Towards a National Agenda for Hurricane Science and Engineering: Academic Research Perspectives

18 April, 2006

National Science Board Workshop

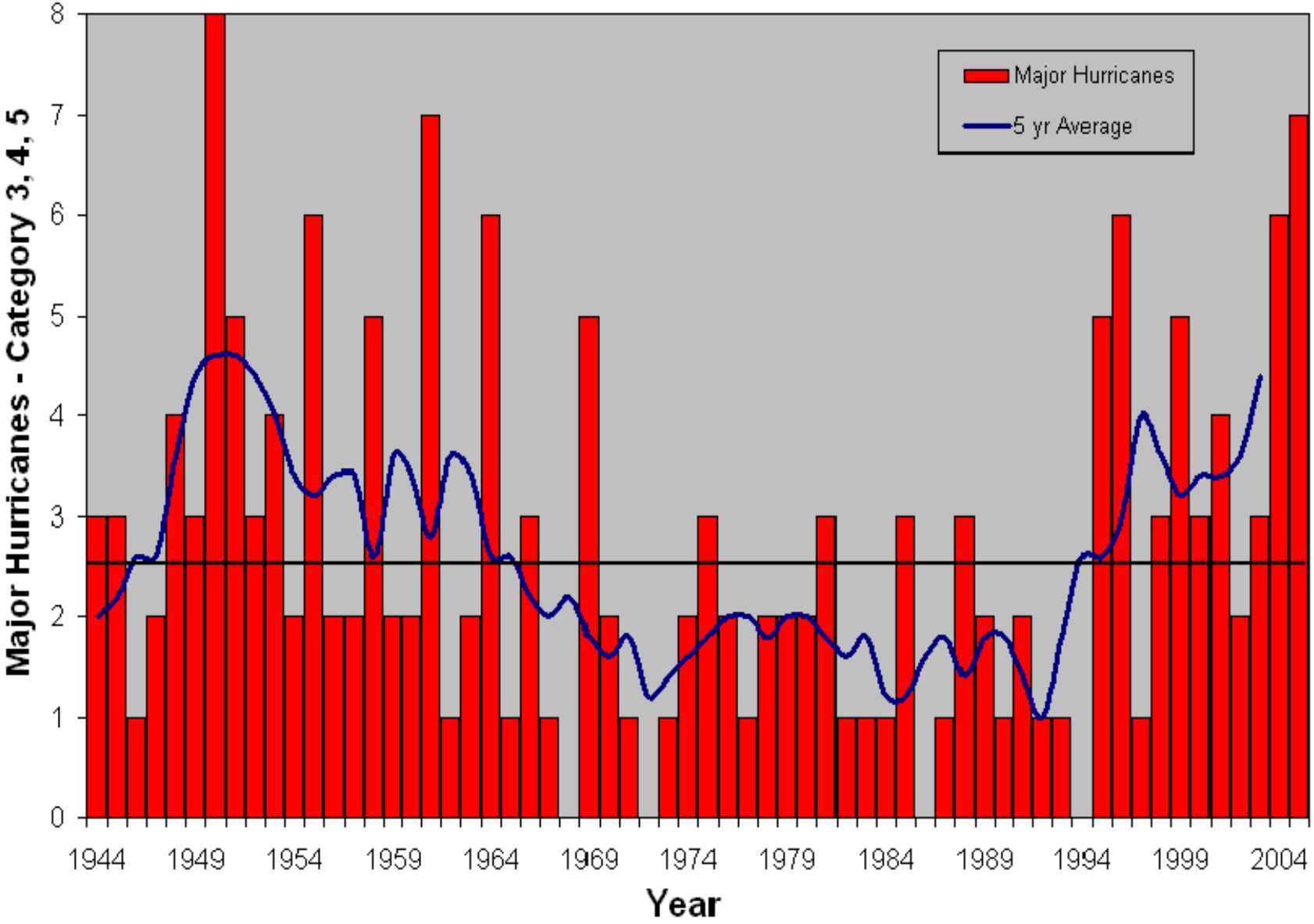
Chris Landsea
National Hurricane Center, Miami

2005


Dennis
10 July
Rita
23 September
Katrina
28 August
Wilma
21 October
Emily
17 July
NASA
CIMSS
NOAA

Atlantic Major Hurricanes

1944 to 2005

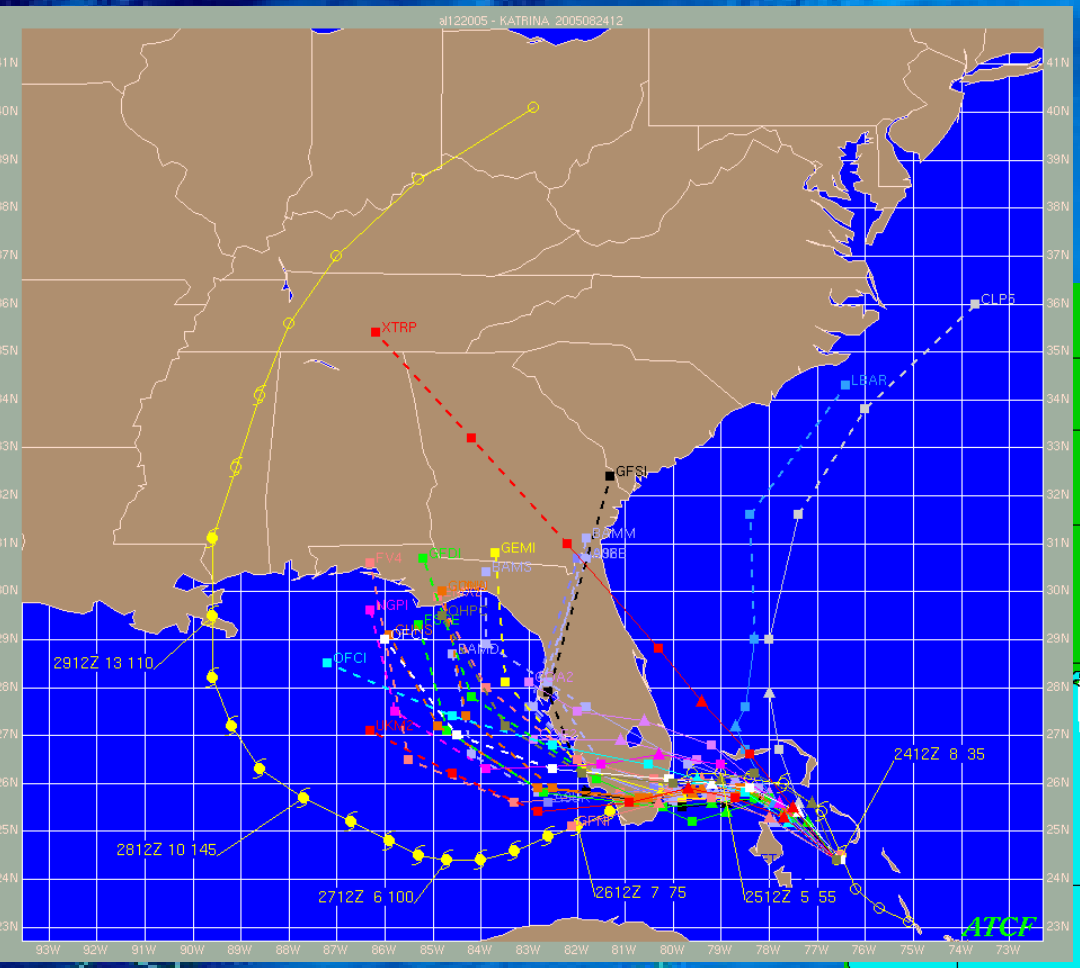


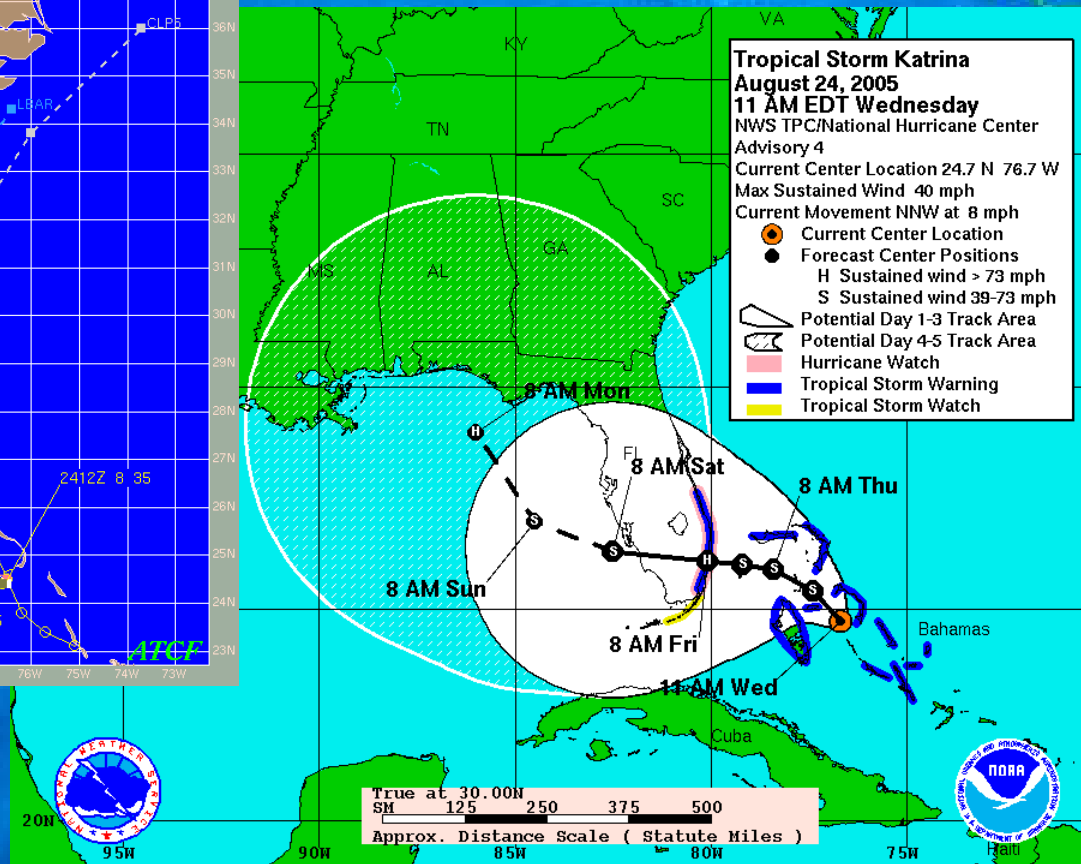
Katrina –

U.S.' Largest Loss of Life in a Hurricane since 1928: 1,300 lives

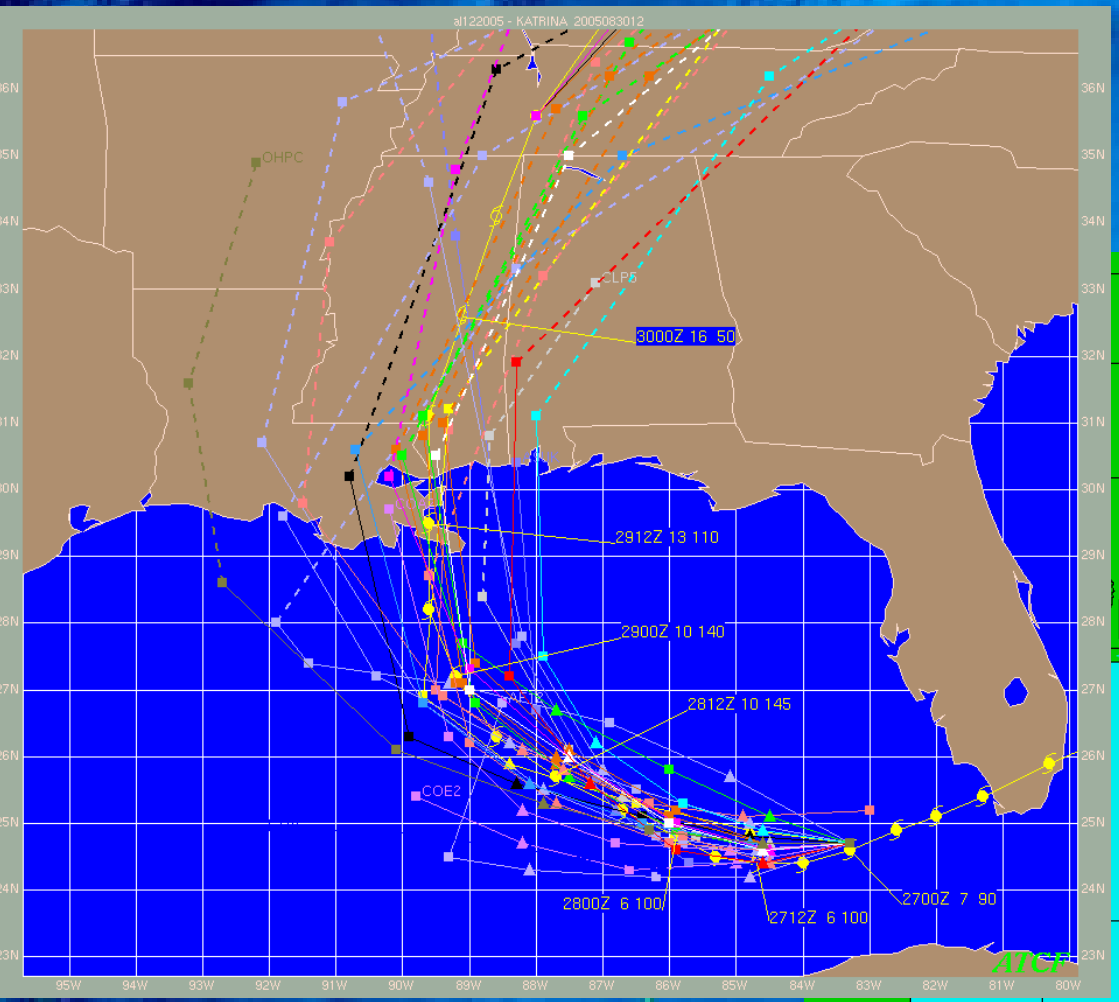
U.S.' Costliest One-Day Natural Disaster: $75 BILLION

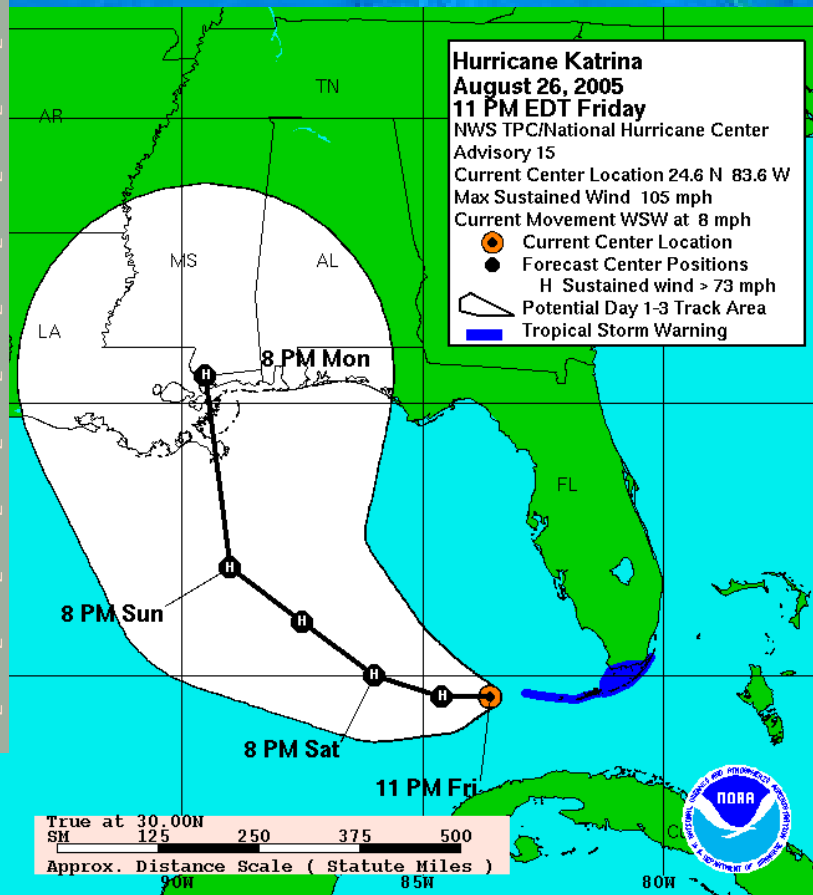
Katrina Track Forecasts
1200 UTC 24 August



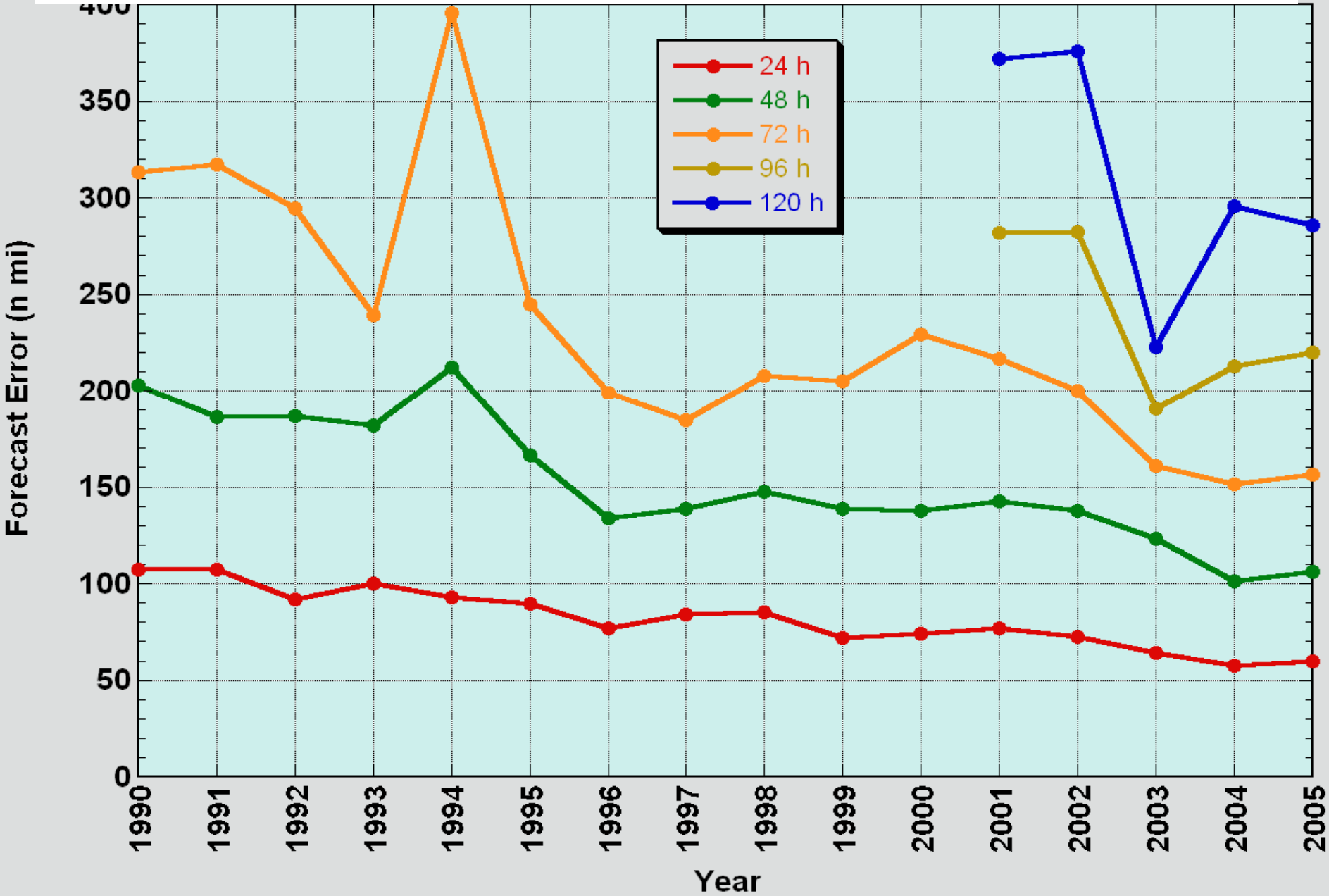


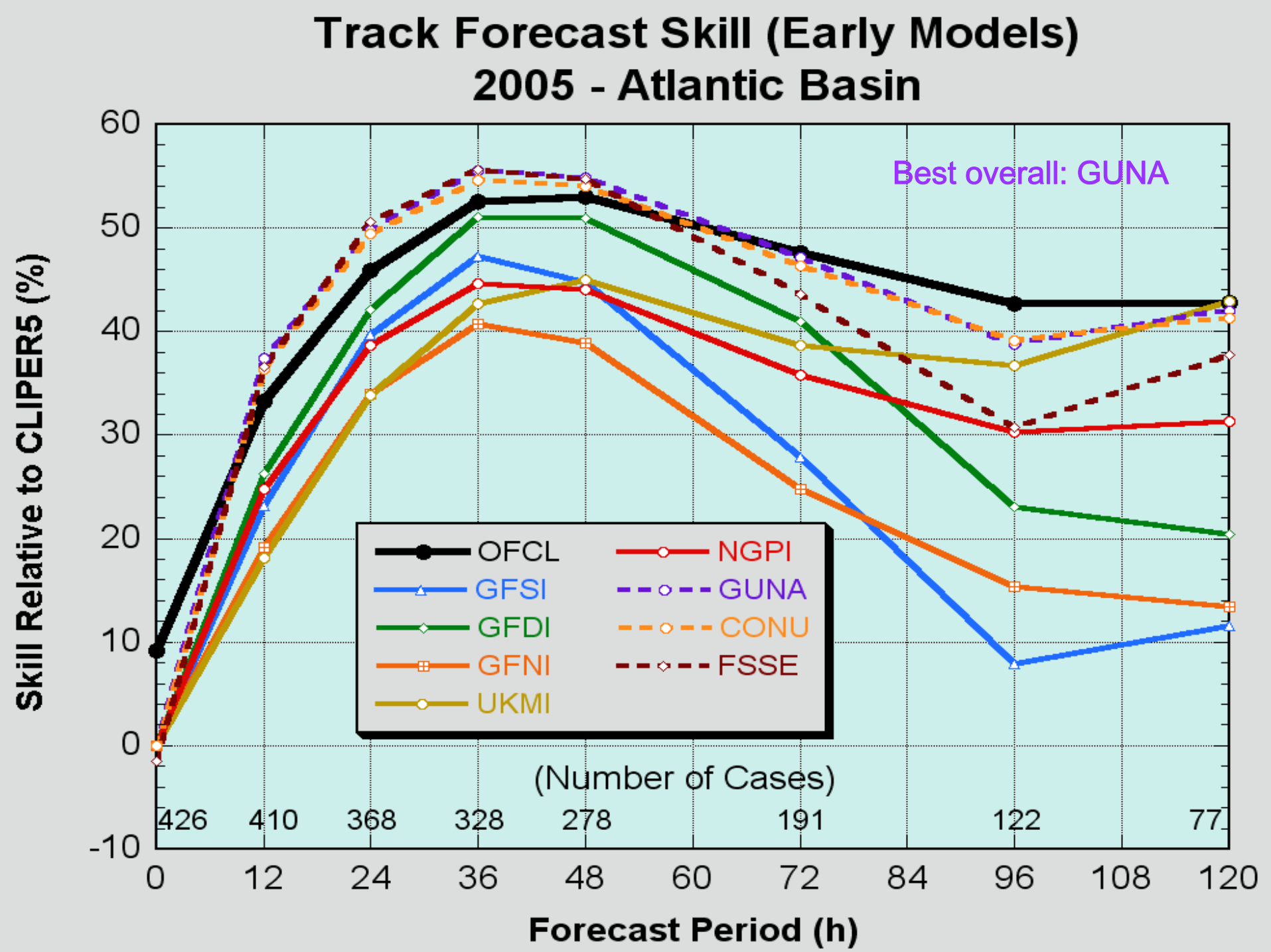
Katrina Track Forecasts
0000 UTC 27 August



