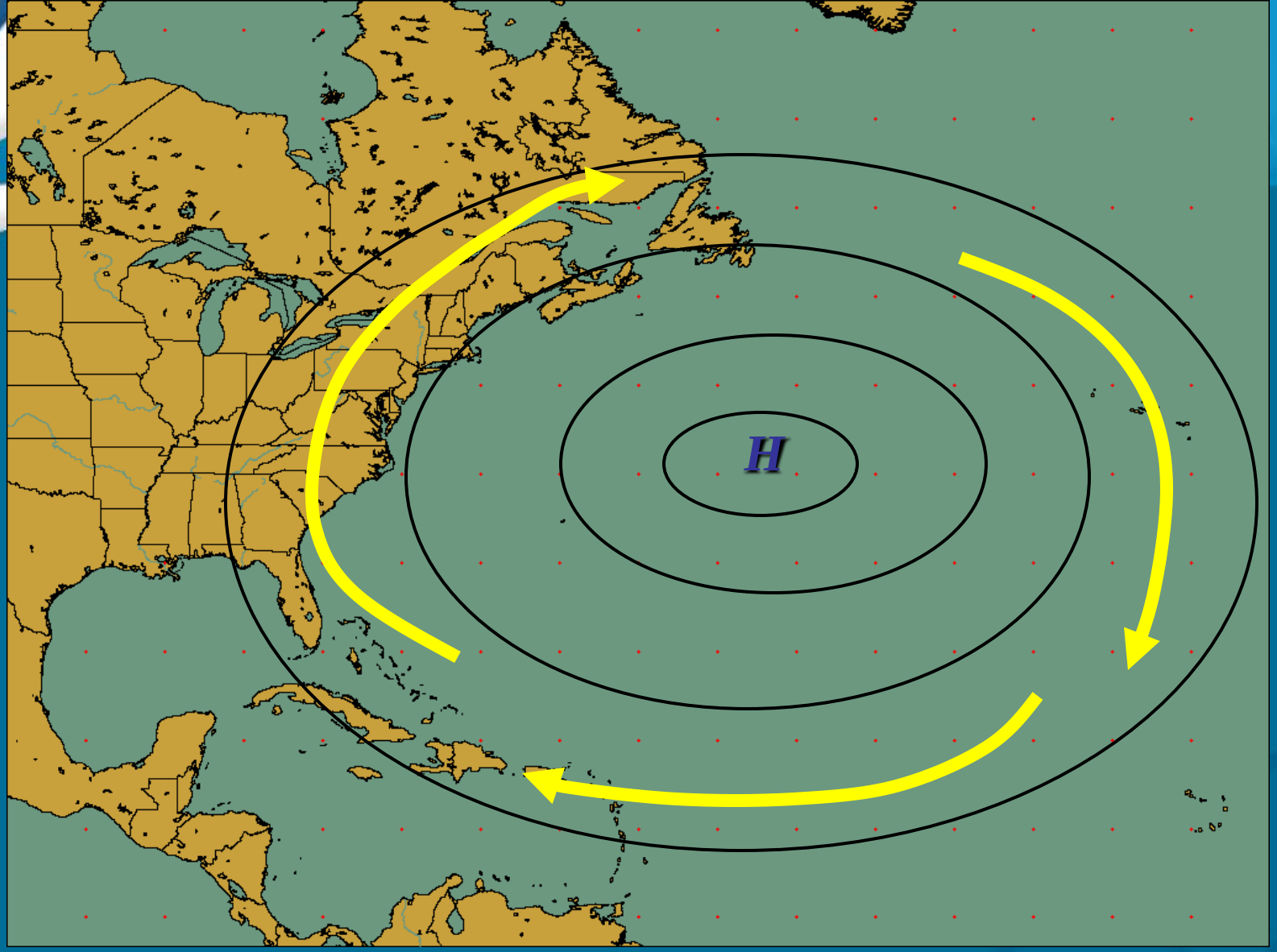


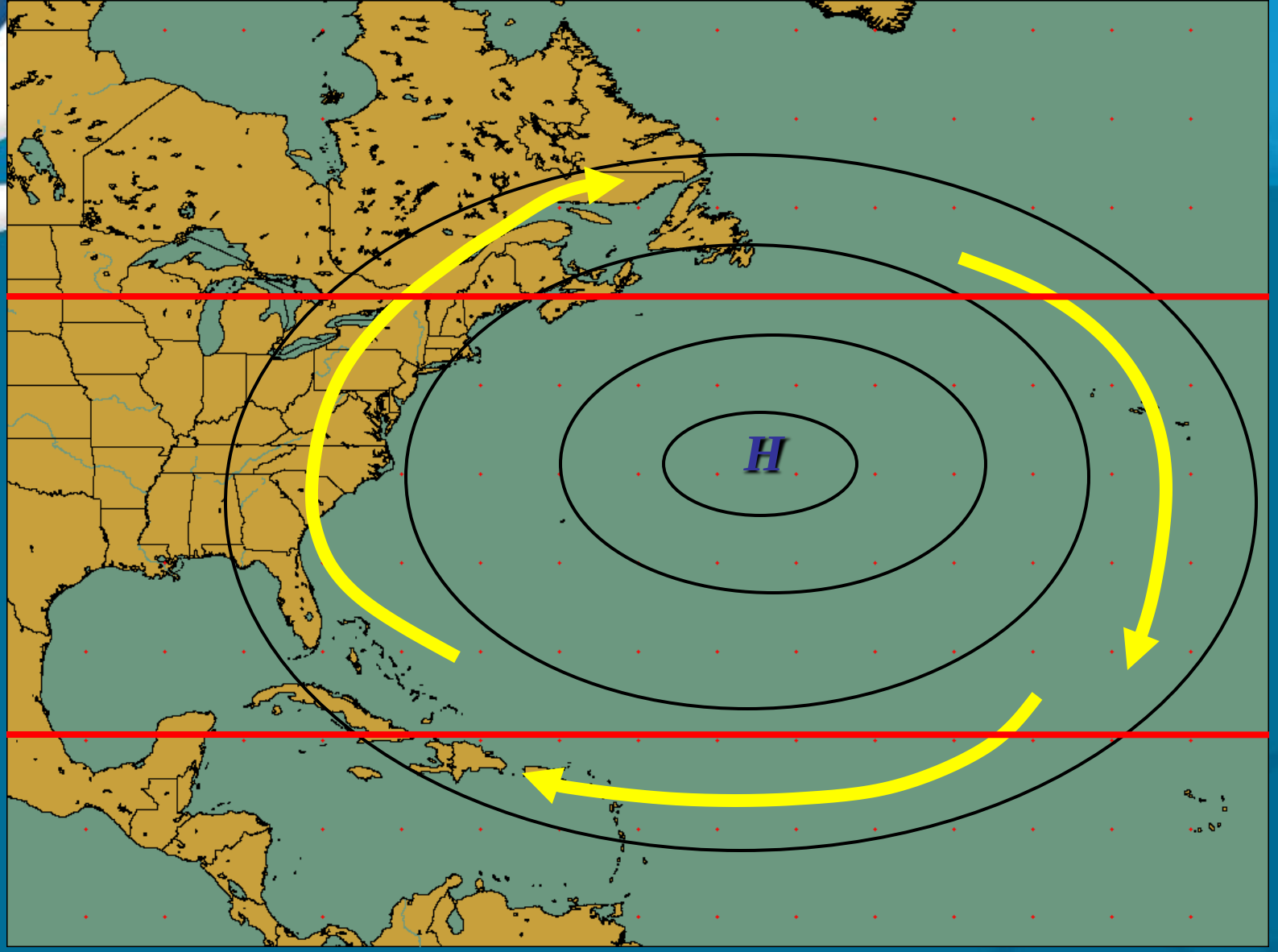
Tropical Cyclones Are "Steered" Westward Across The Tropics Along The Underside Of This Atlantic High, Before Eventually Recurving Around The Western Edge.