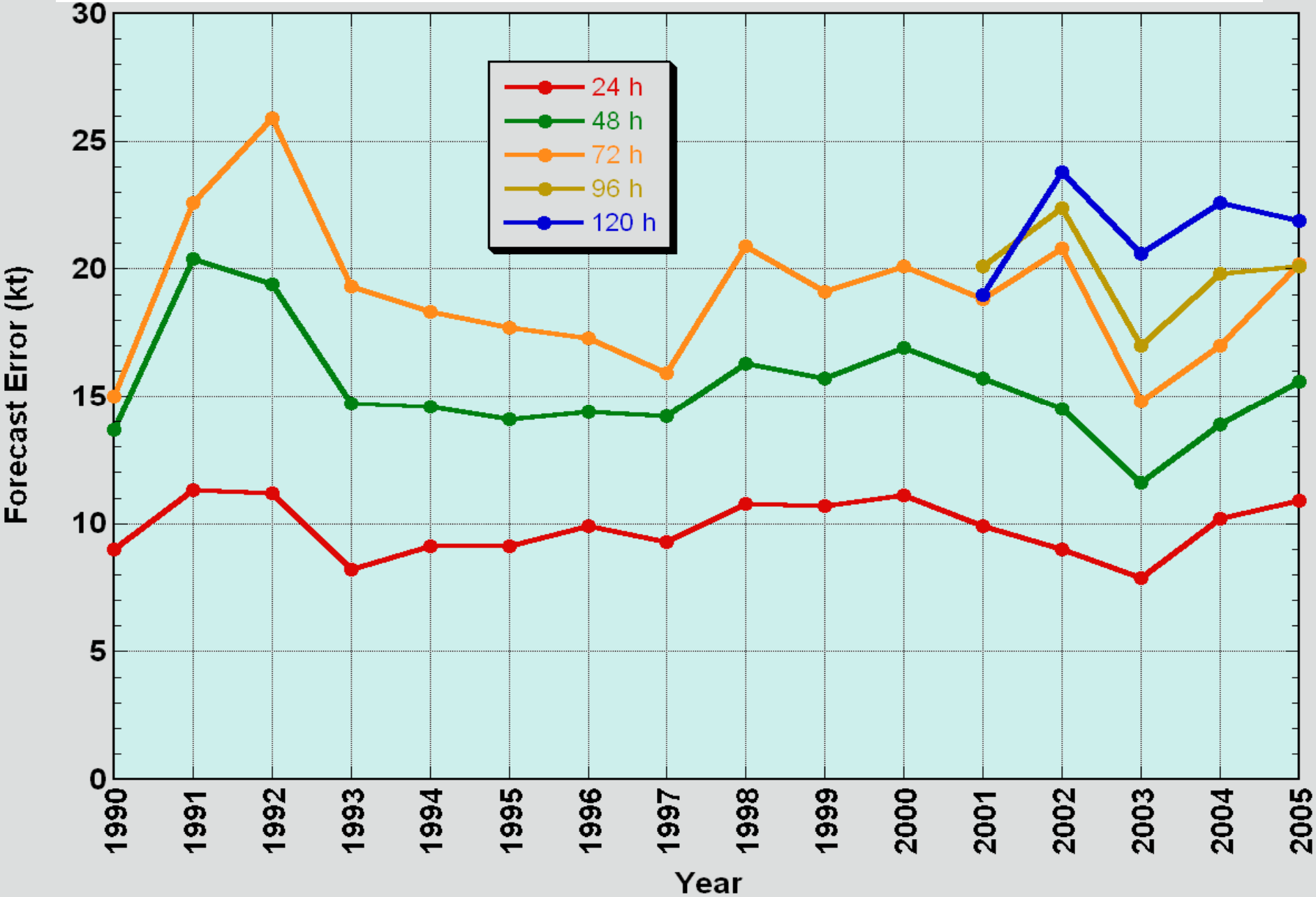


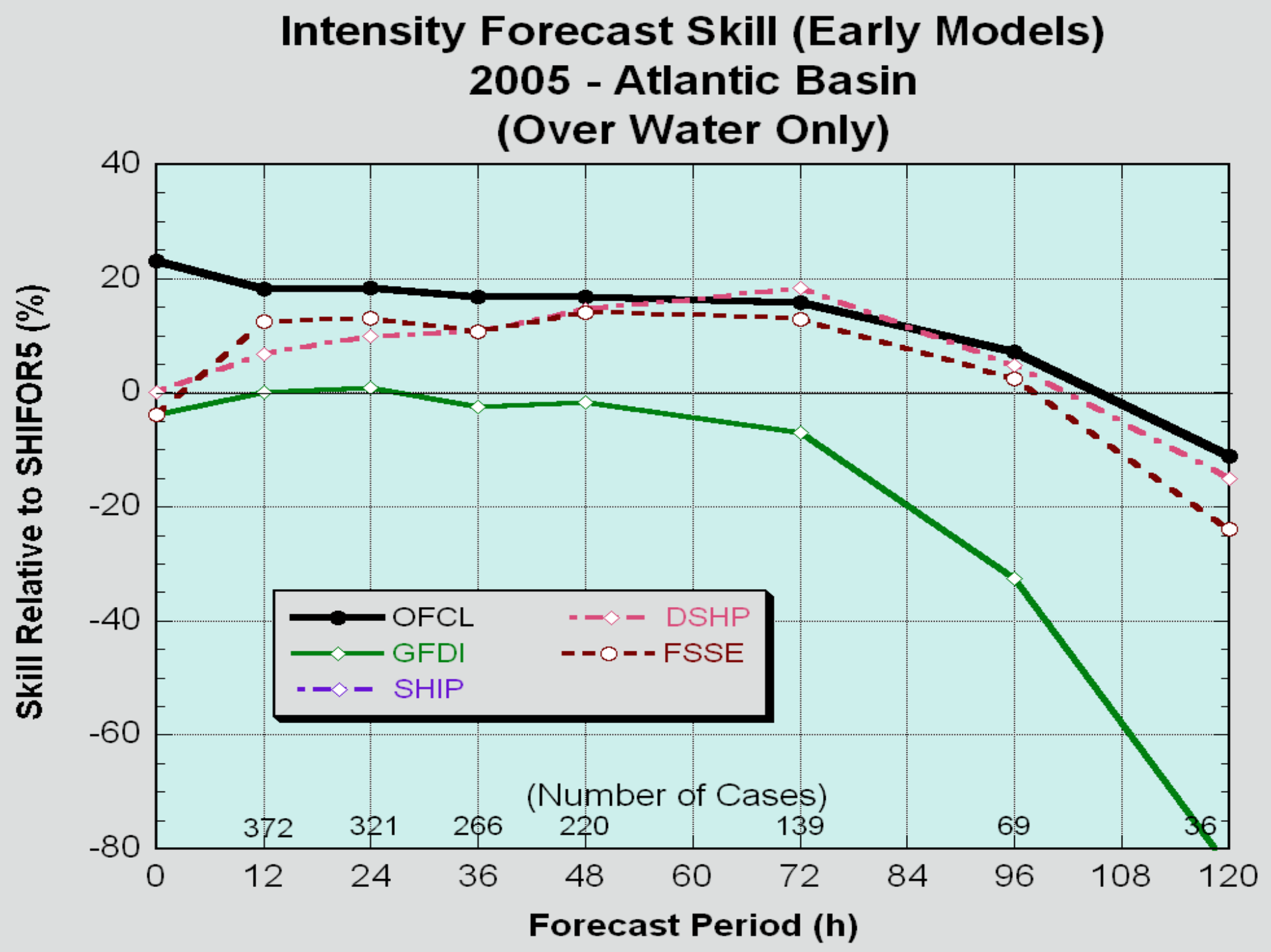
Track Errors cut in half in 15 years




Track Forecast Skill (Early Models)
2005 - Atlantic Basin
Best overall: GUNA
Skill Relative to CLIPER5 (%)
60
50
40
30
20
10
0
-10
OFCL
NGPI
GFSI
GUNA
GFDI
CONU
GFNI
FSSE
UKMI
(Number of Cases)
426
410
368
328
278
191
122
77
0
12
24
36
48
60
72
84
96
108
120
Forecast Period (h)

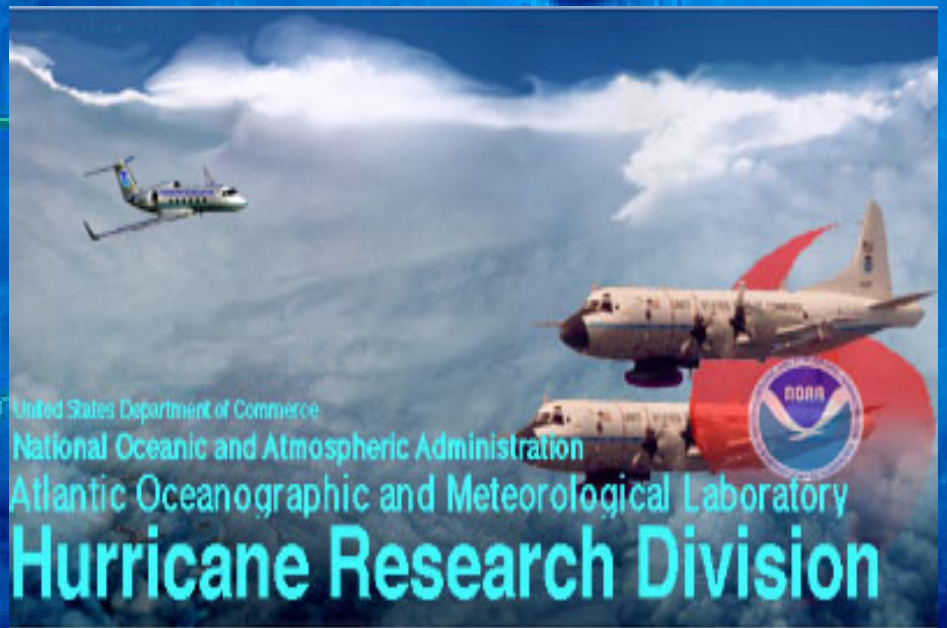
No Progress with Wind Intensity?




Intensity Forecast Skill (Early Models)
2005 - Atlantic Basin
(Over Water Only)
Skill Relative to SHIFOR5 (%)
40
20
0
-20
-40
-60
-80
OFCL
GFDI
SHIP
DSHP
FSSE
(Number of Cases)
372
321
266
220
139
69
36
0
12
24
36
48
60
72
84
96
108
120
Forecast Period (h)

The Forecasters (us):

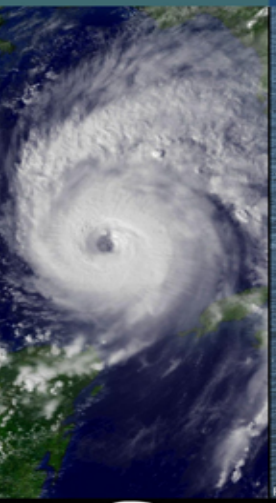
The Researchers (them):



How to bridge the "valley of death"?

National Hurricane Preparedness Week

May 21-27, 2006

HISTORY	HURRICANE HAZARDS			FORECAST	PREPARE	ACT
						
S	M	T	W	Th	F	S
MAY 21	MAY 22	MAY 23	MAY 24	MAY 25	MAY 26	MAY 27
Hurricane Basics **Hurricane History**	**Storm Surge** **Marine Safety**	**High Winds** **Tornadoes**	**Inland Flooding**	**Forecast Process**	**Disaster Prevention**	**National Day of Family Preparedness**

www.nhc.noaa.gov

Fundamental questions (process/sensitivity studies):

- Relative role of vortex (internal dynamics/eyewall replacement) vs. environment in influencing intensity.
- Role of ocean. Role of Oceanic heat content.
- Processes within atmosphere-ocean boundary layer on intensity/structure changes.
- Determinants of structure and relationship with preexisting wave disturbance. Relationship between structure and intensity.
- Relative role of physics, e.g. Air-sea, microphysics, convection etc. on intensity change in various environments (sheared vs. non-shear)

Hurricane Intensity Forecast Experiment - Led by NOAA

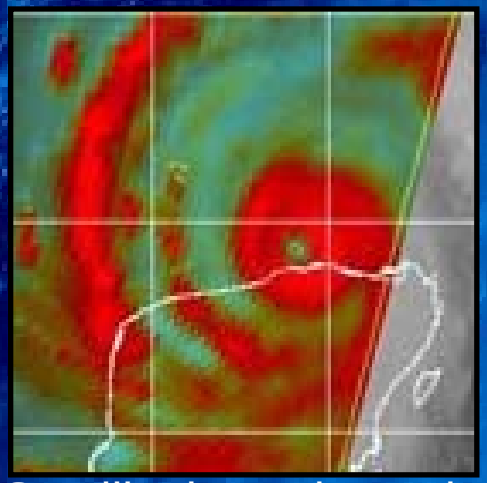
NOAA's Gulfstream-IV Jet and Orion P-3 Turboprop

INTENSITY FORECAST EXPERIMENT

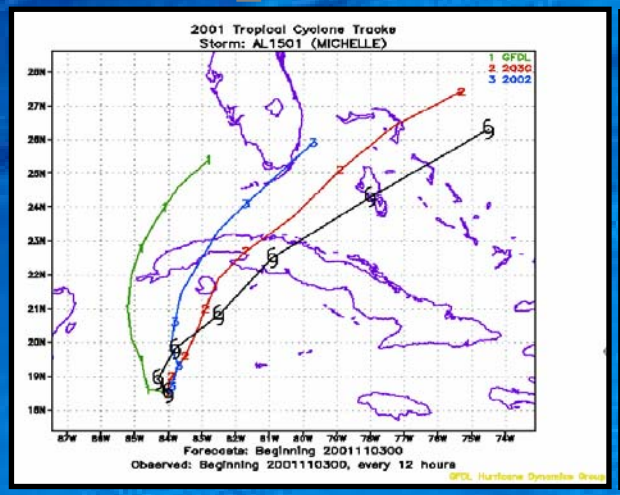
IFEX

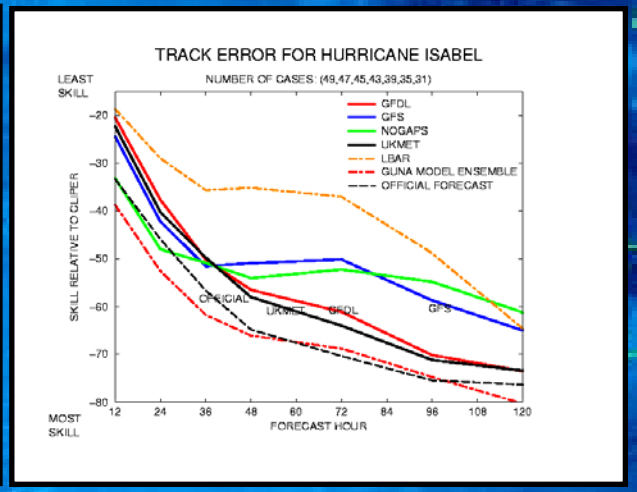
EMC - TPC -HRD

Joint Hurricane Testbed – New Techniques and Models

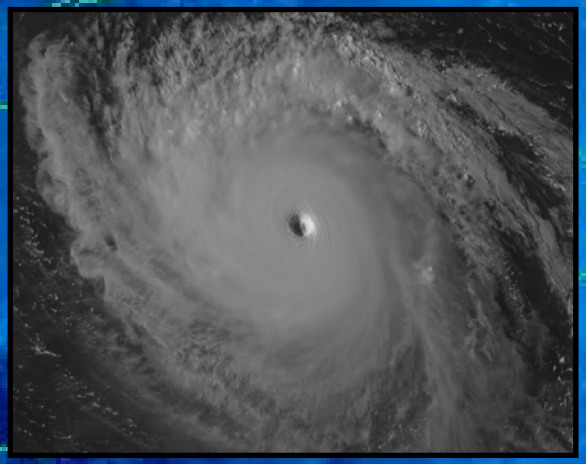


Satellite intensity and size estimates

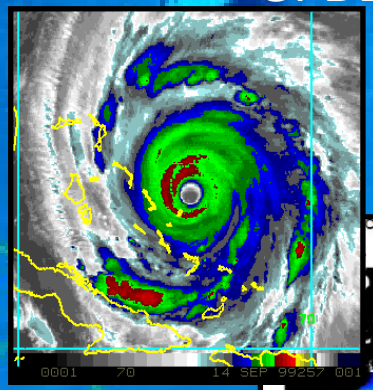


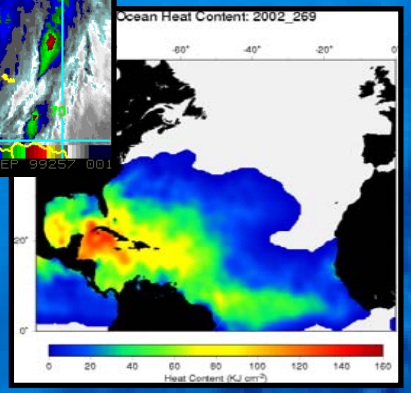


GFDL Hurricane Model upgrades

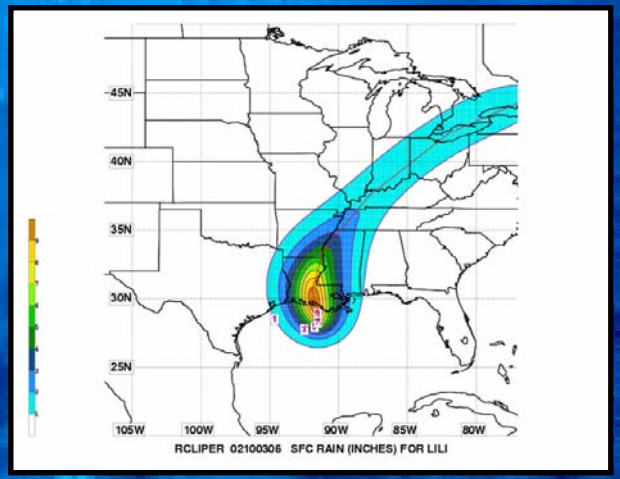


Probability of rapid intensification

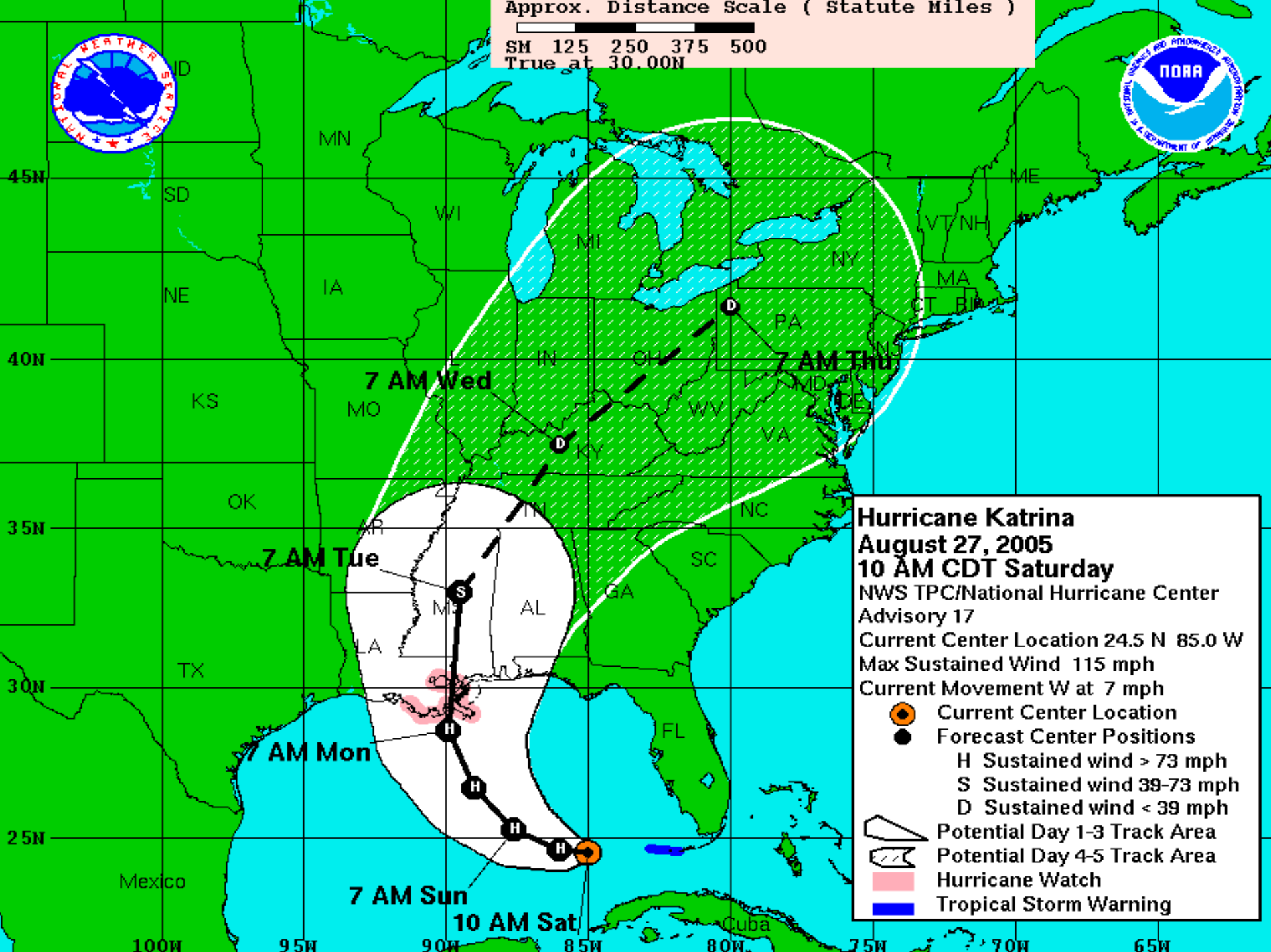




New wind prediction scheme



Improved Rainfall Forecasts


Approx. Distance Scale (Statute Miles)
SM 125 250 375 500
True at 30.00N
Hurricane Katrina
August 27, 2005
10 AM CDT Saturday
NWS TPC/National Hurricane Center
Advisory 17
Current Center Location 24.5 N 85.0 W
Max Sustained Wind 115 mph
Current Movement W at 7 mph
Current Center Location
Forecast Center Positions
H Sustained wind > 73 mph
S Sustained wind 39-73 mph
D Sustained wind < 39 mph
Potential Day 1-3 Track Area
Potential Day 4-5 Track Area
Hurricane Watch
Tropical Storm Warning
7 AM Wed
7 AM Thu
7 AM Tue
7 AM Mon
7 AM Sun
10 AM Sat
45N
40N
35N
30N
25N
100W
95W
90W
85W
80W
75W
70W
65W
ID
MN
SD
WI
MI
NY
ME
VT
NH
MA
CT
RI
NE
IA
PA
NJ
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OH
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OK
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AR
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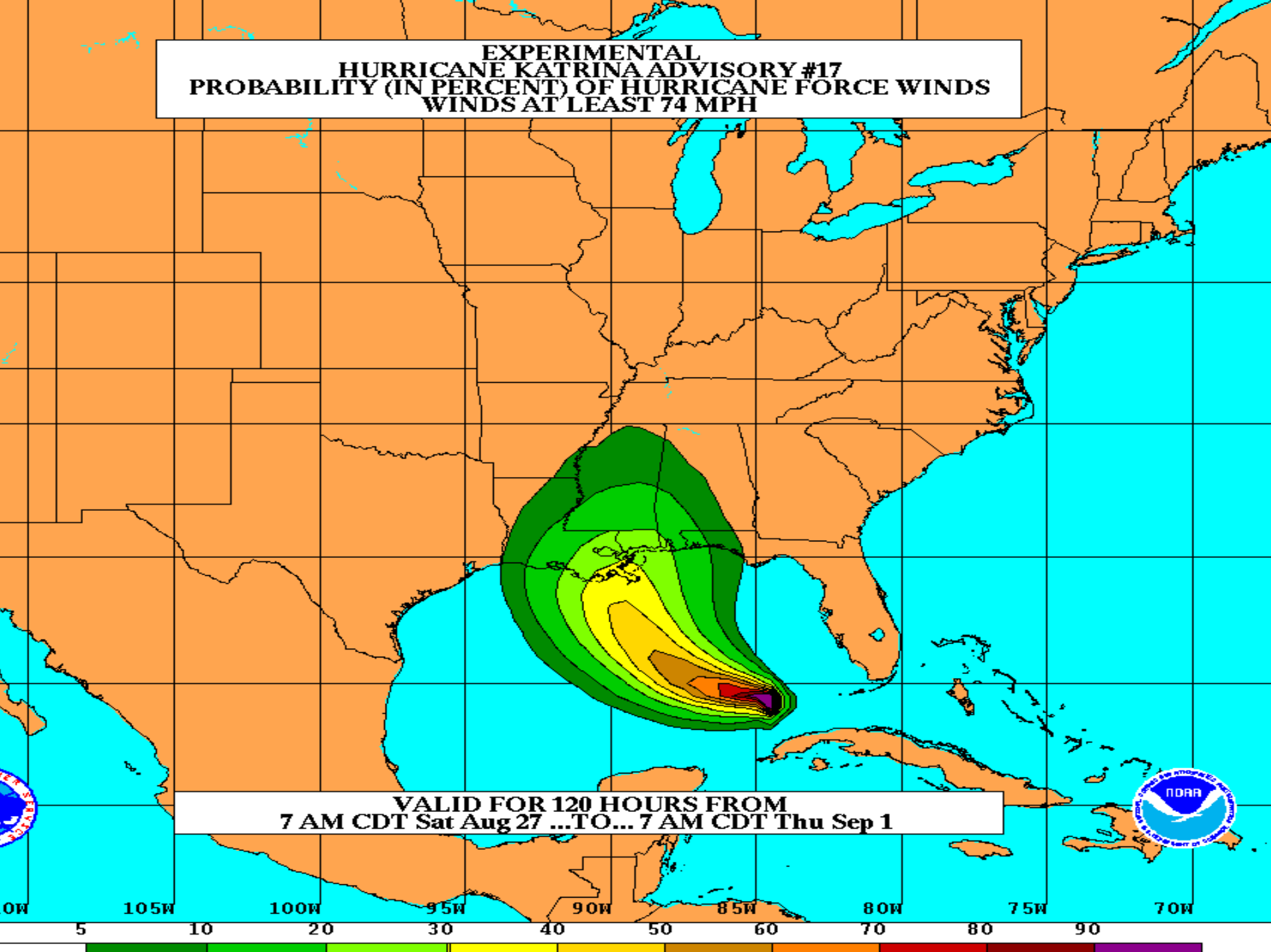
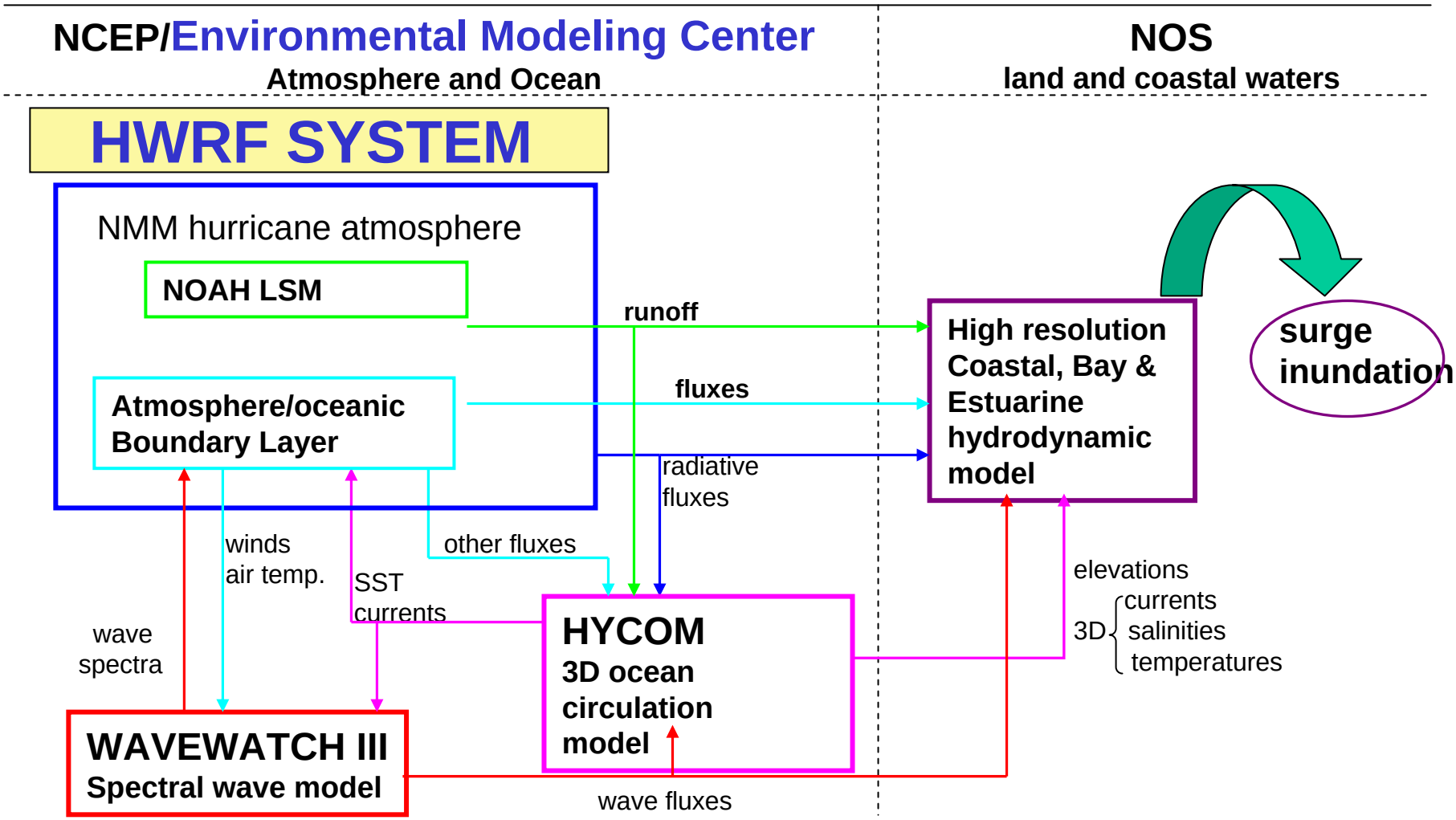
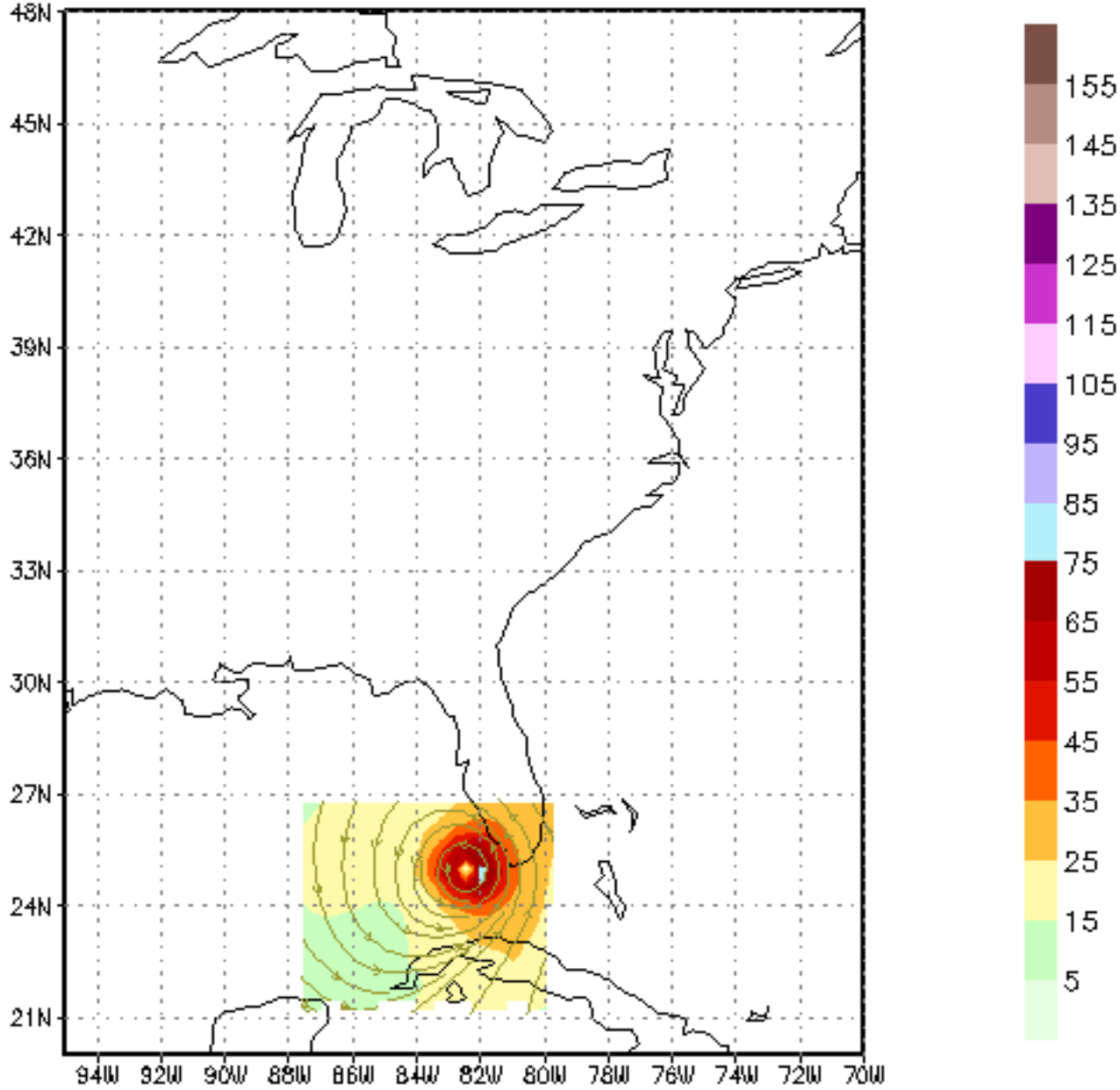
MS
AL
GA
LA
TX
FL
Mexico
Cuba


EXPERIMENTAL
HURRICANE KATRINA ADVISORY #17
PROBABILITY (IN PERCENT) OF HURRICANE FORCE WINDS
WINDS AT LEAST 74 MPH
VALID FOR 120 HOURS FROM
7 AM CDT Sat Aug 27 ...TO... 7 AM CDT Thu Sep 1
105W
100W
95W
90W
85W
80W
75W
70W
5
10
20
30
40
50
60
70
80
90

Hurricane-Wave-Ocean-Surge-Inundation Coupled Models



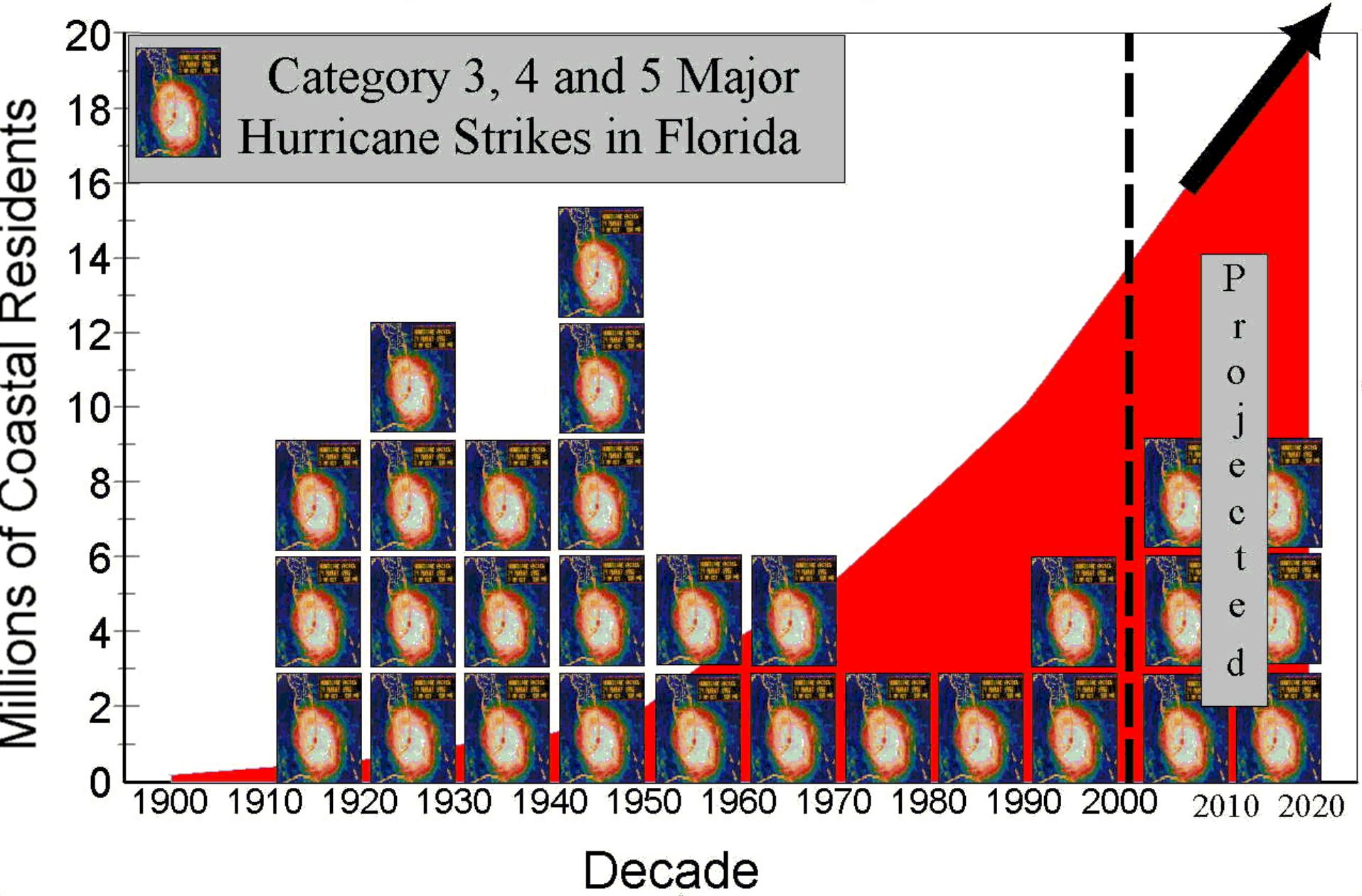
AUG 26, 2005 18Z: HURRICANE KATRINA MOVING NEST FCST: 0



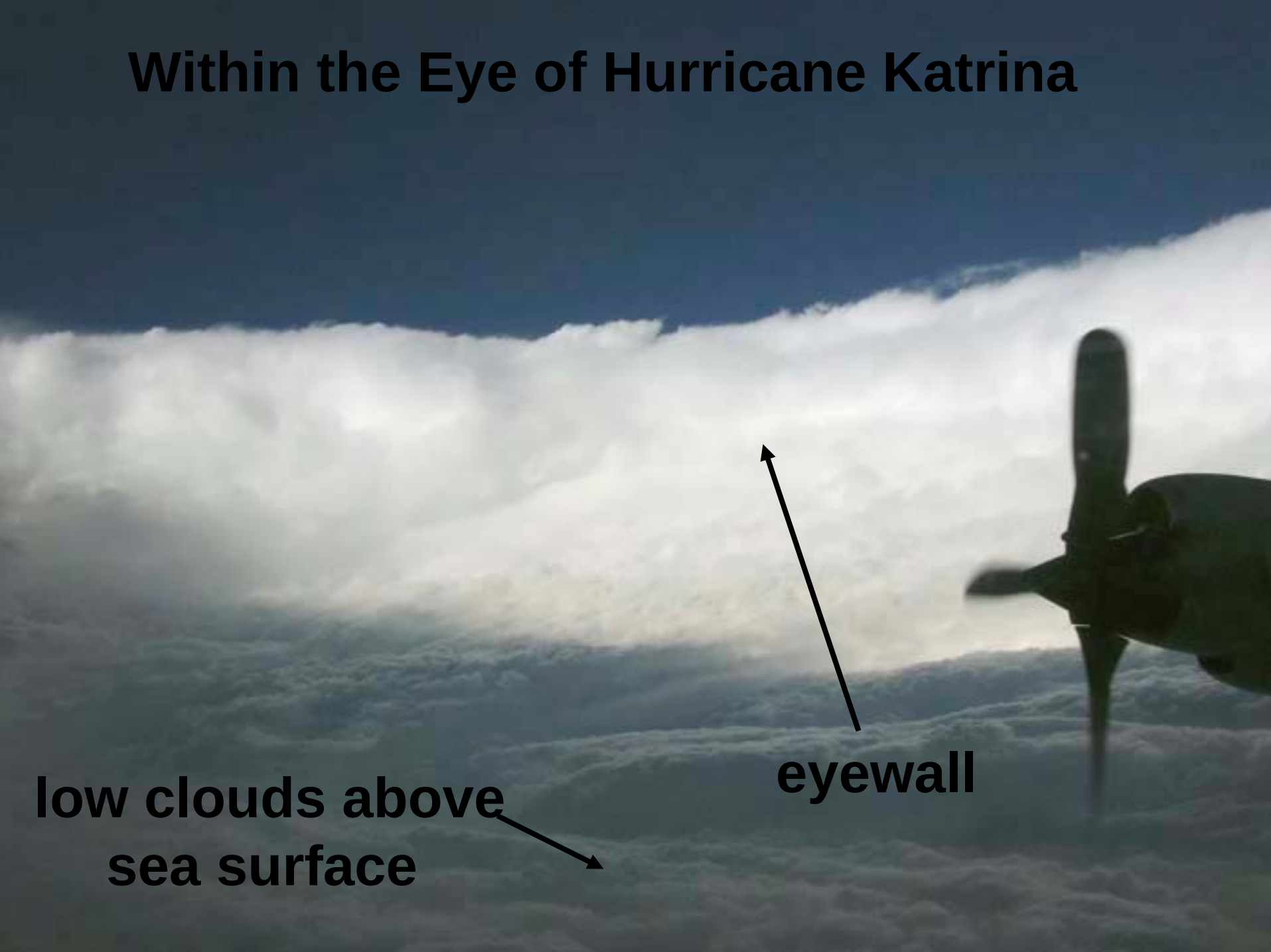
GrADS: COLA/IGES

2005-08-27-13:05

Florida Population and Major Hurricanes

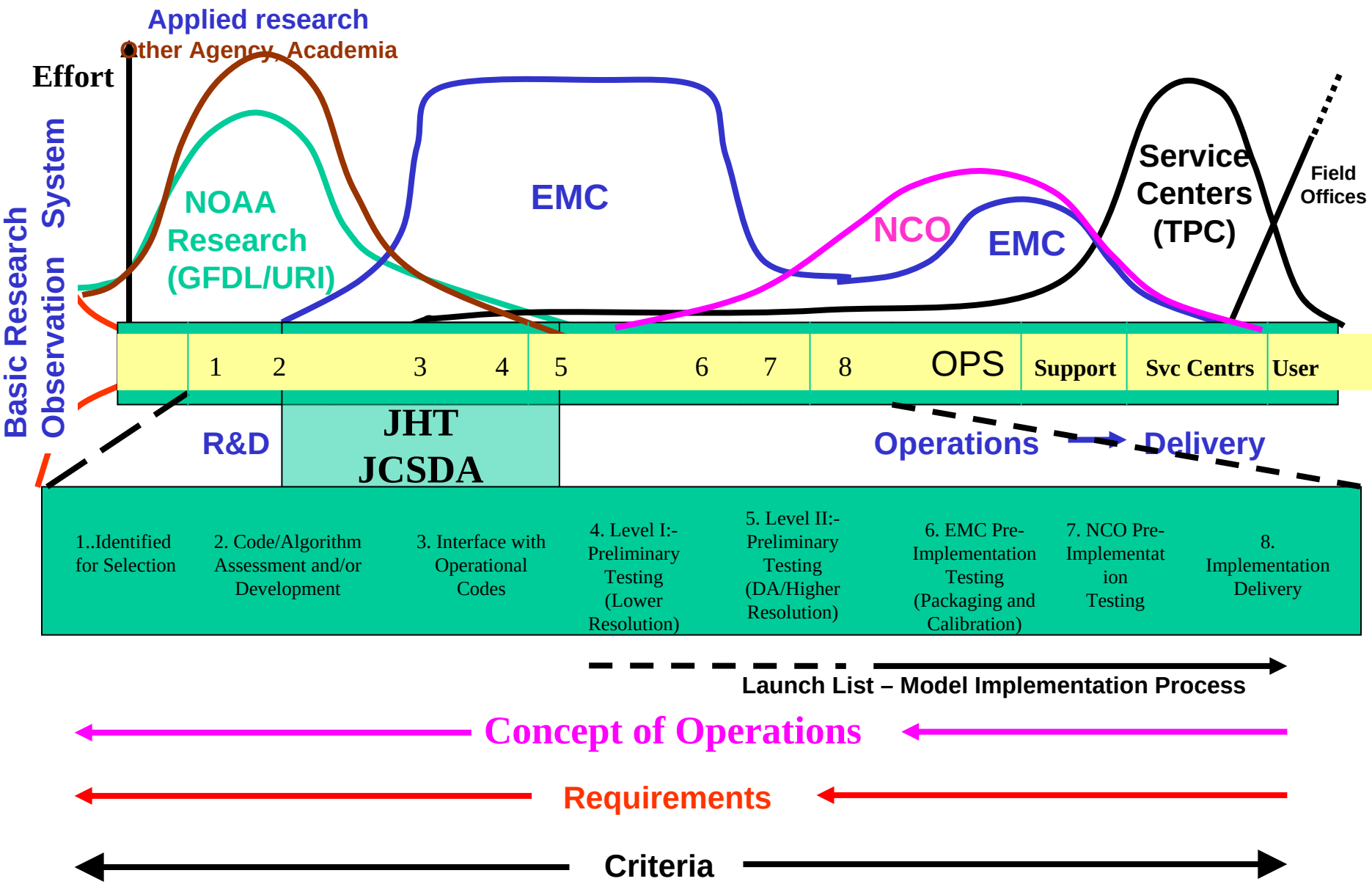


Within the Eye of Hurricane Katrina



NCEP's Role in the Model Transition Process

EMC and NCO have critical roles in the transition from NOAA R&D to operations



Examples of basic & applied science issues, for modeling and data assimilation, to accelerate progress on the hurricane intensity and structure forecast problem…….

Some Model Related Issues

- Data Assimilation
  - Assimilation of satellite radiances
  - Vortex Initialization

    definition of hurricane "core" circulation

    where to take obs? difficult for mature storms; more elusive weaker circulations. (obs taken during RAINEX?)

- Physics
  - role of radiation? complexity of microphysics and interaction of microphysics with radiation
  - atmosphere/oceanic boundary layer for coupled air-sea-wave problem. Momentum (wave induced drag) and enthalpy fluxes (sea spray complexity?)