5/21/2008



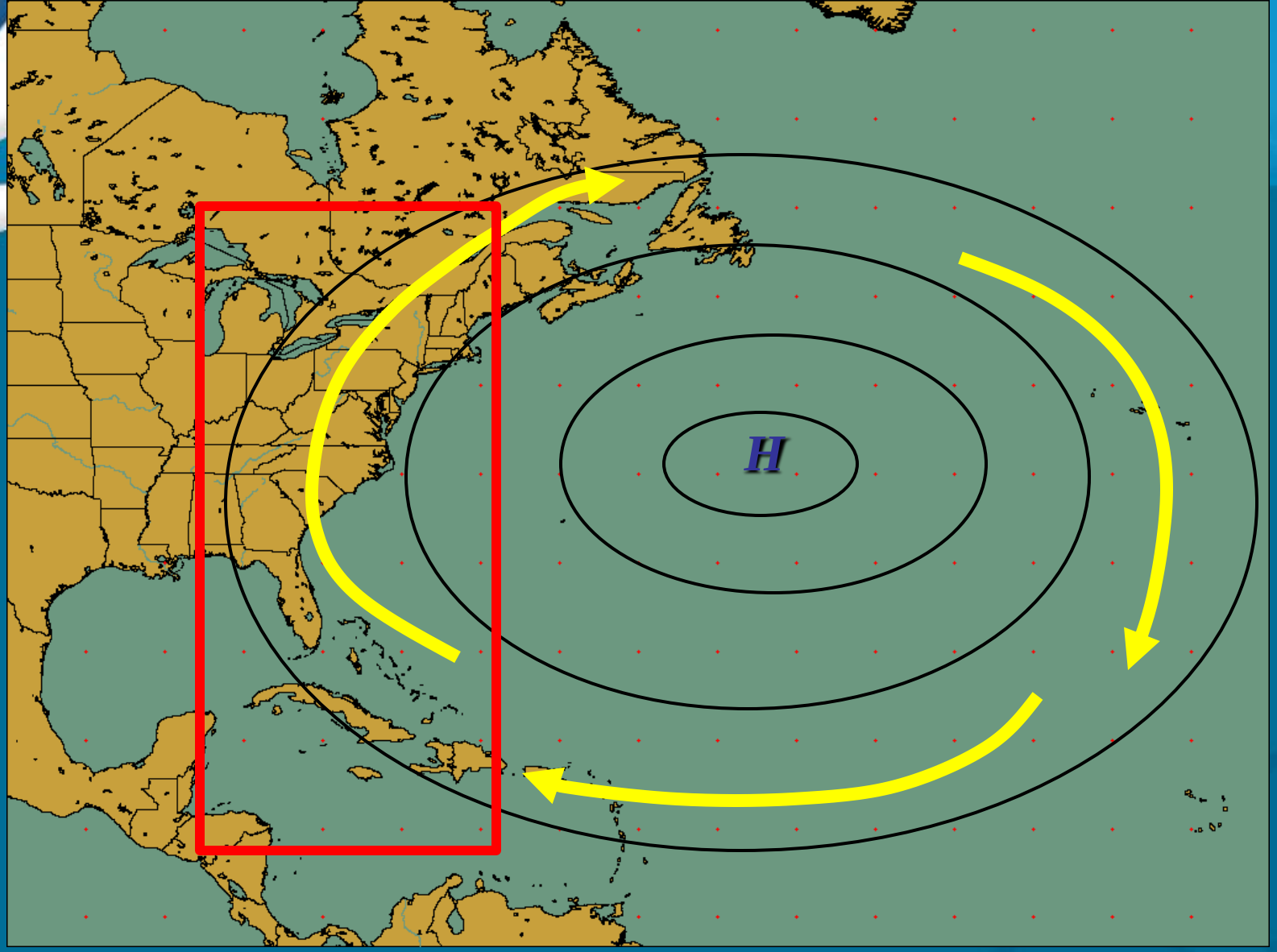
Winds Around High Pressure Are Weaker Near The Center And Stronger Around The Periphery