- Resolution -
  - relative importance of horizontal vs. vertical resolution for modeling intensity/structure (important consideration for ops)
- Coupled Ocean -
  - advancements to support
  - initialization
  - vertical mixing
  - Obs to support effort data assimilation for improved ocean state (discussed at 2003 Air-Sea workshop at EMC)
- Land Surface Coupling -
  - Complexity of coupling w/HWRF?
  - Sensitivity of LSM for track, structure/intensity, rainfall?
  - Future coupling with hydrology/inundation models.

- Validation/Verification/Diagnostics –
  - initialization
  - requirement for development of verification techniques
  - all stages of storm evolution; varying atmos/ocean environment
  - required obs to support model diagnoistics and verification,

    e.g IFEX effort led by HRD
  - particularly deficient in ocean obs.
  - temporal and spatial scales?

Development of Advanced Probabilistic Guidance

HWRF Ensembles

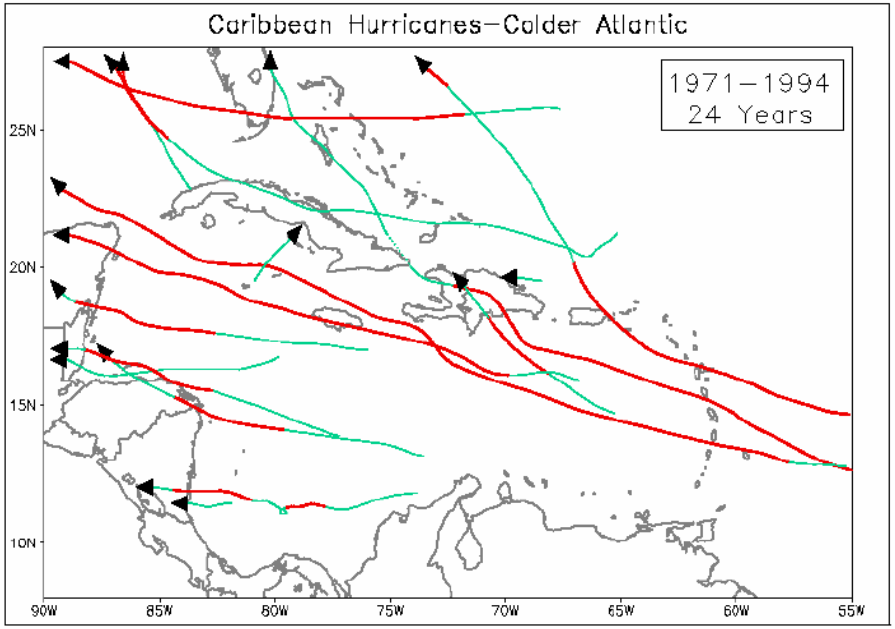
Configuration

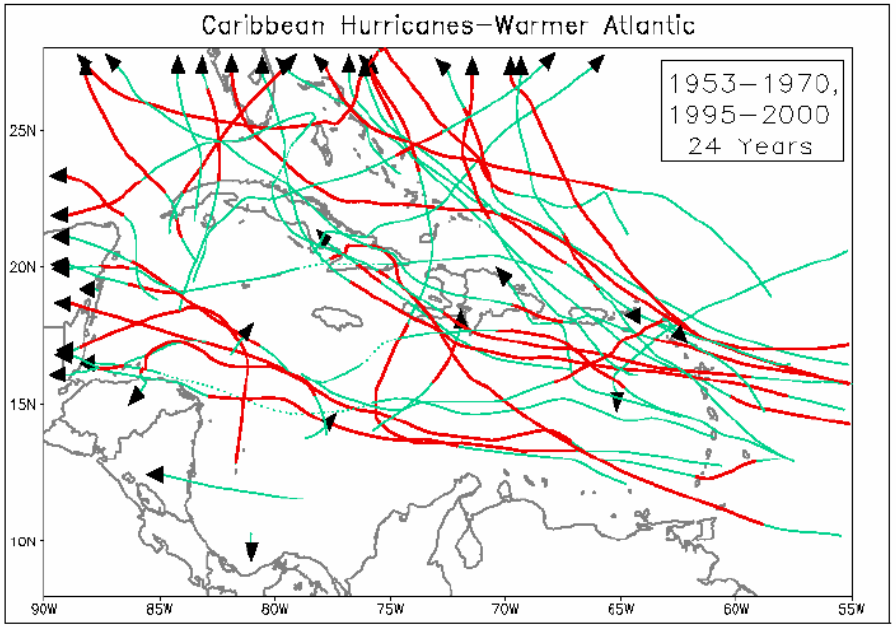
initial conditions, resolution, members

Will use of multi model ensembles (MME) be tractable for this problem several years from now as is the use now of MME for track ?

Value of very hi-resolution deterministic forecasts vs. ensembles?

Caribbean Hurricanes – Atlantic Multidecadal Mode





Global Warming – Past Temperature Changes

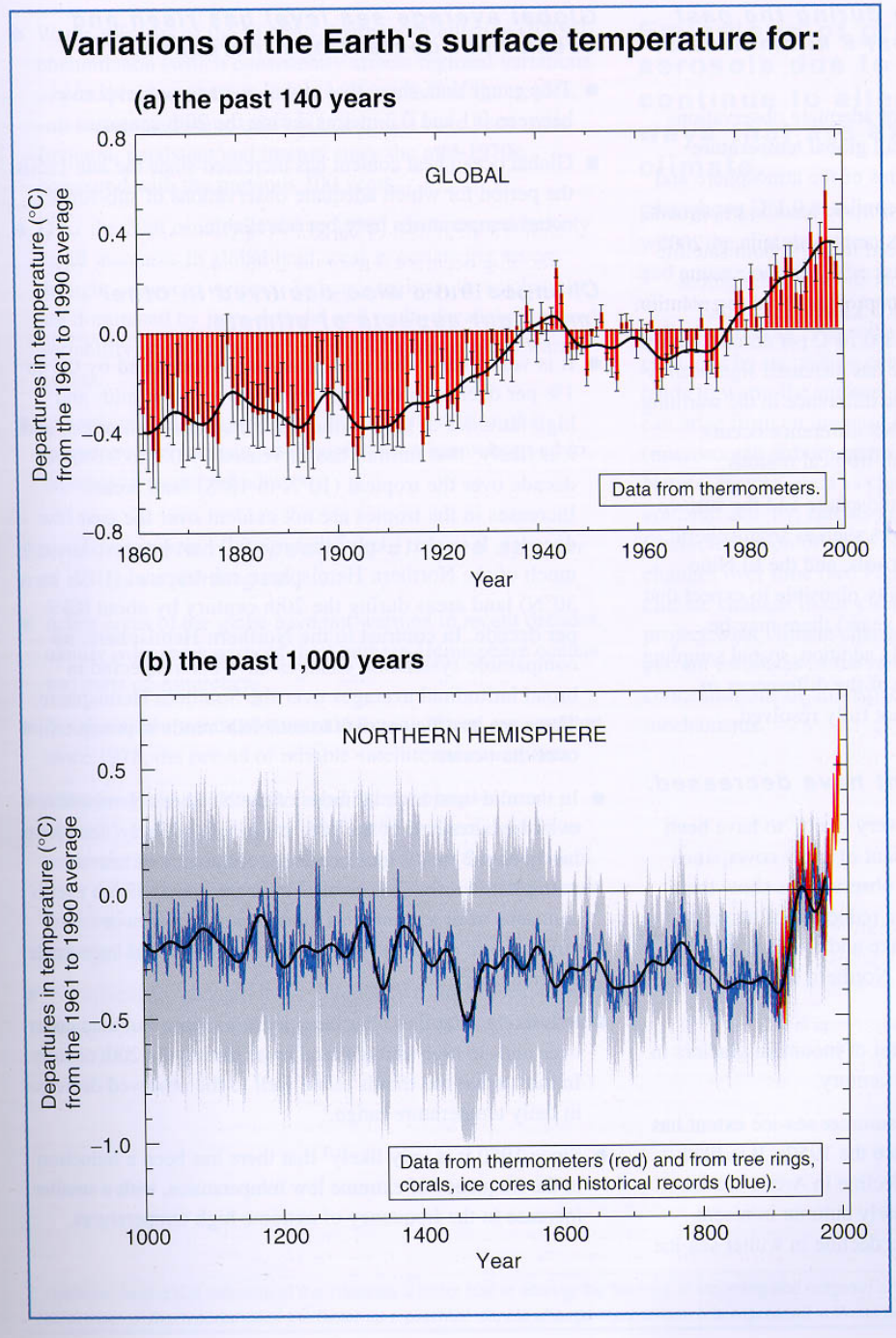


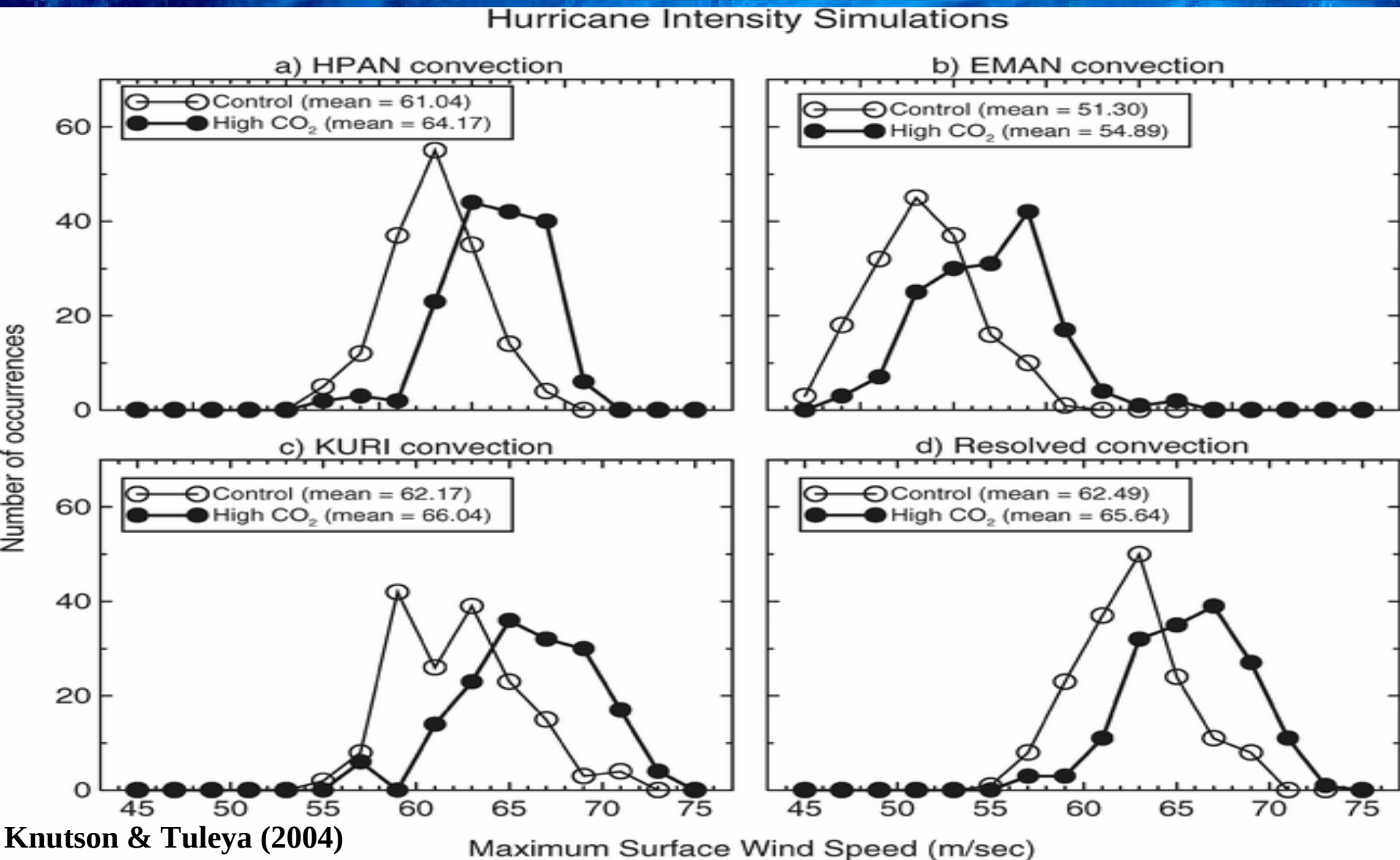
Figure 1: Variations of the Earth's surface temperature over the last 140 years and the last millennium.

(a) The Earth's surface temperature is shown year by year (red bars) and approximately decade by decade (black line, a filtered annual curve suppressing fluctuations below near decadal time-scales). There are uncertainties in the annual data (thin black whisker bars represent the 95% confidence range) due to data gaps, random instrumental errors and uncertainties, uncertainties in bias corrections in the ocean surface temperature data and also in adjustments for urbanisation over the land. Over both the last 140 years and 100 years, the best estimate is that the global average surface temperature has increased by 0.6 ± 0.2°C.

(b) Additionally, the year by year (blue curve) and 50 year average (black curve) variations of the average surface temperature of the Northern Hemisphere for the past 1000 years have been reconstructed from "proxy" data calibrated against thermometer data (see list of the main proxy data in the diagram). The 95% confidence range in the annual data is represented by the grey region. These uncertainties increase in more distant times and are always much larger than in the instrumental record due to the use of relatively sparse proxy data. Nevertheless the rate and duration of warming of the 20th century has been much greater than in any of the previous nine centuries. Similarly, it is likely[7] that the 1990s have been the warmest decade and 1998 the warmest year of the millennium.

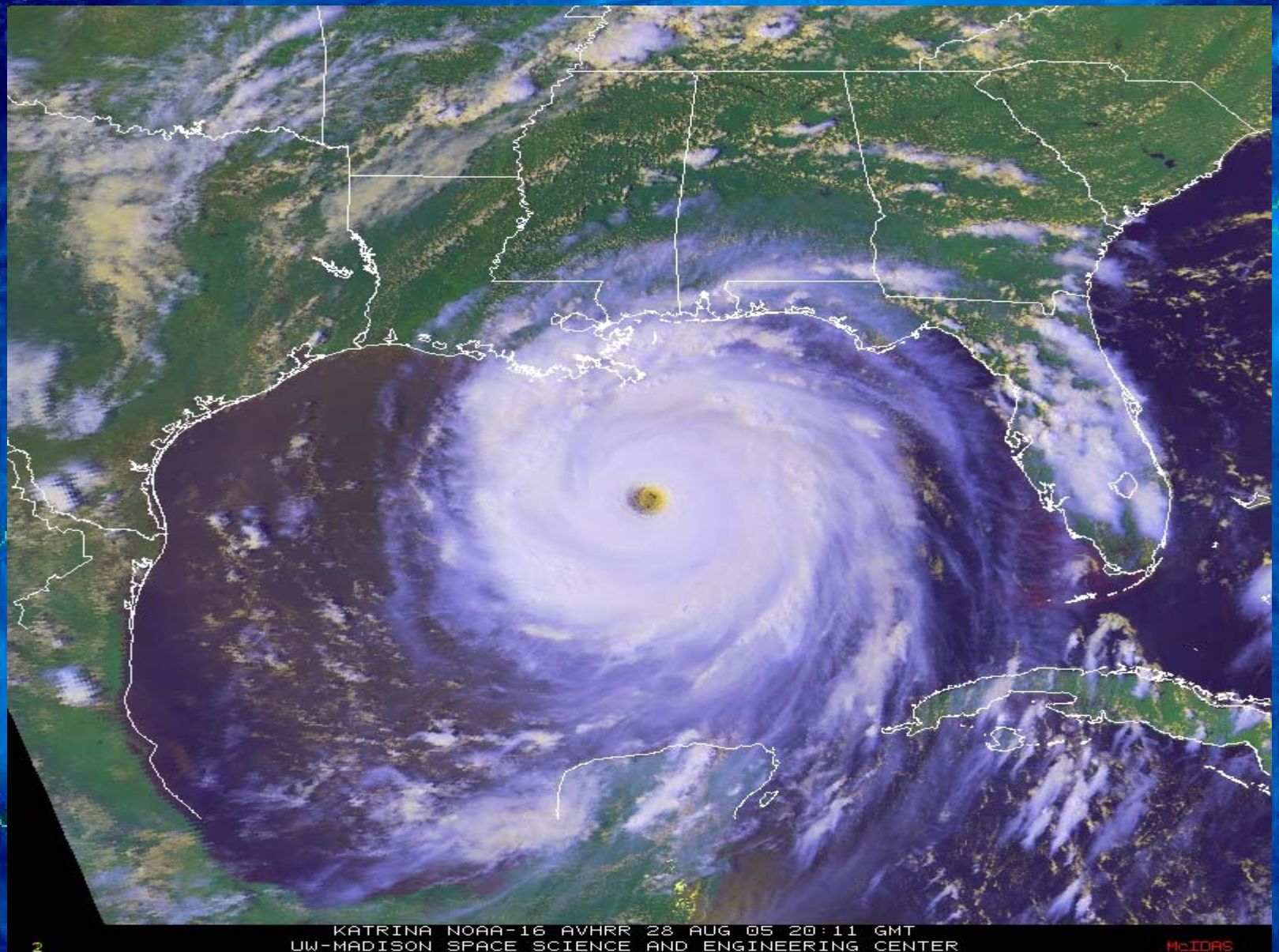
[Based upon (a) Chapter 2, Figure 2.7c and (b) Chapter 2, Figure 2.20]

Global Warming and Hurricane Winds:
Theory and Modeling Work Suggest 5% increase by late 21st Century

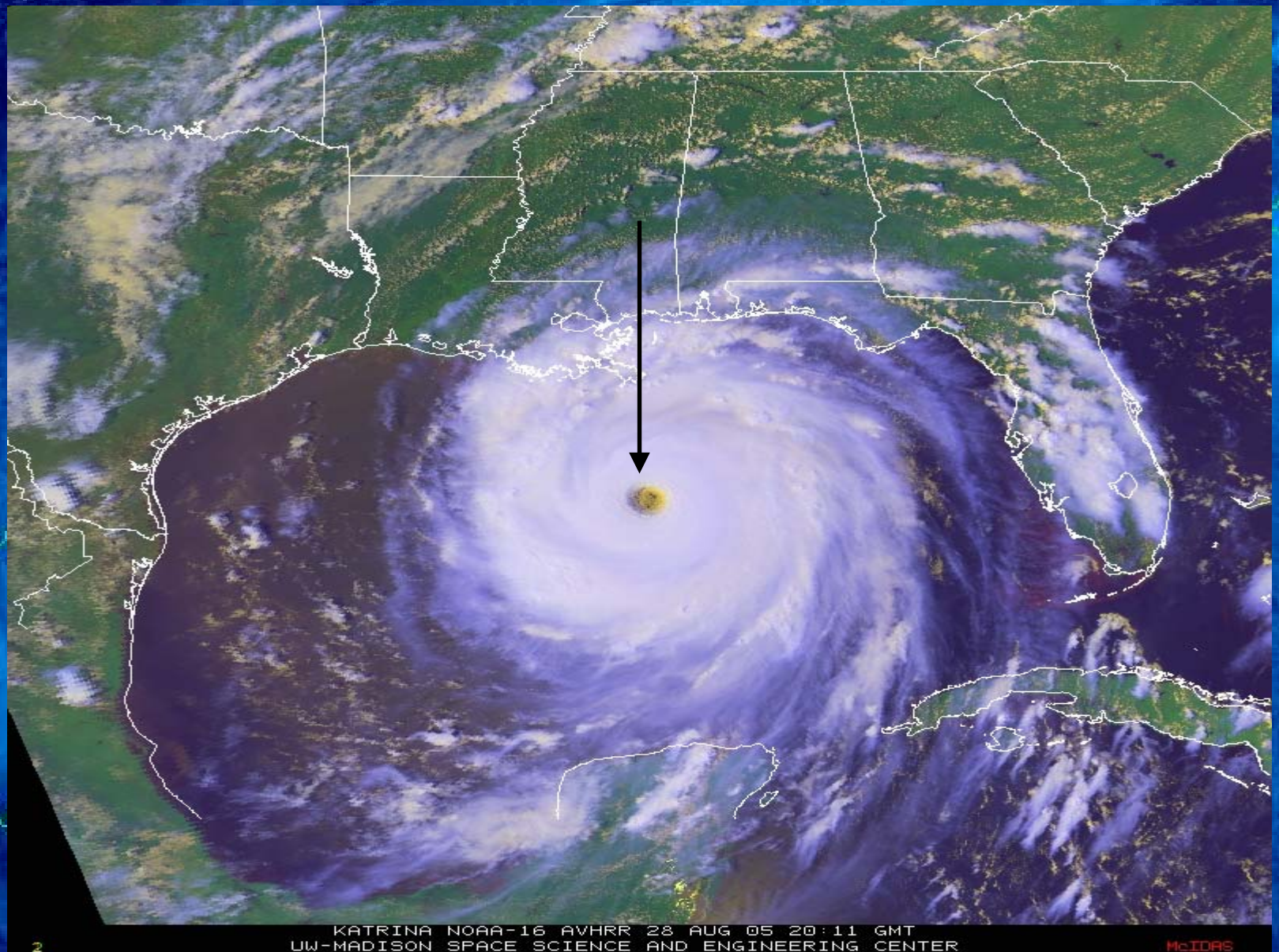


Knutson & Tuleya (2004)

Global Warming and Hurricane Winds:
Theory and Modeling Work Suggest ~1% Increase Today



Global Warming and Hurricane Winds:
Theory and Modeling Work Suggest ~1% Increase Today



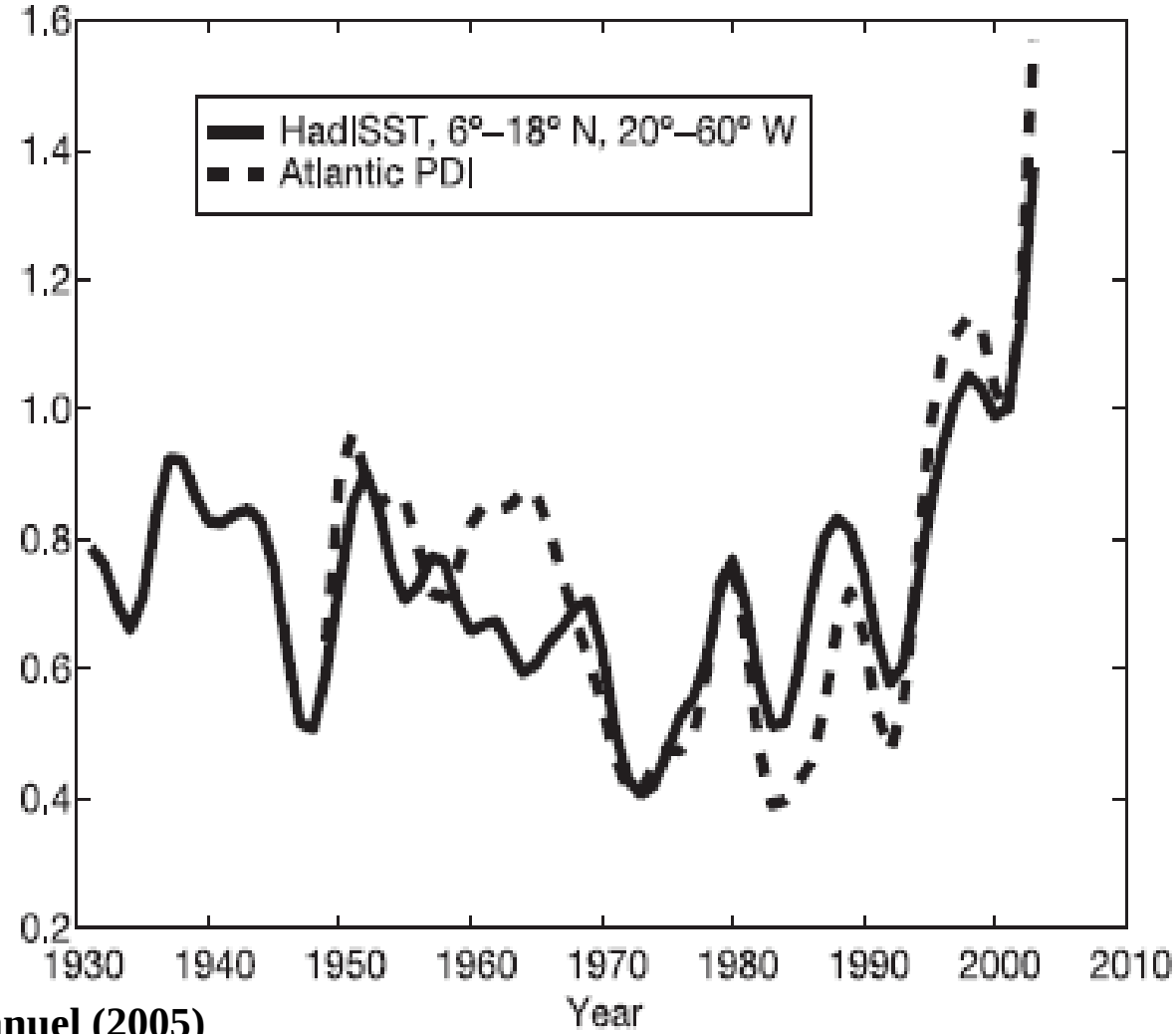
"Can one detect an actual increase in global tropical cyclone Intensity? … Since 1950 … one would expect to have observed an average increase in intensity of around 0.5 m/s or 1 knot. Because tropical cyclone maximum wind speeds are only reported at 5-knot intervals and are not believed to be accurate to better than 5 to 10 knots, and given the large interannual variability of tropical cyclone activity, *such an increase would not be detectable*. Thus any increase in hurricane intensity that may have already occurred as a result of global warming is inconsequential compared to natural variability."

--- Kerry Emanuel, 2004

"An important issue is whether and when any CO2-induced increase of tropical cyclone intensity is likely to be detectable in the observations. The magnitude of the simulated increase in our experiments is about +6% for maximum tropical cyclone surface winds … The SST changes observed for the past 50 yr in the Tropics imply that the likely SST-inferred intensity change for the past half century is small, relative to both the limited accuracy of historical records of storm intensity and to the apparently large magnitude of interannual variability of storm intensities in some basins. This further implies that CO2-induced tropical cyclone intensity changes are unlikely to be detectable in historical observations and will probably not be detectable for decades to come."

--- Knutson and Tuleya (2004)

Emanuel's study:
Doubling in Atlantic Hurricane Wind Index – "Unprecedented"

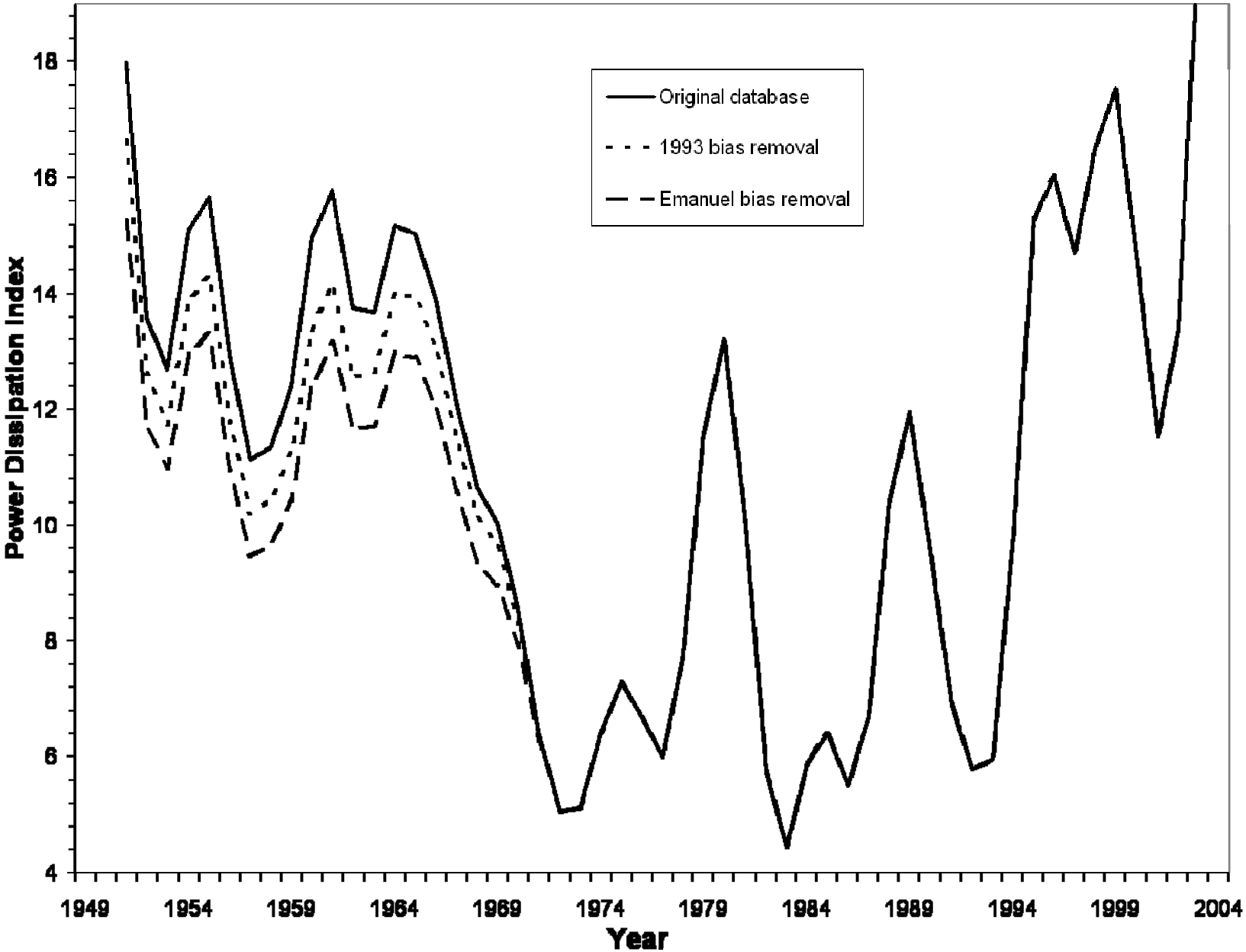


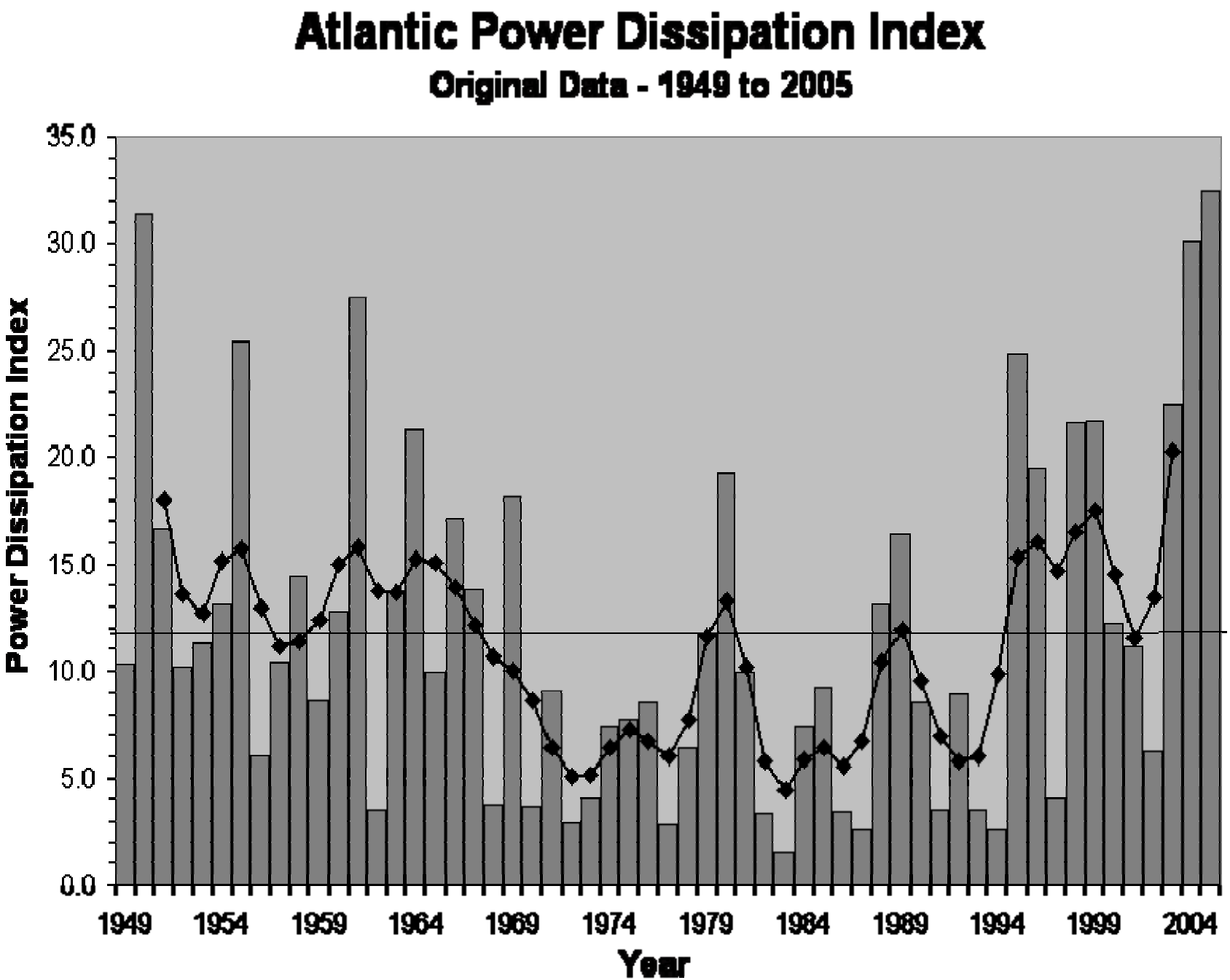
Emanuel (2005)

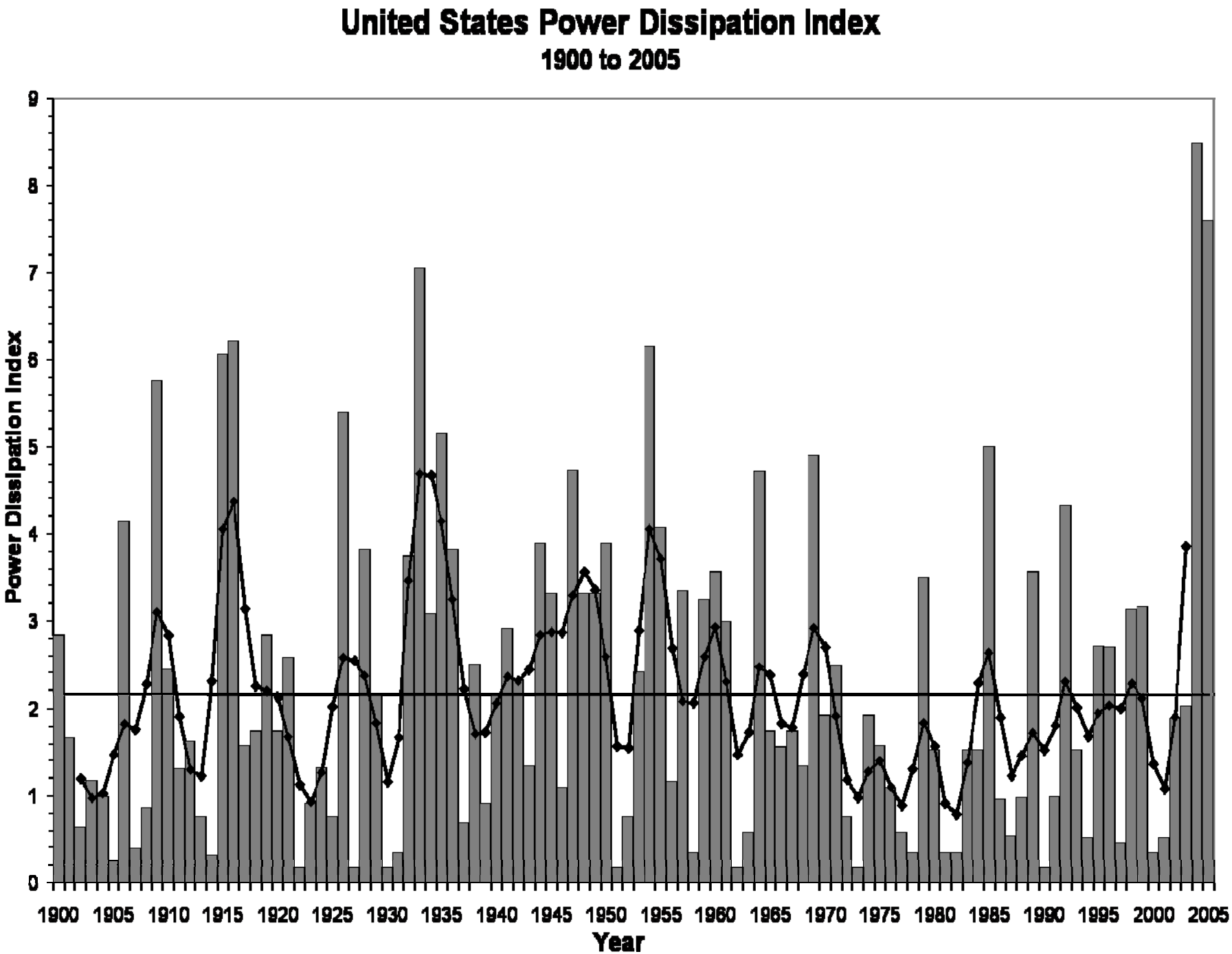
PDI = Power Dissipation Index (winds cubed & summed for season)

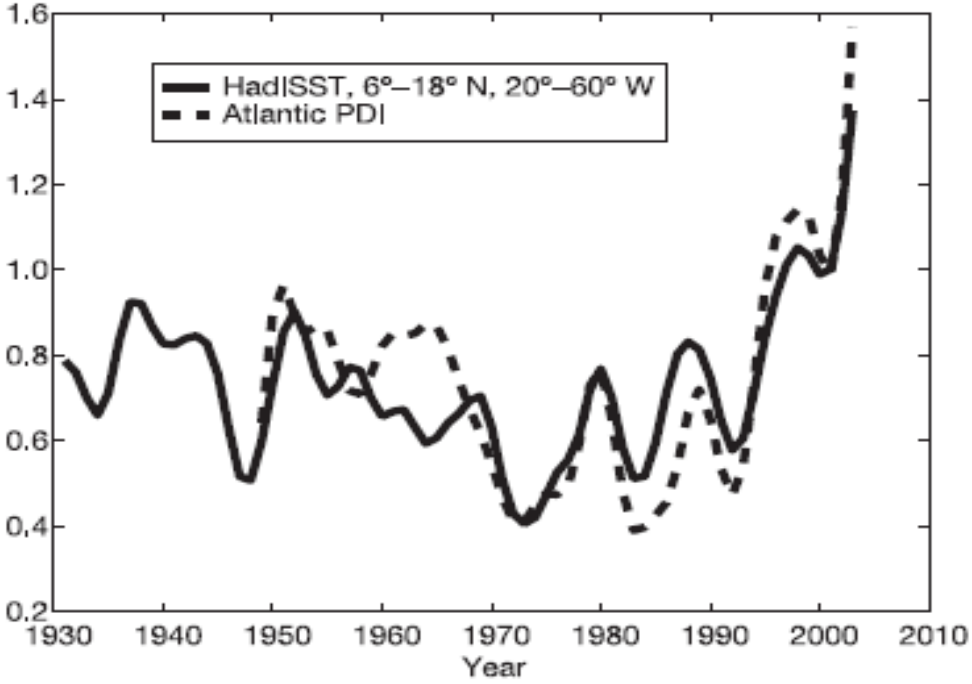
Atlantic Power Dissipation Index

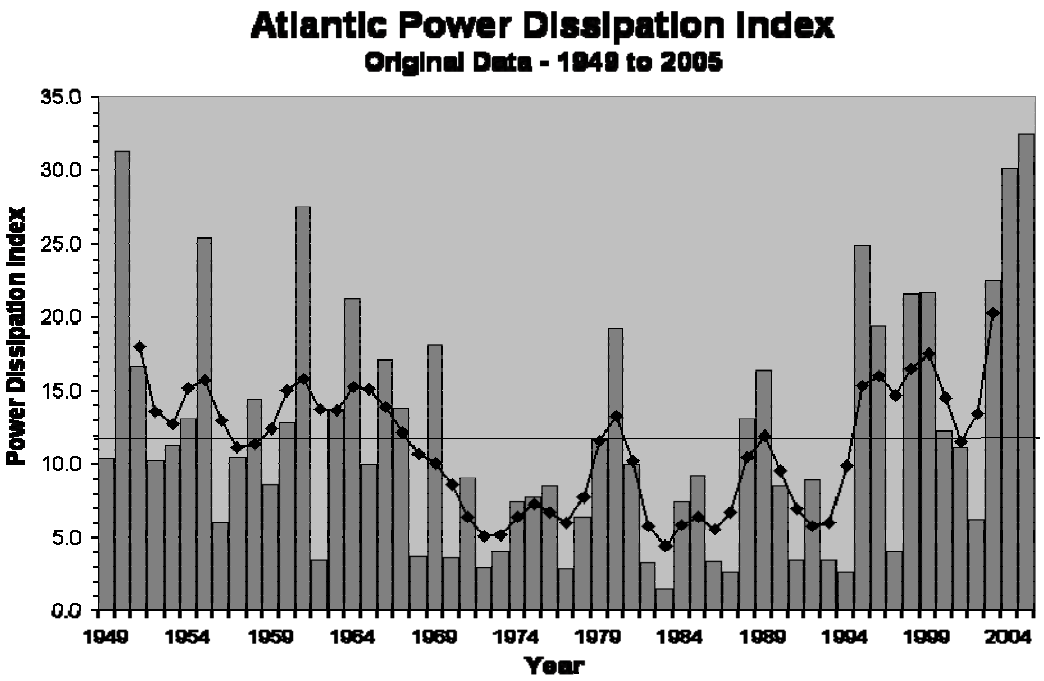
Original and two bias removals - 1949 to 2004




Atlantic Power Dissipation Index
Original Data - 1949 to 2005
Power Dissipation Index
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999
2004
Year

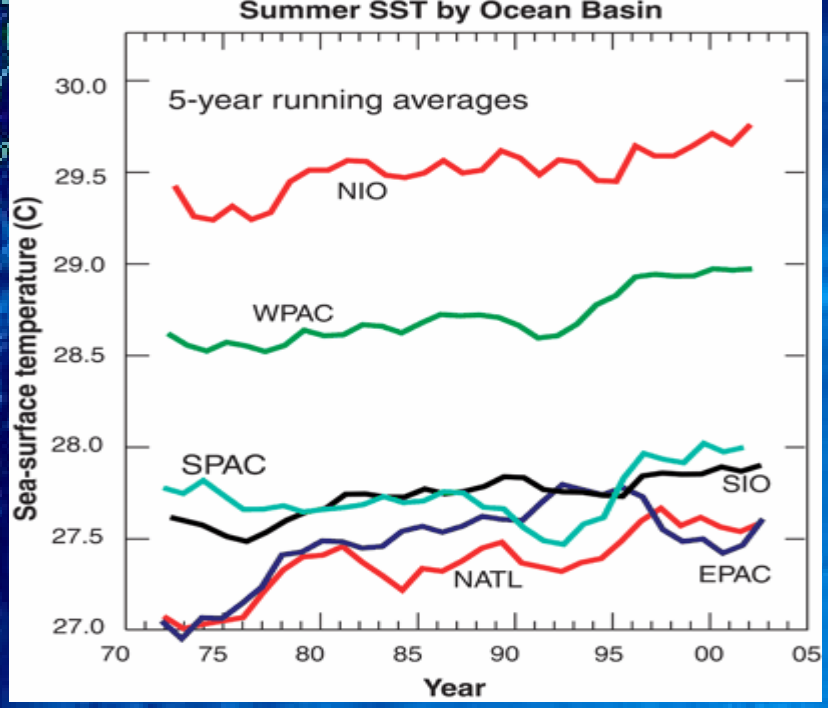

United States Power Dissipation Index
1900 to 2005
Power Dissipation Index
0
1
2
3
4
5
6
7
8
9
1900
1905
1910
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
Year



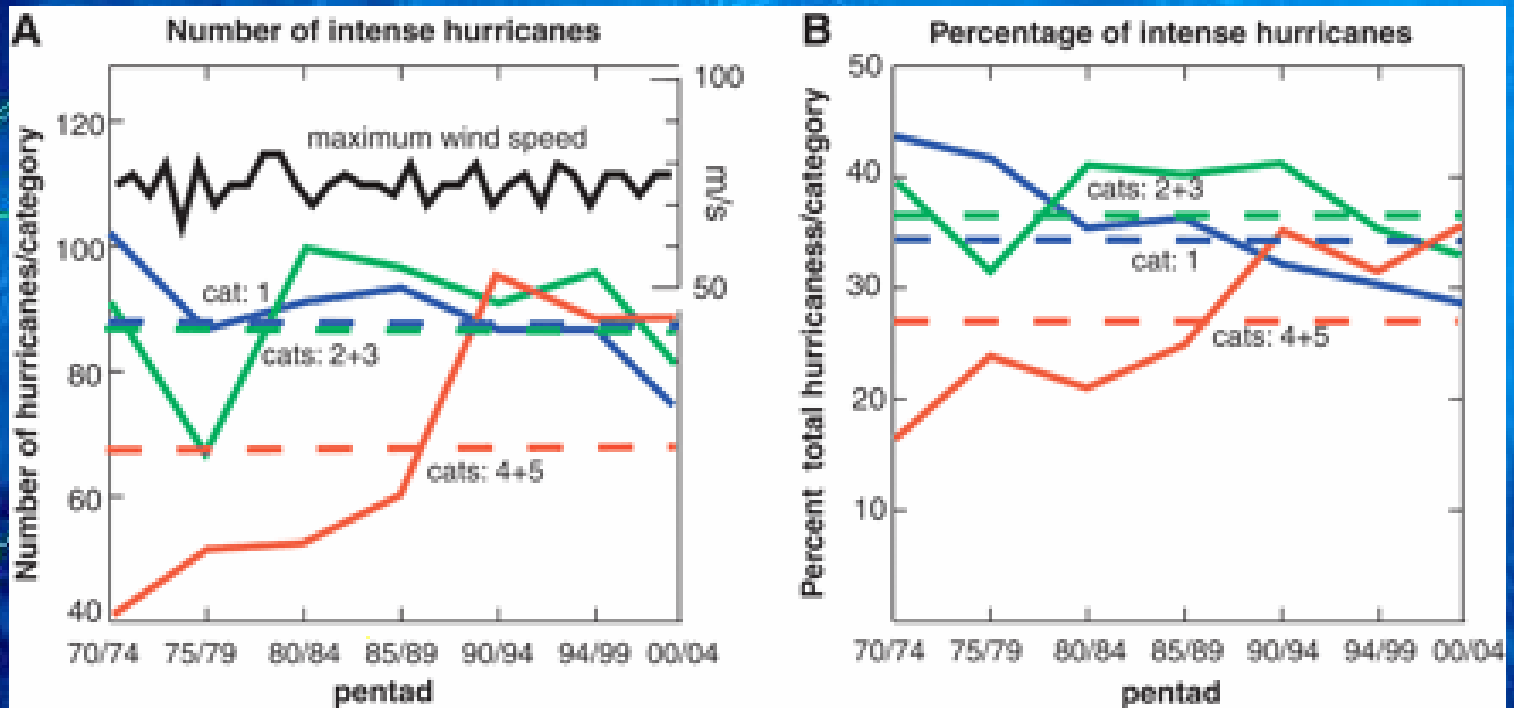


Original PDI from Emanuel (2005)