5/21/2008



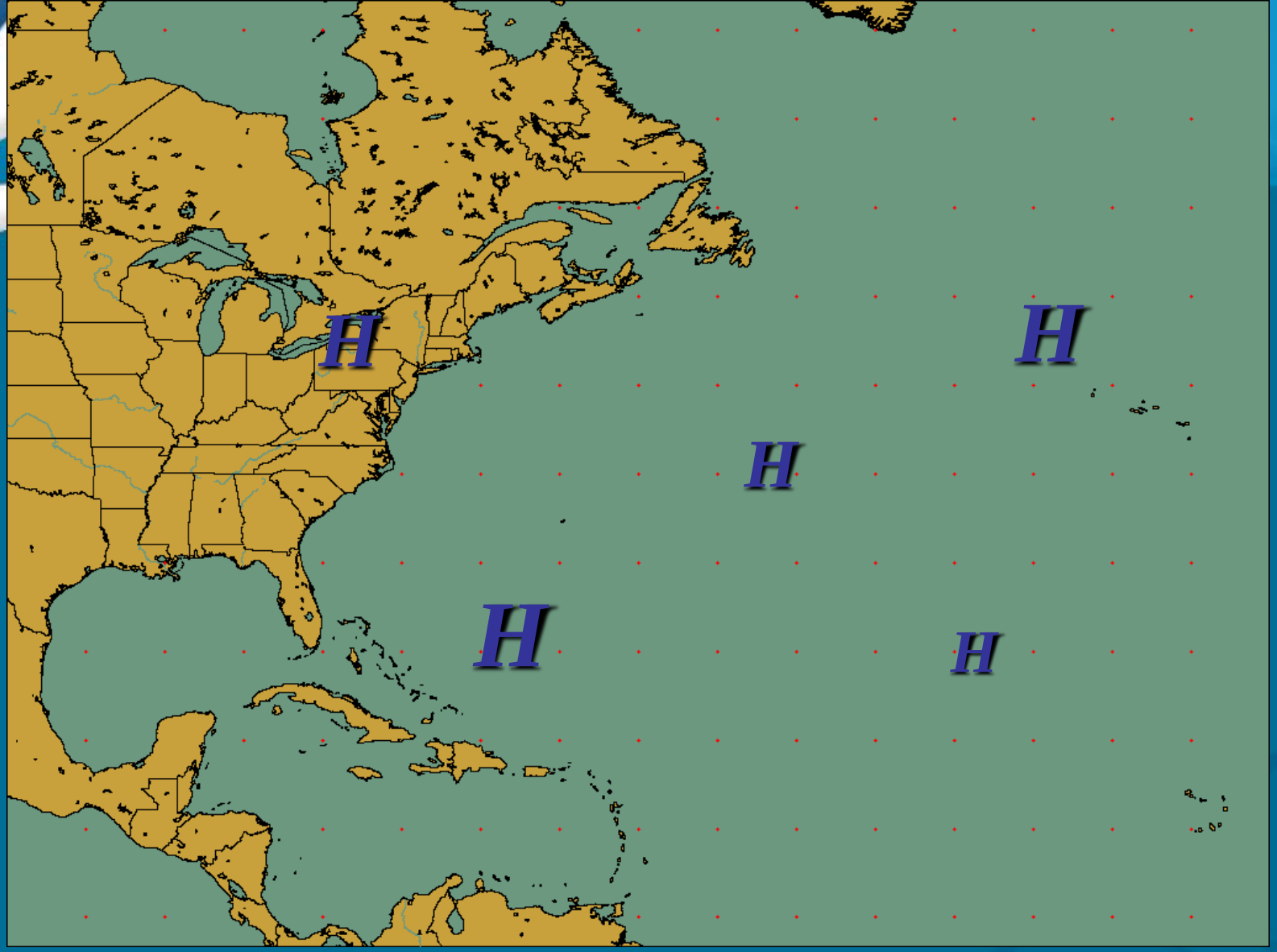
This Is Why Steering Currents Are Usually More Well Defined South of 20 Degrees and North of 40 Degrees

5/21/2008



So… Why Is There Often So Much Uncertainty In The Forecast On The *Western* Edge… When Storms Are Approaching Florida???

5/21/2008



The Problem Is That The Atlantic High Is *Not Constant*… Either In Strength, Size Or Position… And This Leads To Great Differences In The Motion Of Individual Tropical Cyclones… And The Point Of Their Recurvature!!!