Revised PDI from Landsea (2005)

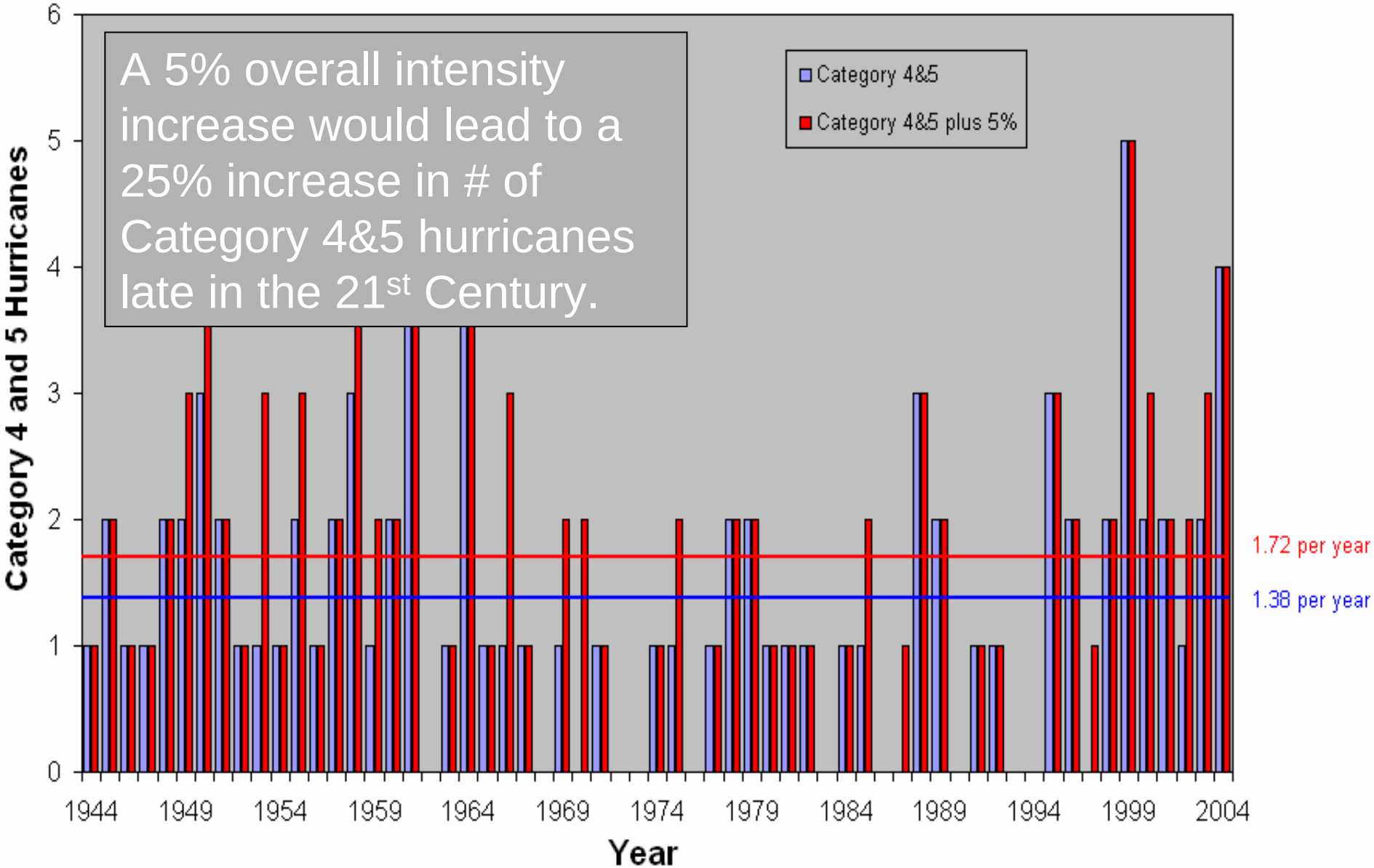


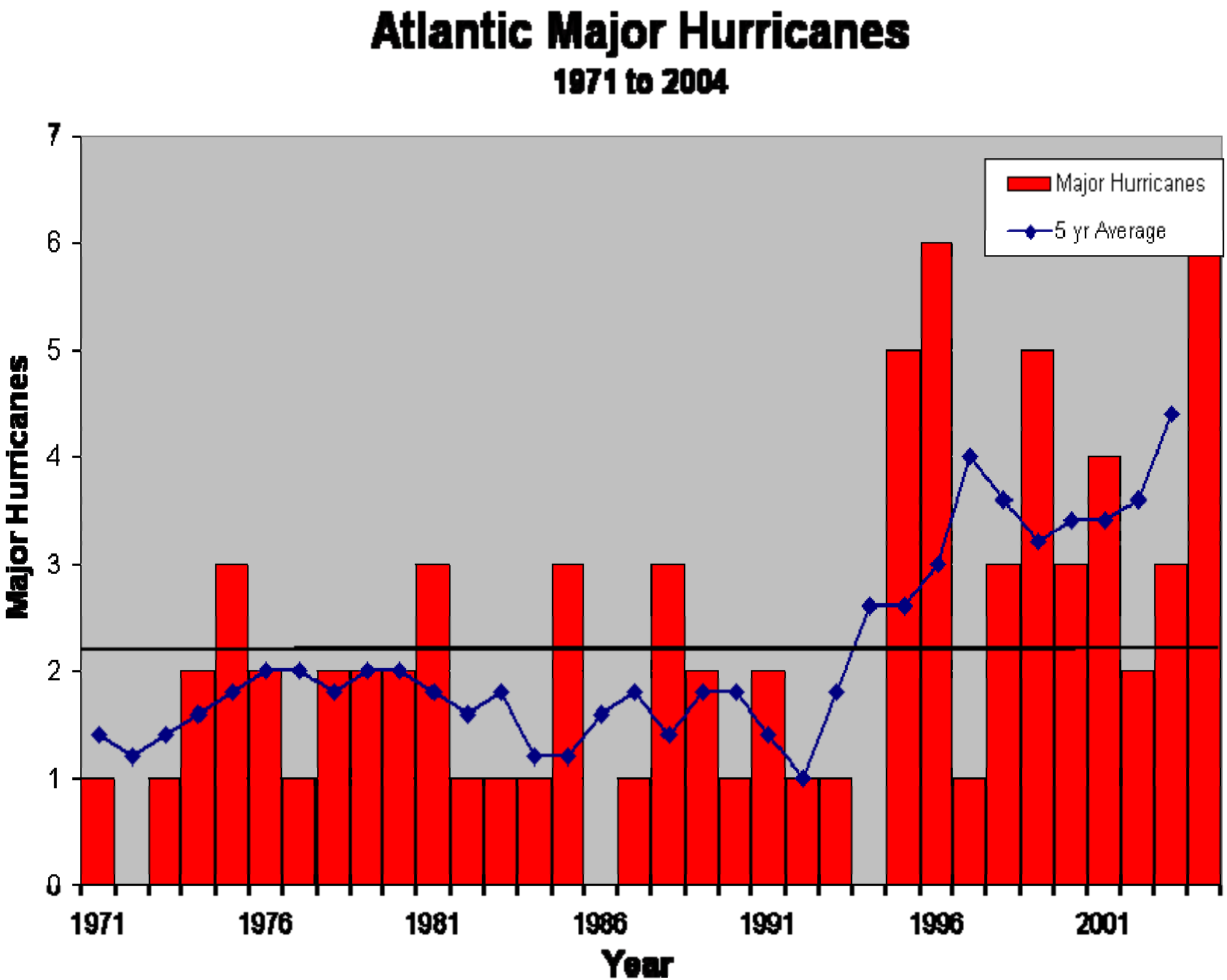
"P. Webster (EAS, GT), Greg Holland (NCAR), Judy Curry (EAS, GT) and Hai-Ru Chang (EAS, GT) reports in *Science* that the number of Category 4 and 5 hurricanes has nearly doubled over the past 35 years." (Authors' Webpage)



Possible Global Warming Impact

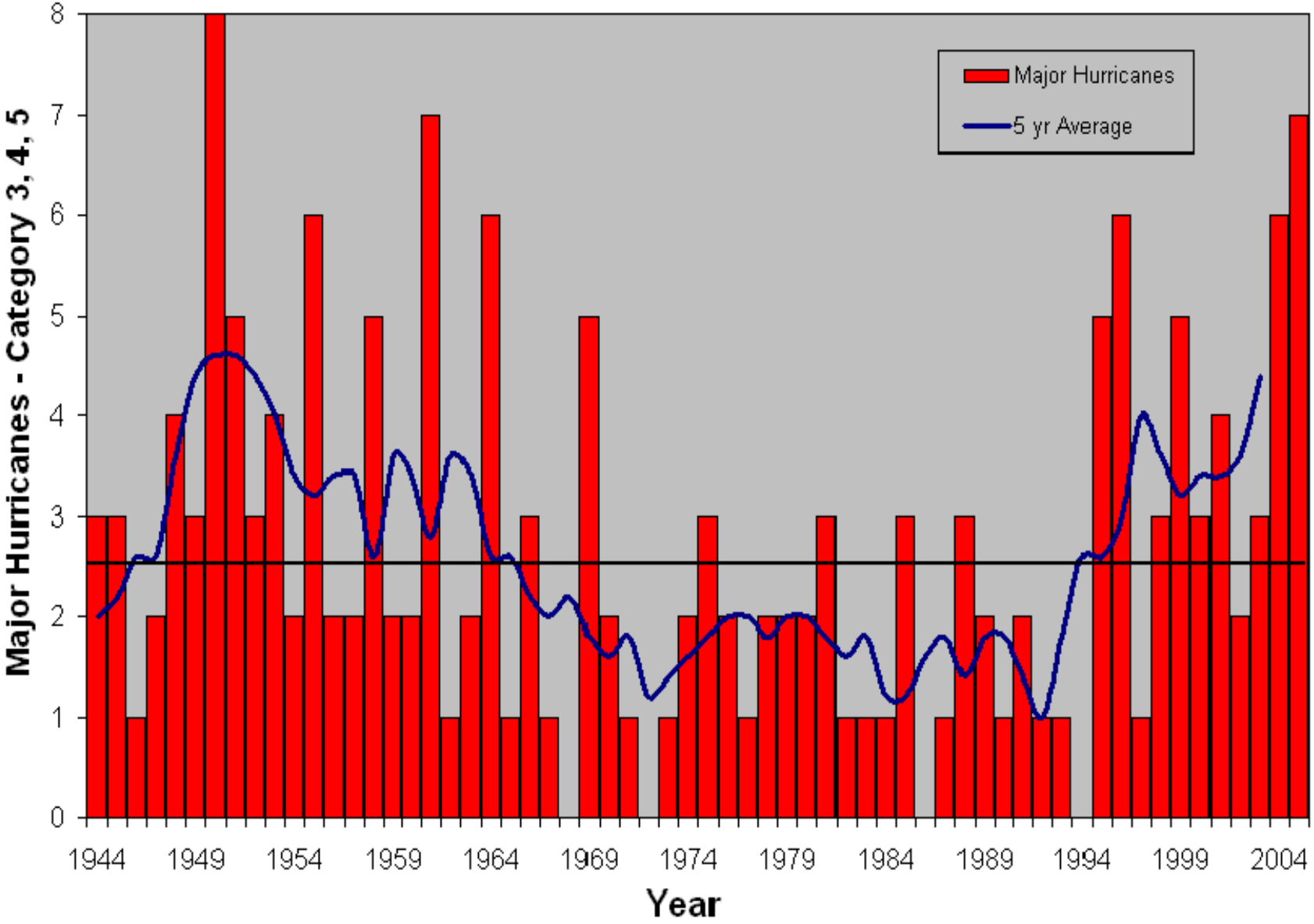
Atlantic Category 4&5 Hurricanes



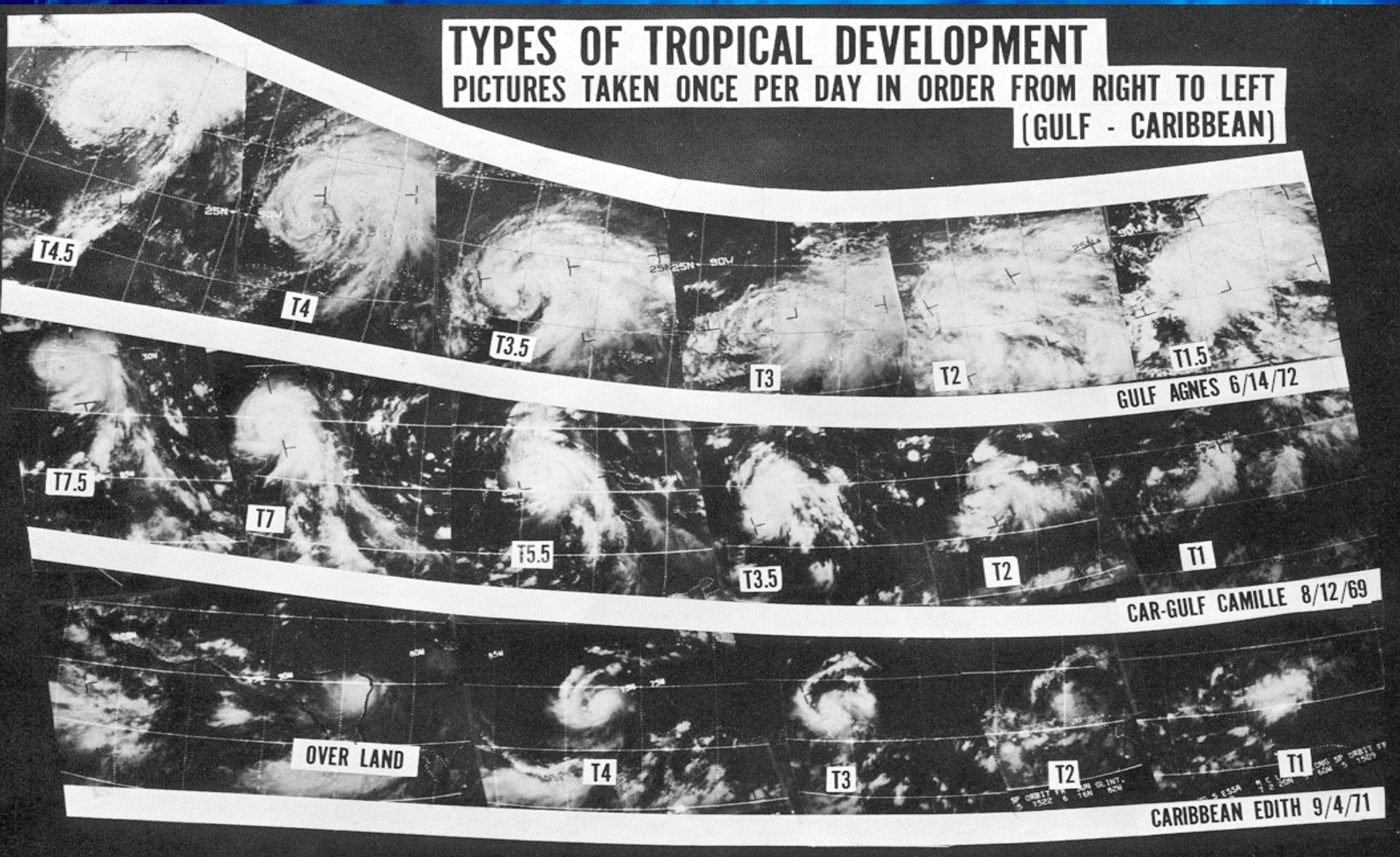

Atlantic Major Hurricanes
1971 to 2004
Major Hurricanes
5 yr Average
Major Hurricanes
0
1
2
3
4
5
6
7
1971
1976
1981
1986
1991
1996
2001
Year

Atlantic Major Hurricanes

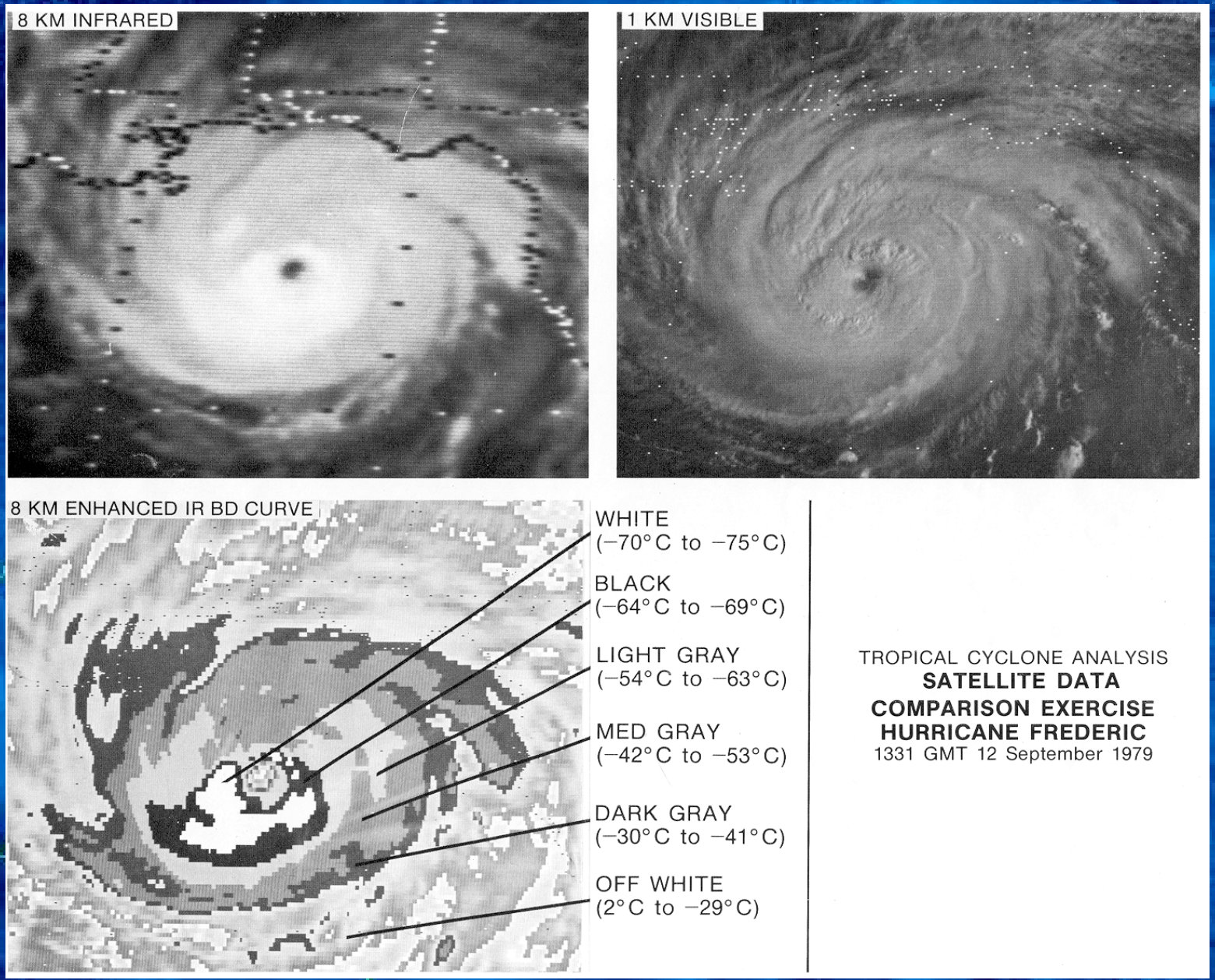
1944 to 2005



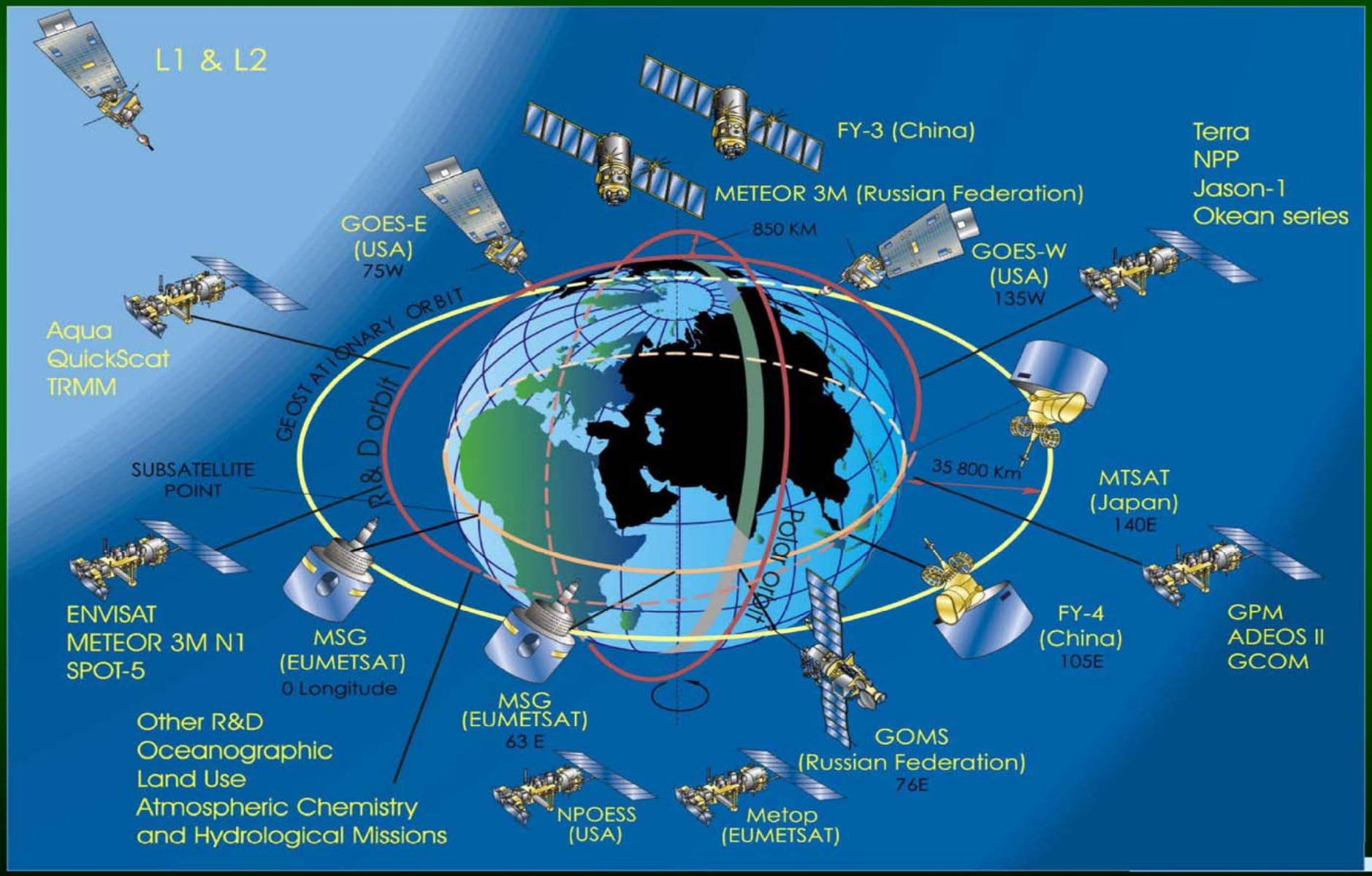
The Dvorak Technique (1972)