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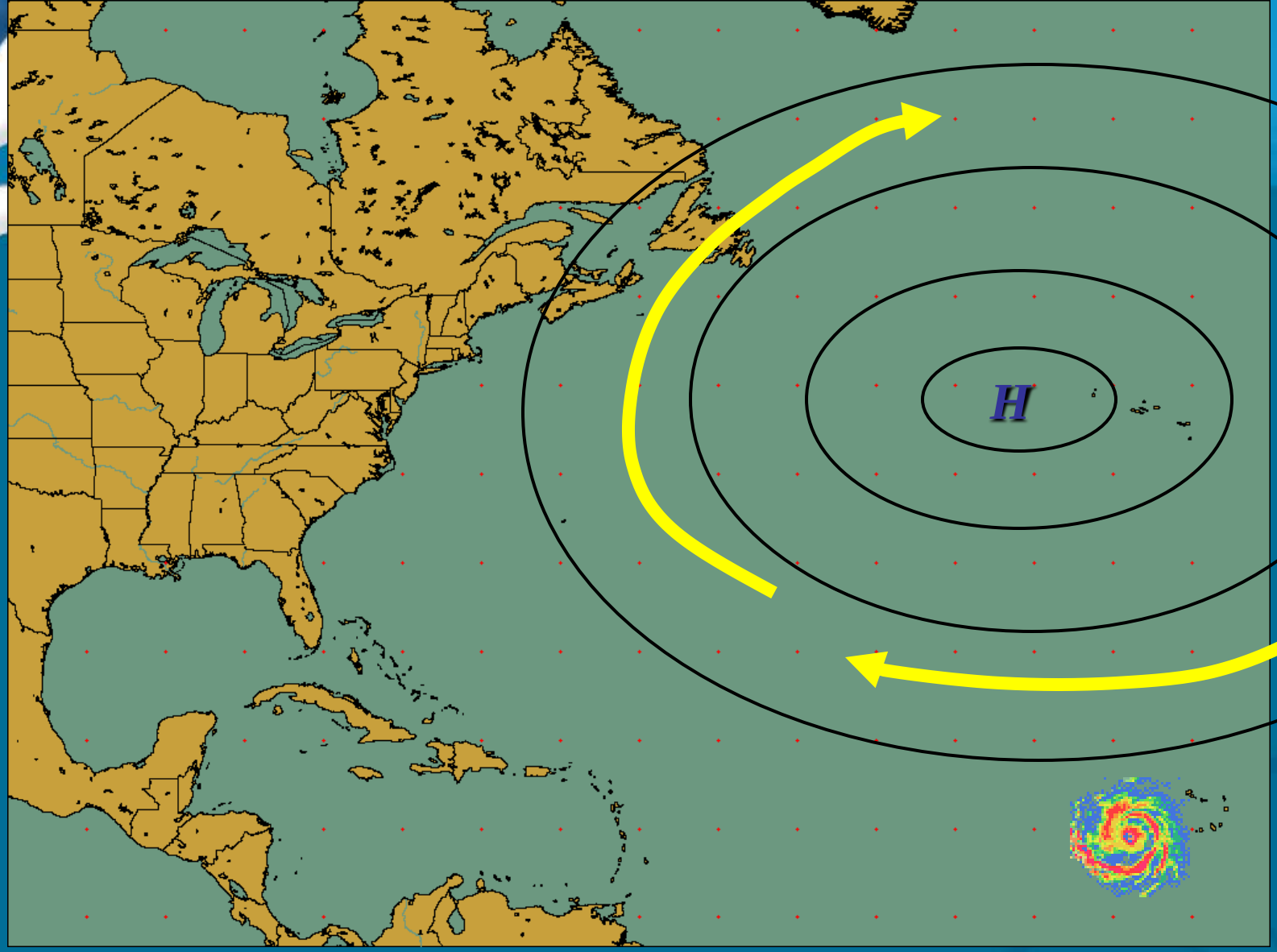
TROPICAL CYCLONE MOTION

- This indicates that for the classic MDR storms, the best predictability will probably be in the early and late stages of its life cycle.

- Unfortunately, this implies that the storm will be less predictable in the middle stages... when it is at max intensity and probably posing the greatest threat to the Florida.

Climatological Tracks of Atlantic Basin Tropical Cyclones

When…and If… A Tropical Cyclone Recurves Is Largely A Function Of The Position And Strength Of The Bermuda High At Any Given Time.



When The Mean High Position Is Far To The East… Storms Recurve Well Out In The Atlantic (i.e., 2006).