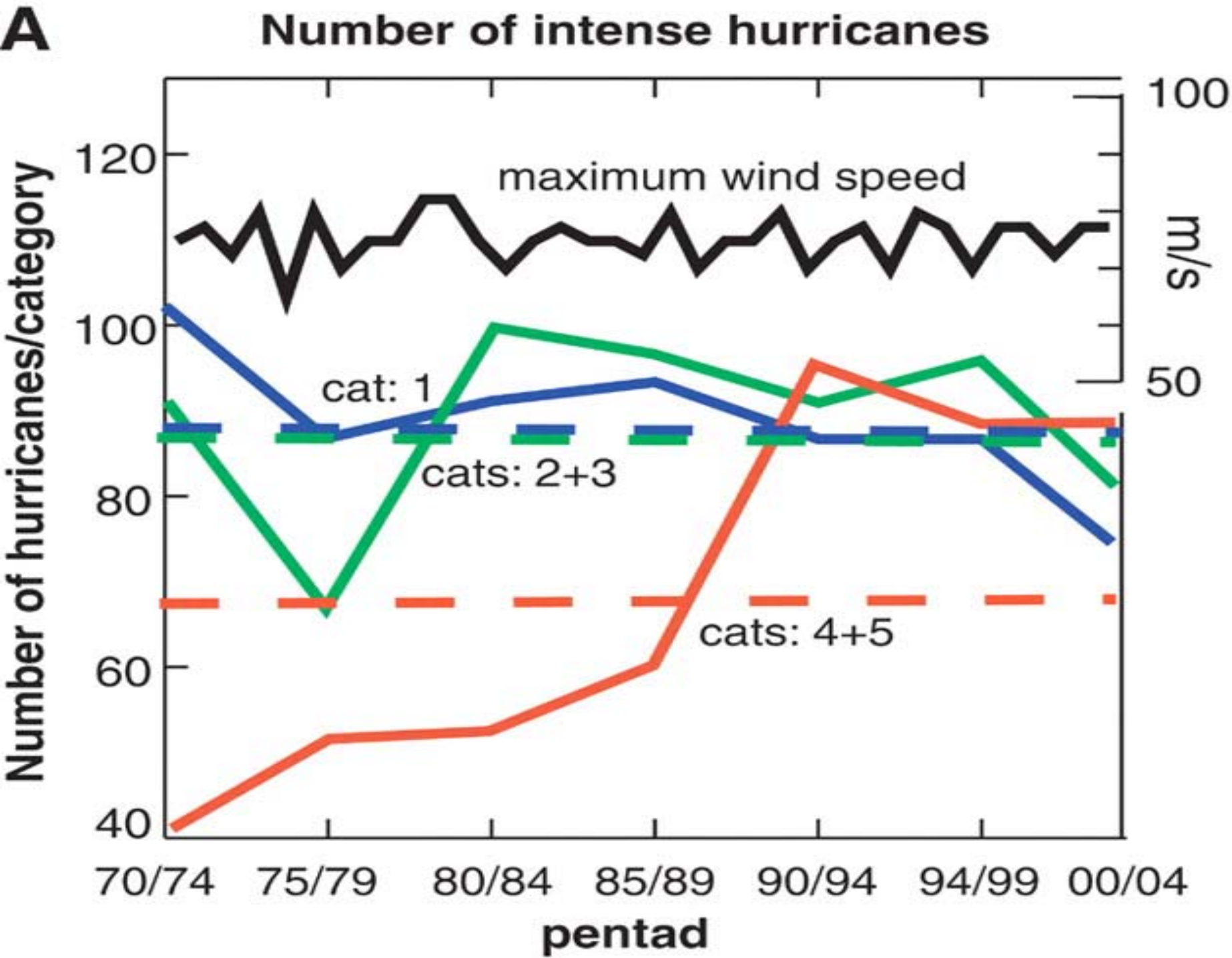


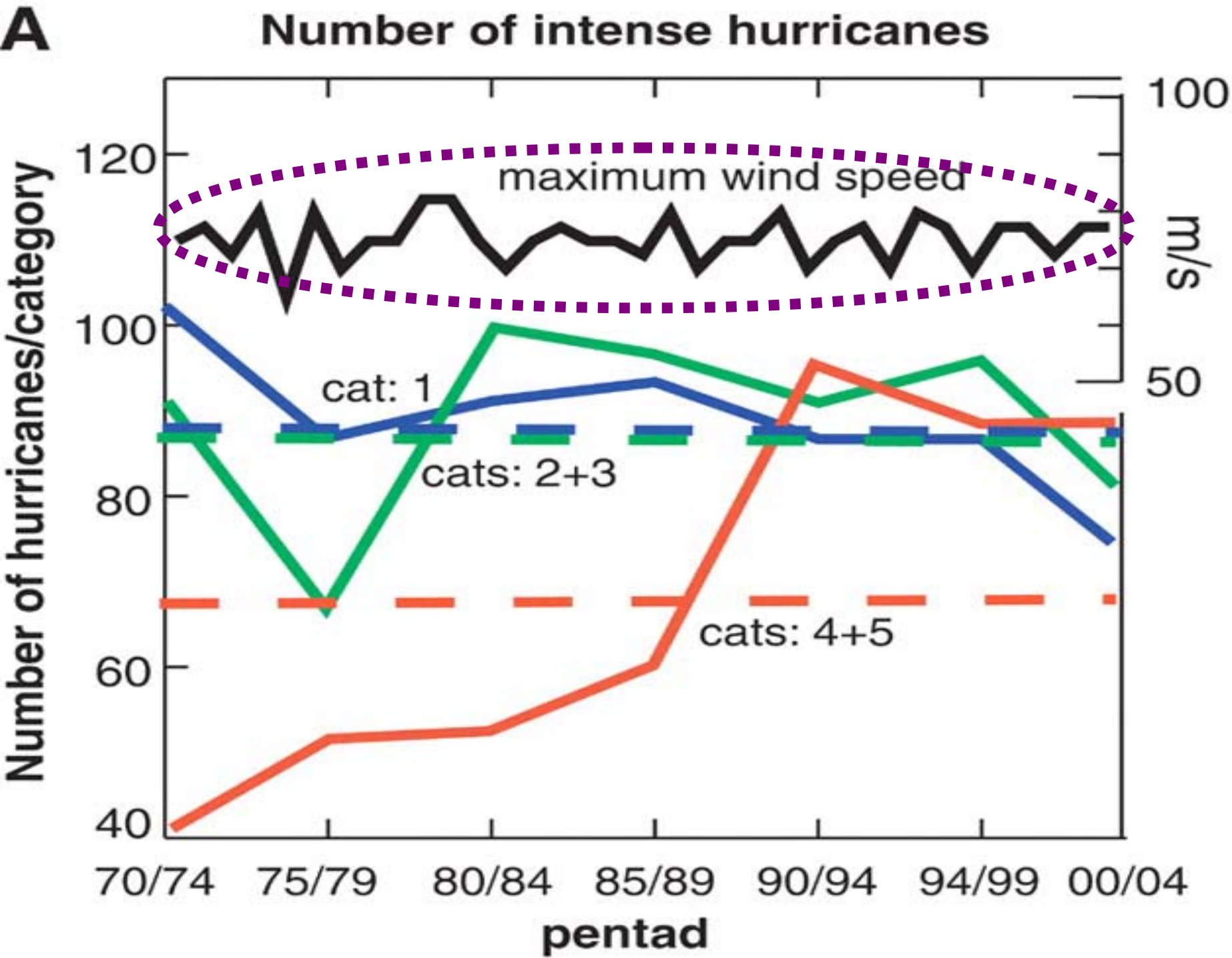
Infrared Version of Dvorak (1984)



Coverage Today of Meteorological/Oceanographic Satellites




A
Number of intense hurricanes
maximum wind speed
cat: 1
cats: 2+3
cats: 4+5
Number of hurricanes/category
m/s
120
100
80
60
40
100
50
70/74
75/79
80/84
85/89
90/94
94/99
00/04
pentad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m/s
120
100
80
60
40
100
50
70/74
75/79
80/84
85/89
90/94
94/99
00/04
pentad

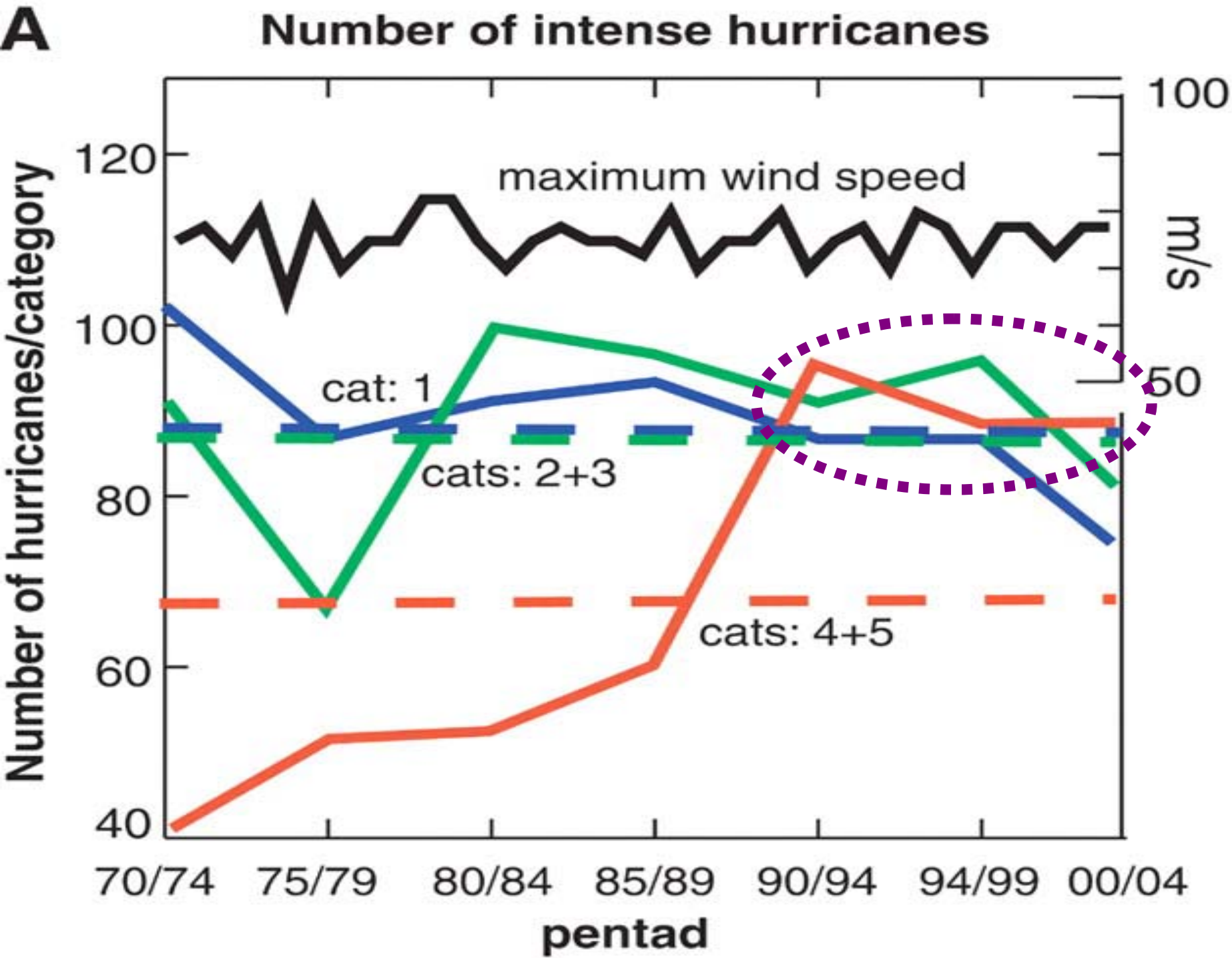
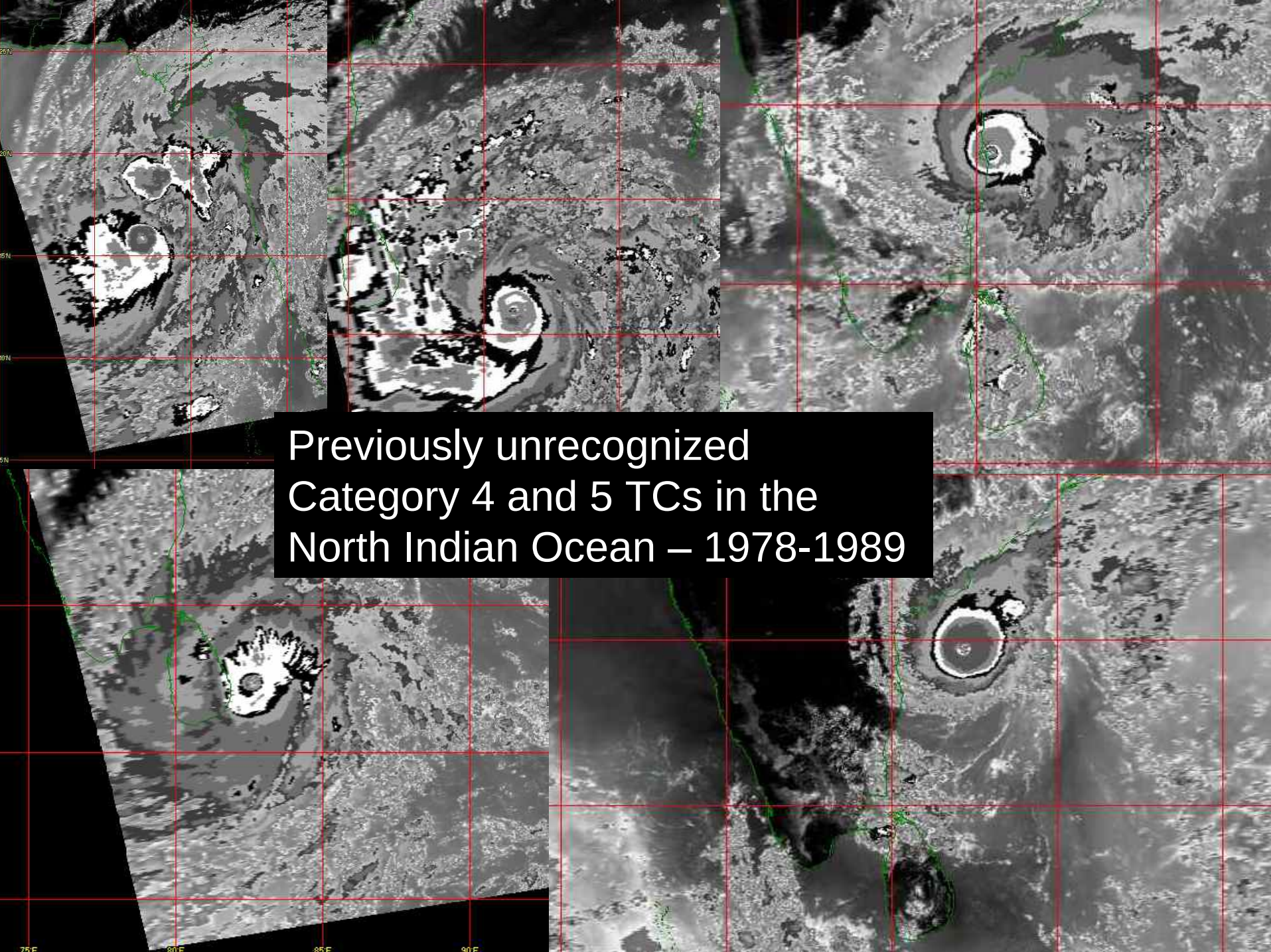
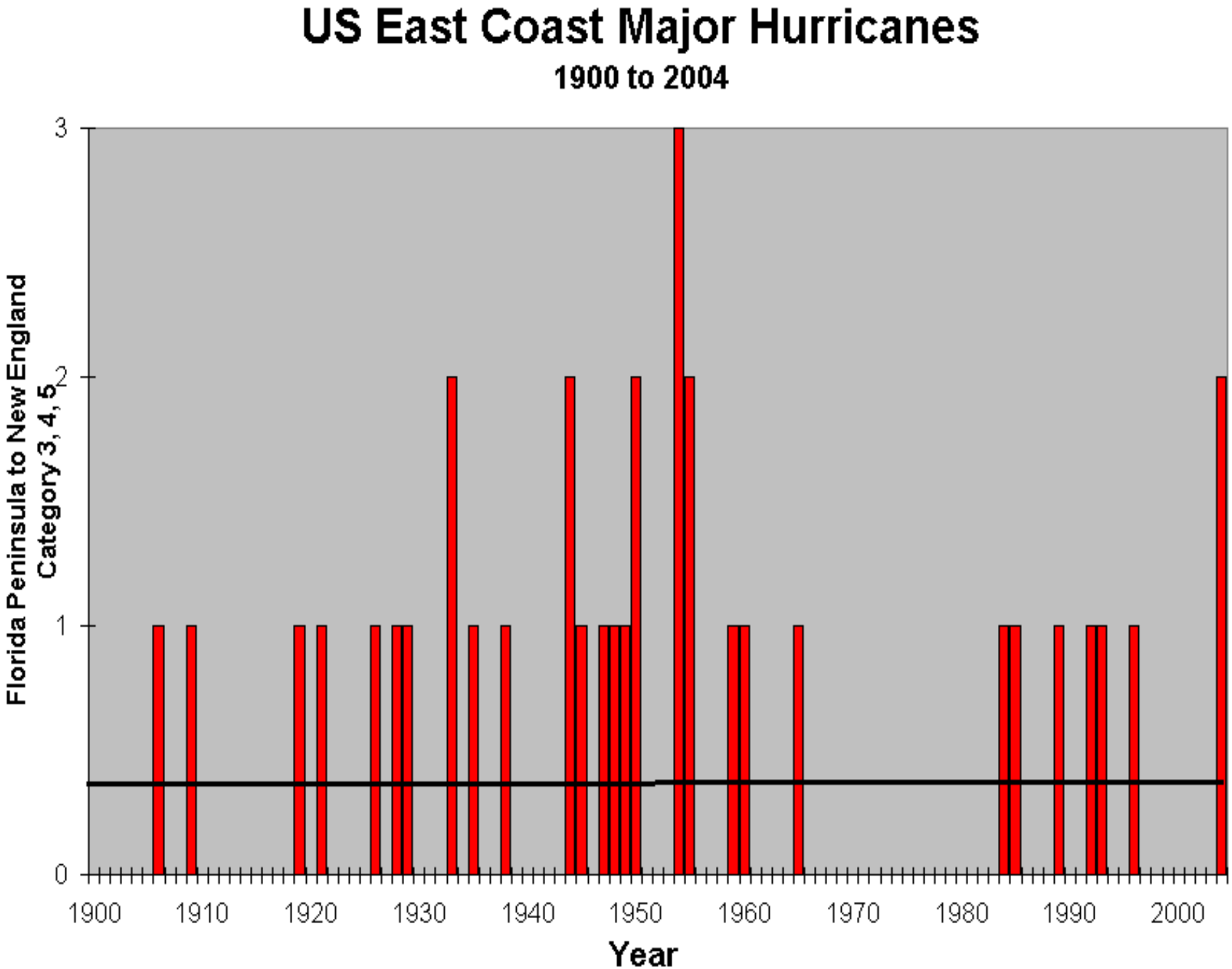

A
Number of intense hurricanes
maximum wind speed
cat: 1
cats: 2+3
cats: 4+5
Number of hurricanes/category
m/s
120
100
80
60
40
100
50
70/74
75/79
80/84
85/89
90/94
94/99
00/04
pentad

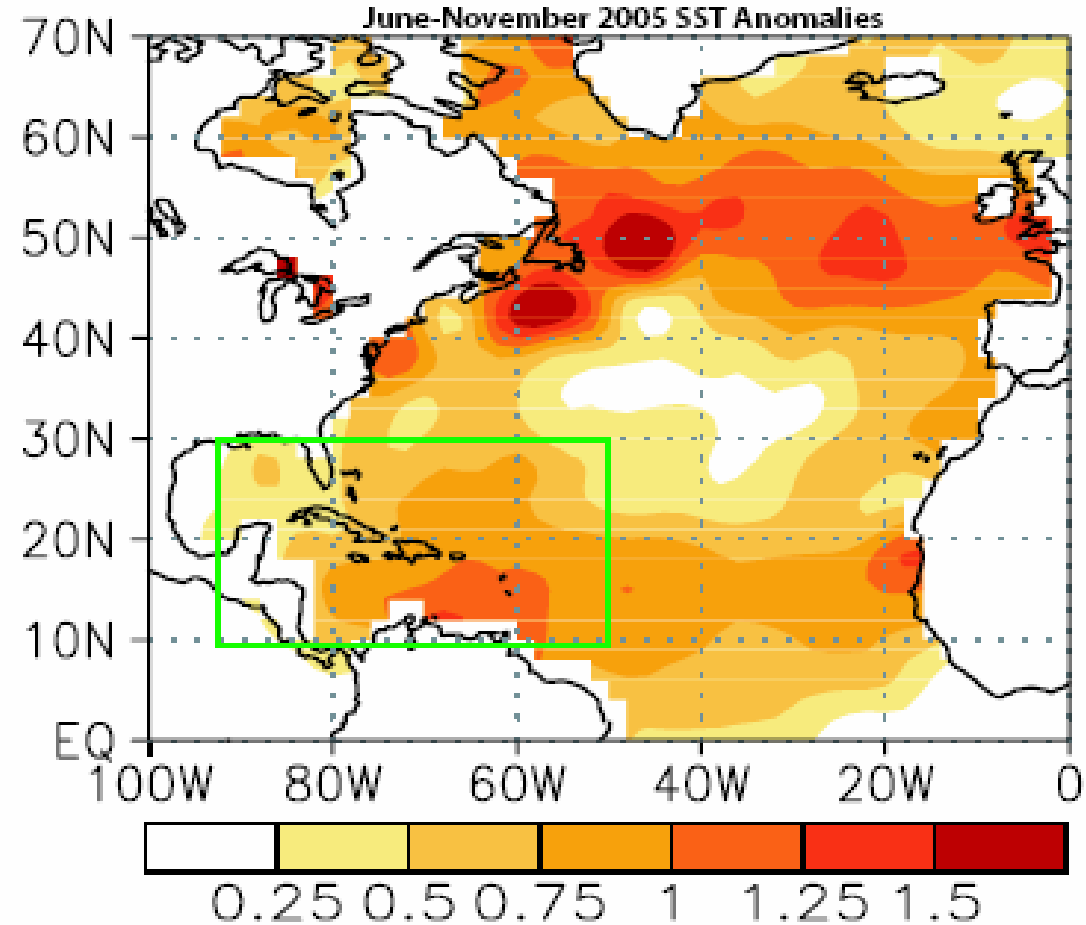
Table 1. Change in the number and percentage of hurricanes in categories 4 and 5 for the 15-year periods 1975–1989 and 1990–2004 for the different

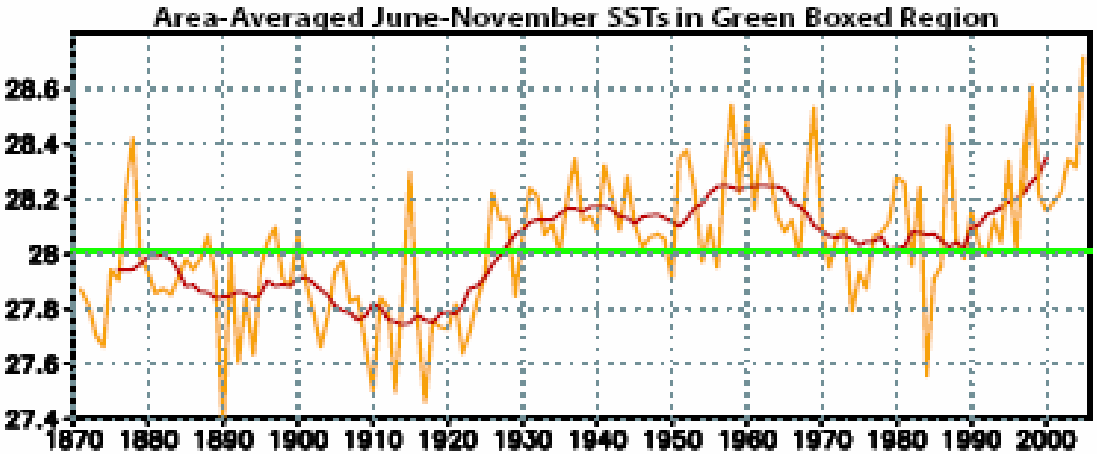
Basin	1975-1989		1990-2004	
	Number	Percentage	Number	Percentage
East Pacific Ocean	36	25	49	35
West Pacific Ocean	85	25	116	41
North Atlantic	16	20	25	25
Southwestern Pacific	10	12	22	28
North Indian	1	8	7	25
South Indian	23	18	50	34