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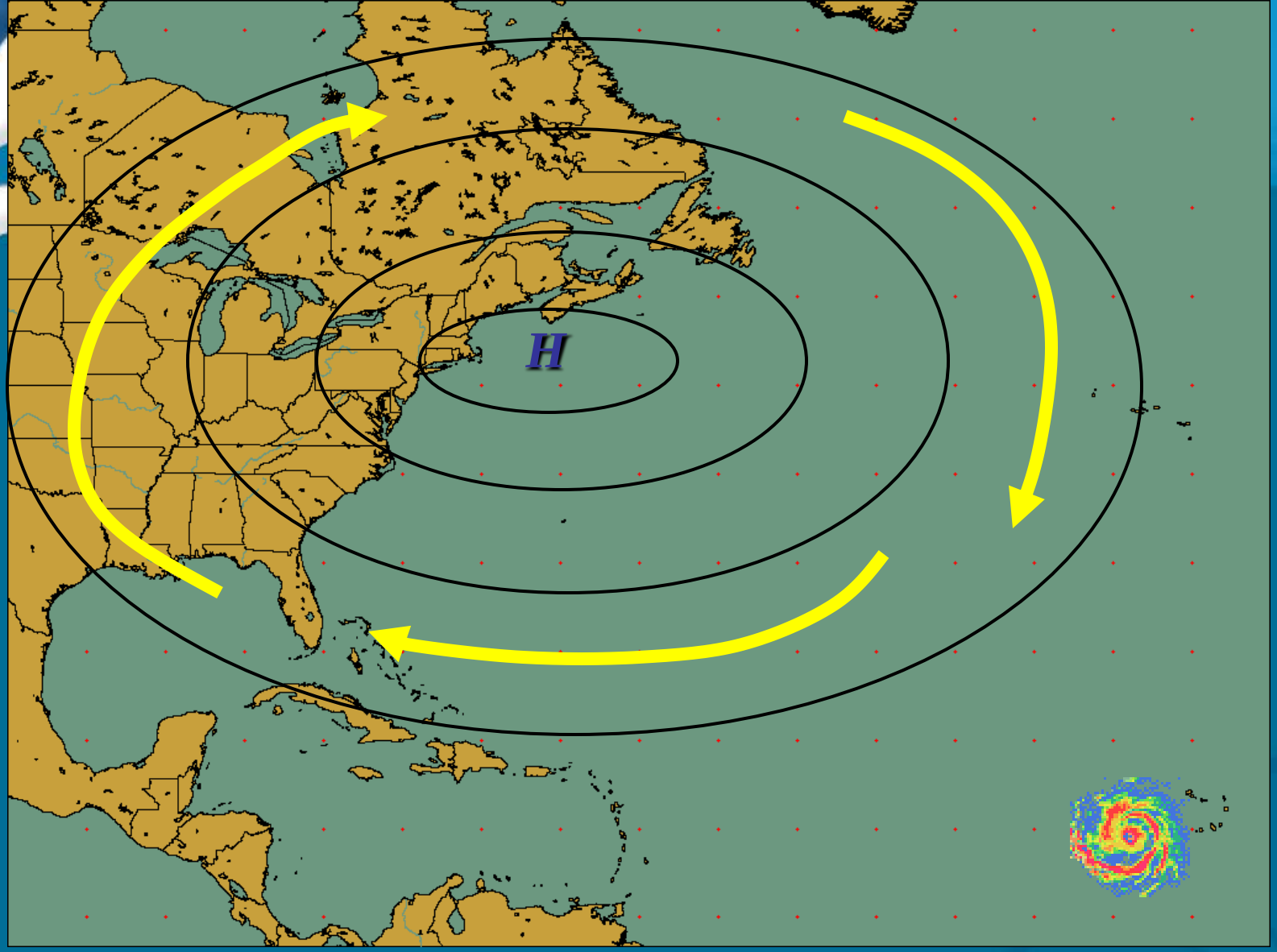

But When The Mean High Position Is Farther West… Storms Recurve Farther West As Well (i.e., 2004, 2005).

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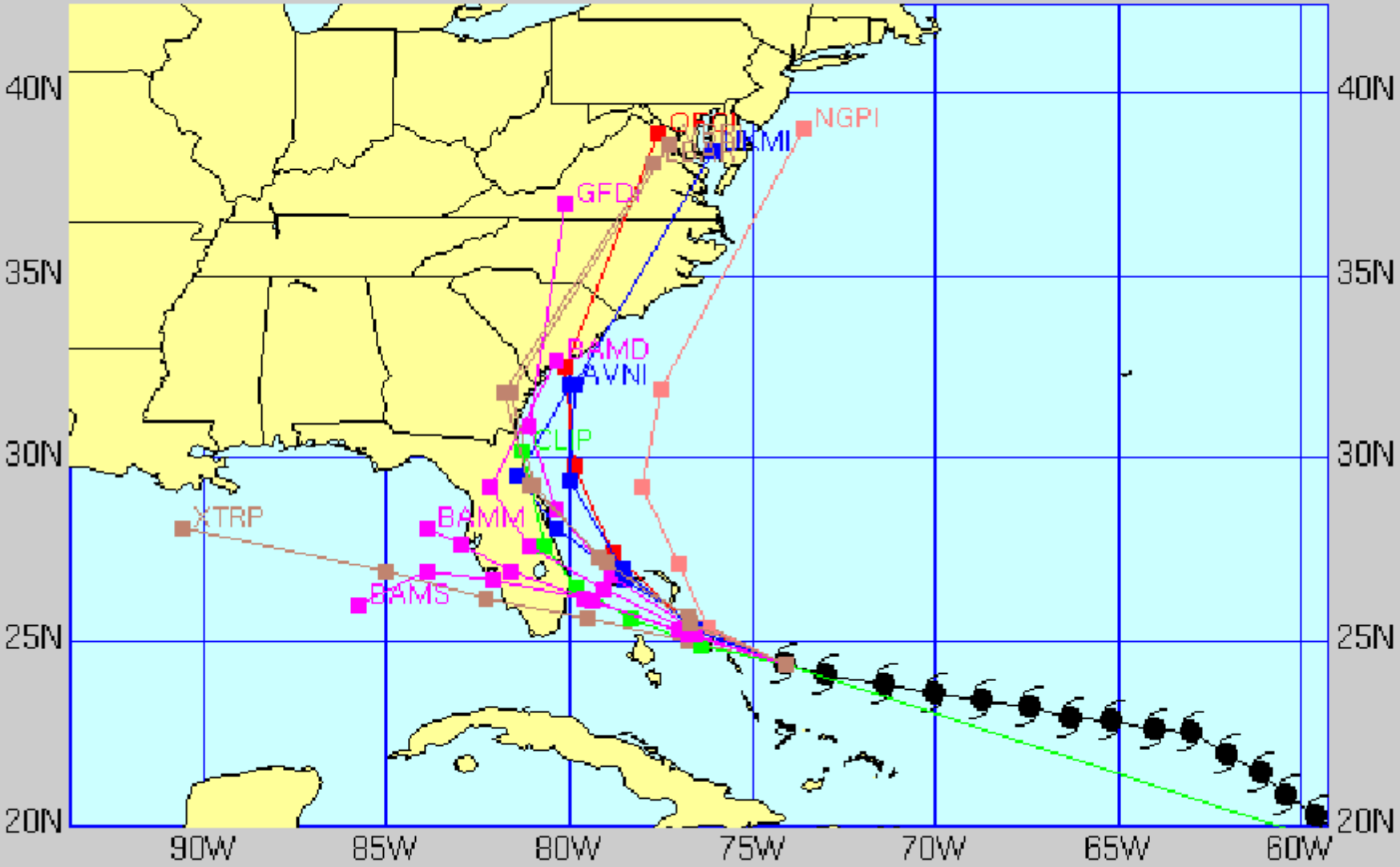
TROPICAL CYCLONE MOTION

- Sometimes, The Atlantic High Is Weak, And There May Be No Well-established Steering Current… Or There May Be Several Fighting For Control.

- This Often Results In Conflicting Guidance On The Forecast Track... A Particular Problem If The System Threatens Land...


40N
35N
30N
25N
20N
90W
85W
80W
75W
70W
65W
60W
NGPI
GFDL
BAMD
AVNI
CLIP
XTRP
BAMM
BAMS

SUMMARY

While There Are Some General "Rules of Thumb" Regarding Hurricane Size, Motion, and Intensity…

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SUMMARY

- Each Storm Is An Individual And Must Be Treated As Such In The Forecast… Warning… and Preparation Process!

- Each Storm Will React According To The Environment Around It At Any Given Moment… And That Is Constantly Changing.

- A Key To Accurate Prediction Lies In Correctly Assessing That Environment (Data!) And Properly Interpreting The Clues That It Provides.

SOME MAJOR QUESTIONS TO BE ANSWERED…

- Is There Any Inherent Predictability In The Intraseasonal Position, Size And Strength Of The Bermuda/Atlantic High?

- What More Can We Learn About Eyewall Replacement Cycles And Their Predictability?

  This May Provide Better Estimates Of Intensity At Landfall.

The End!

This Presentation Will Be Available At:

www.weather.gov/jax