Previously unrecognized
Category 4 and 5 TCs in the
North Indian Ocean – 1978-1989


US East Coast Major Hurricanes
1900 to 2004
Florida Peninsula to New England
Category 3, 4, 5
0
1
2
3
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
Year

2005:
1 –
Wilma

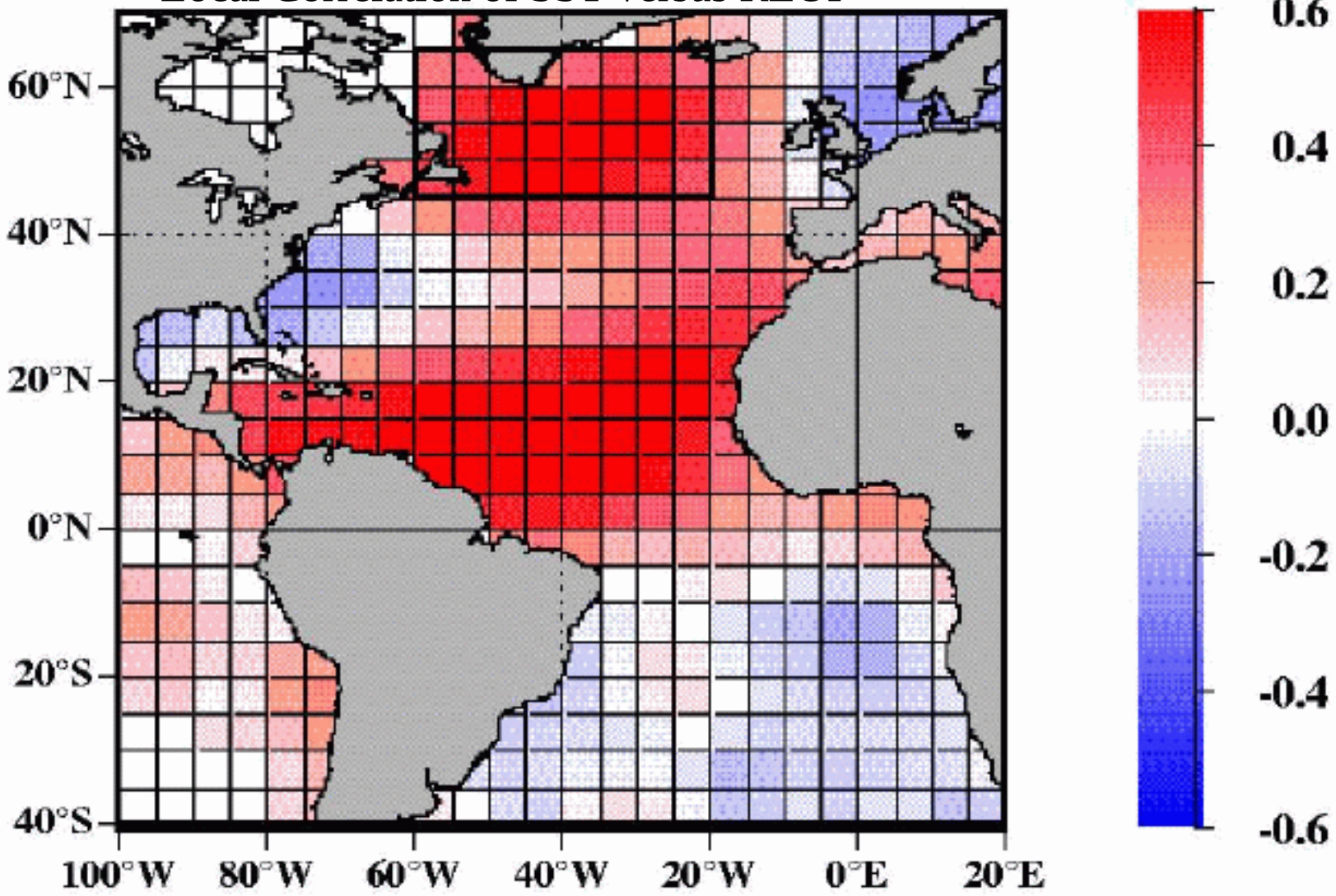




Tropical Atlantic/ Caribbean Ocean Temperatures 1870 to 2005

Atlantic Multidecadal Mode

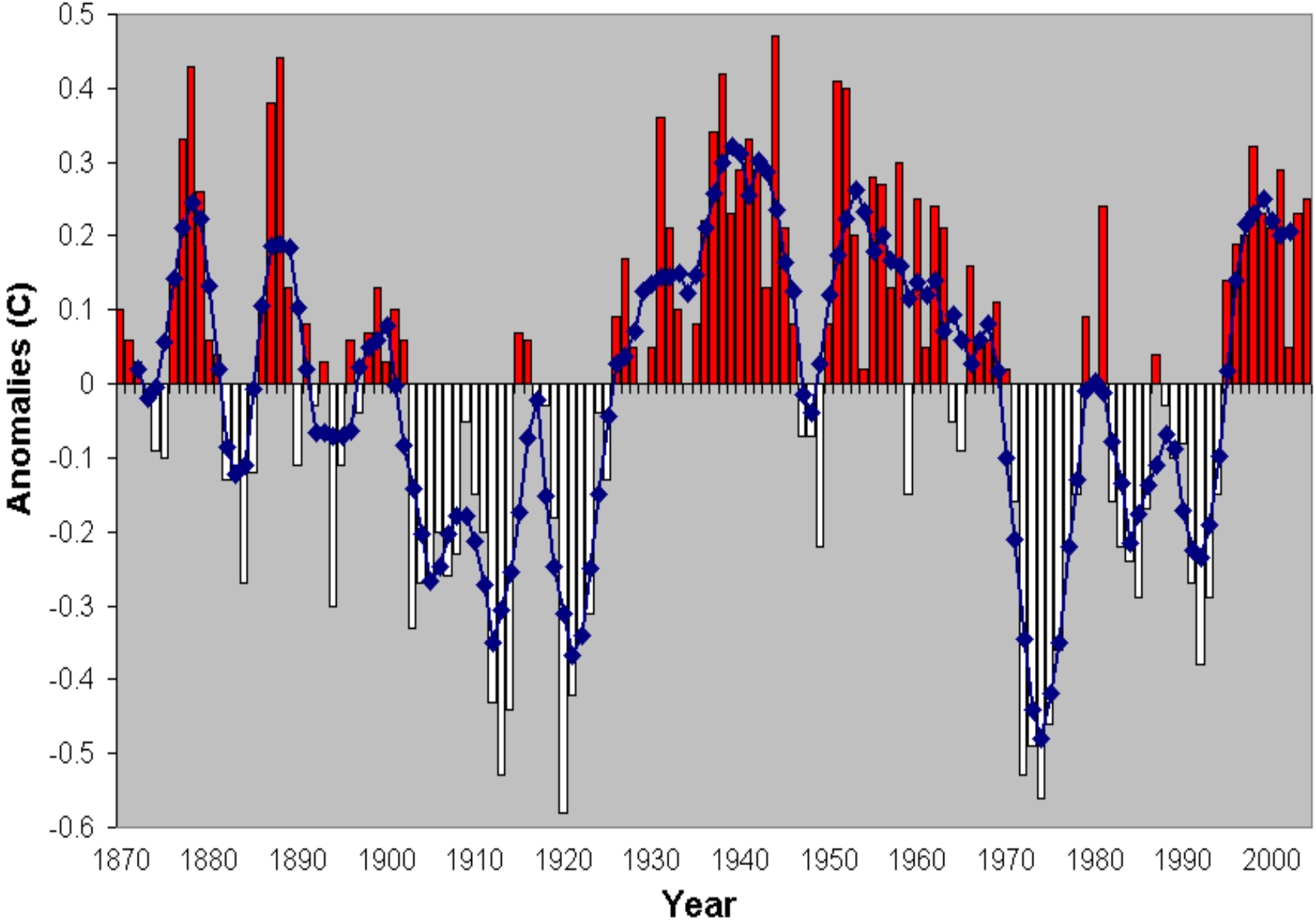
Local Correlation of SST versus REOF



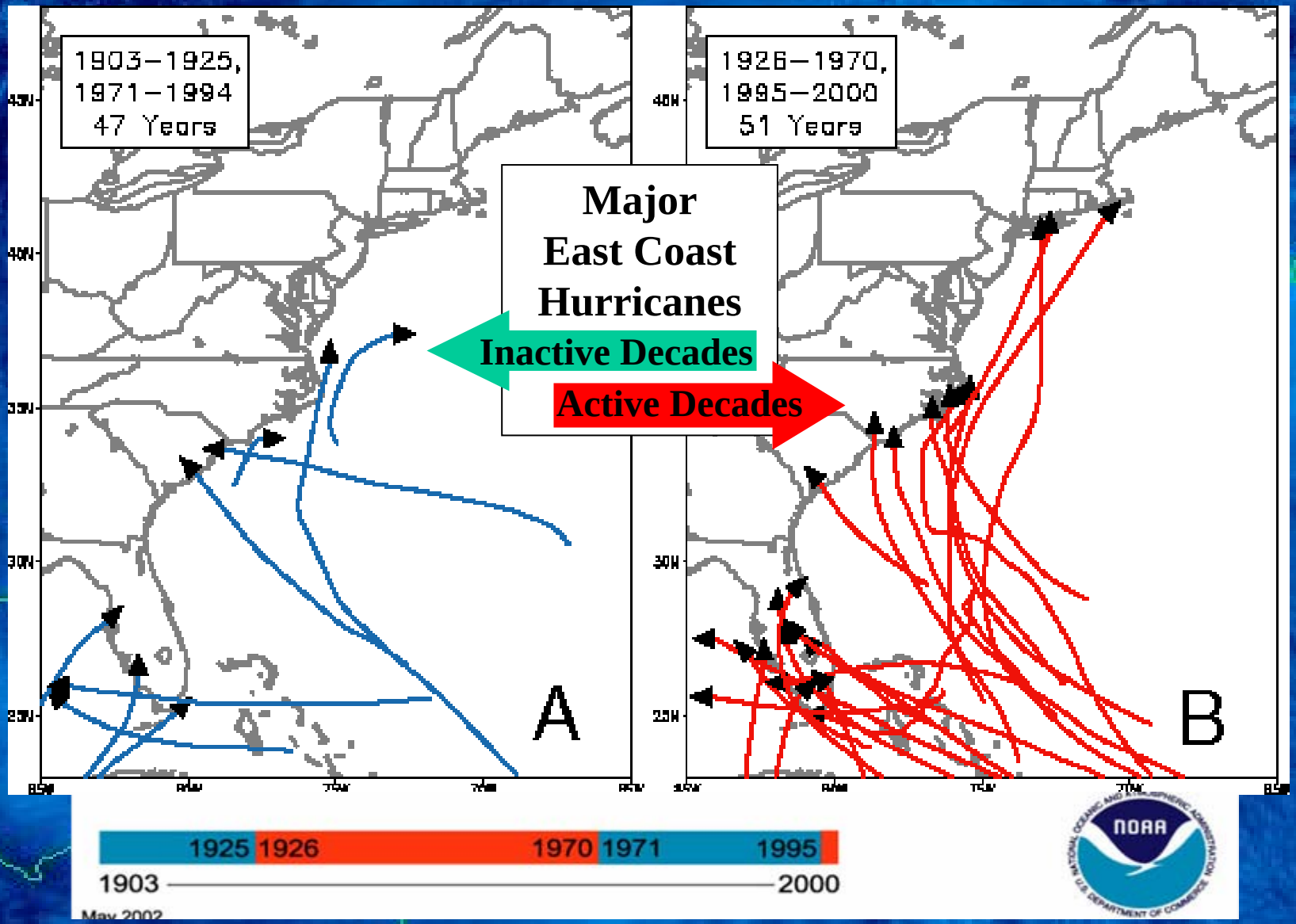
Mestas-Nunez and Enfield (1999)

Atlantic SST Multidecadal Mode

1870-2005

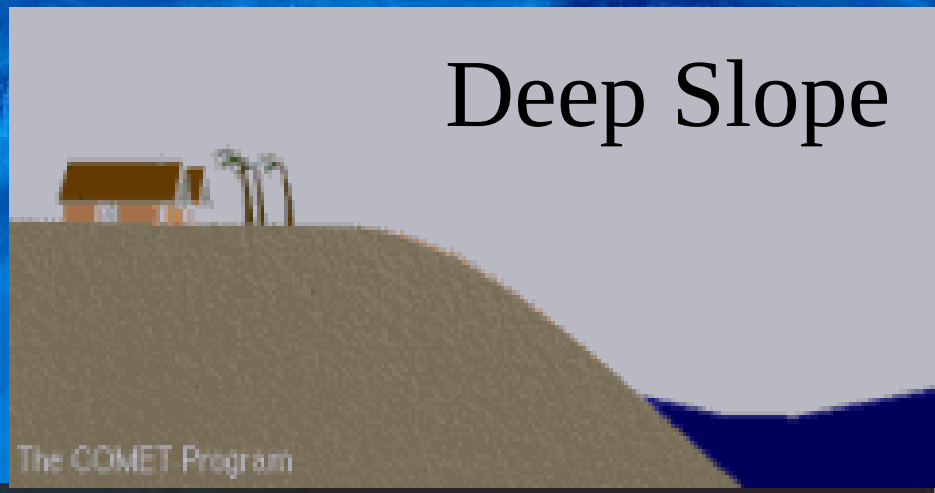


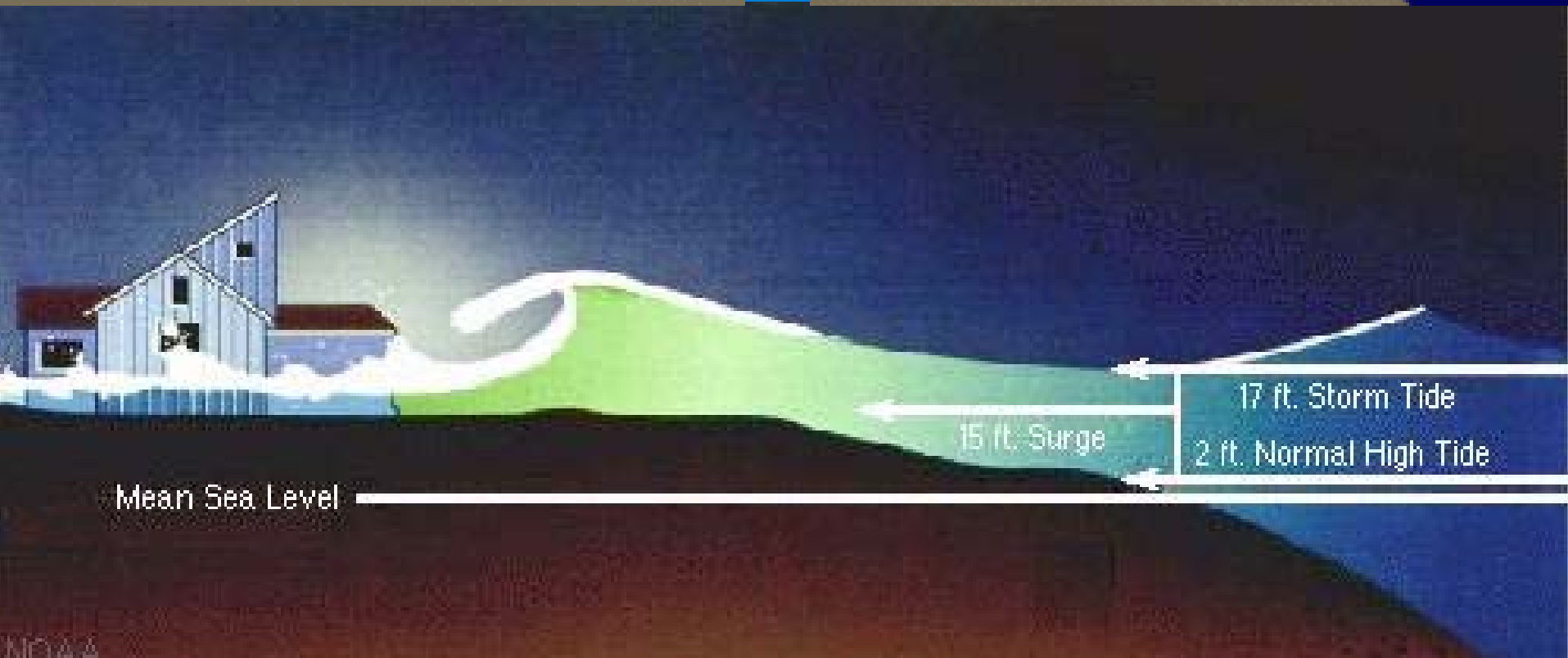
U.S. MAJOR LANDFALLING HURRICANES: 1903-2000



Storm Surge


Shallow Slope
The COMET Program


Deep Slope
The COMET Program


17 ft. Storm Tide
15 ft. Surge
2 ft. Normal High Tide
Mean Sea Level

Inland Flooding - Rainfall from hurricanes

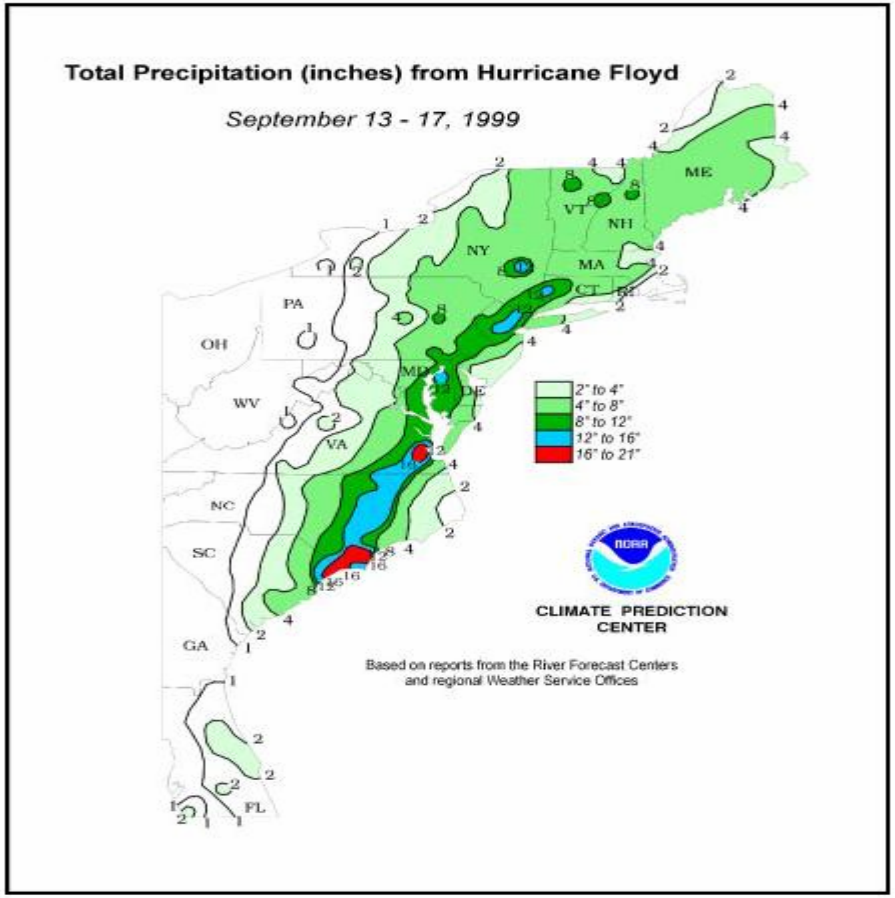
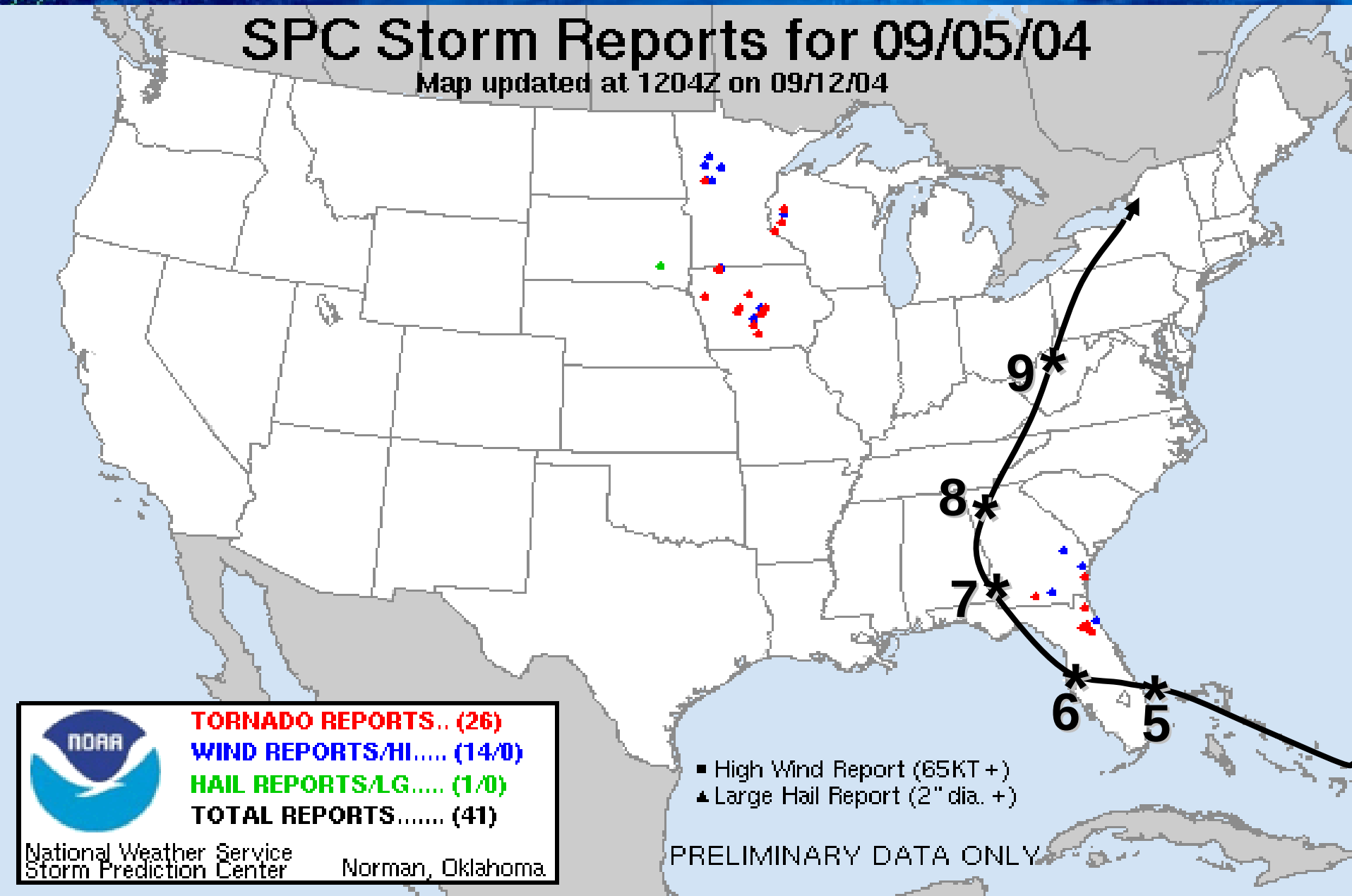
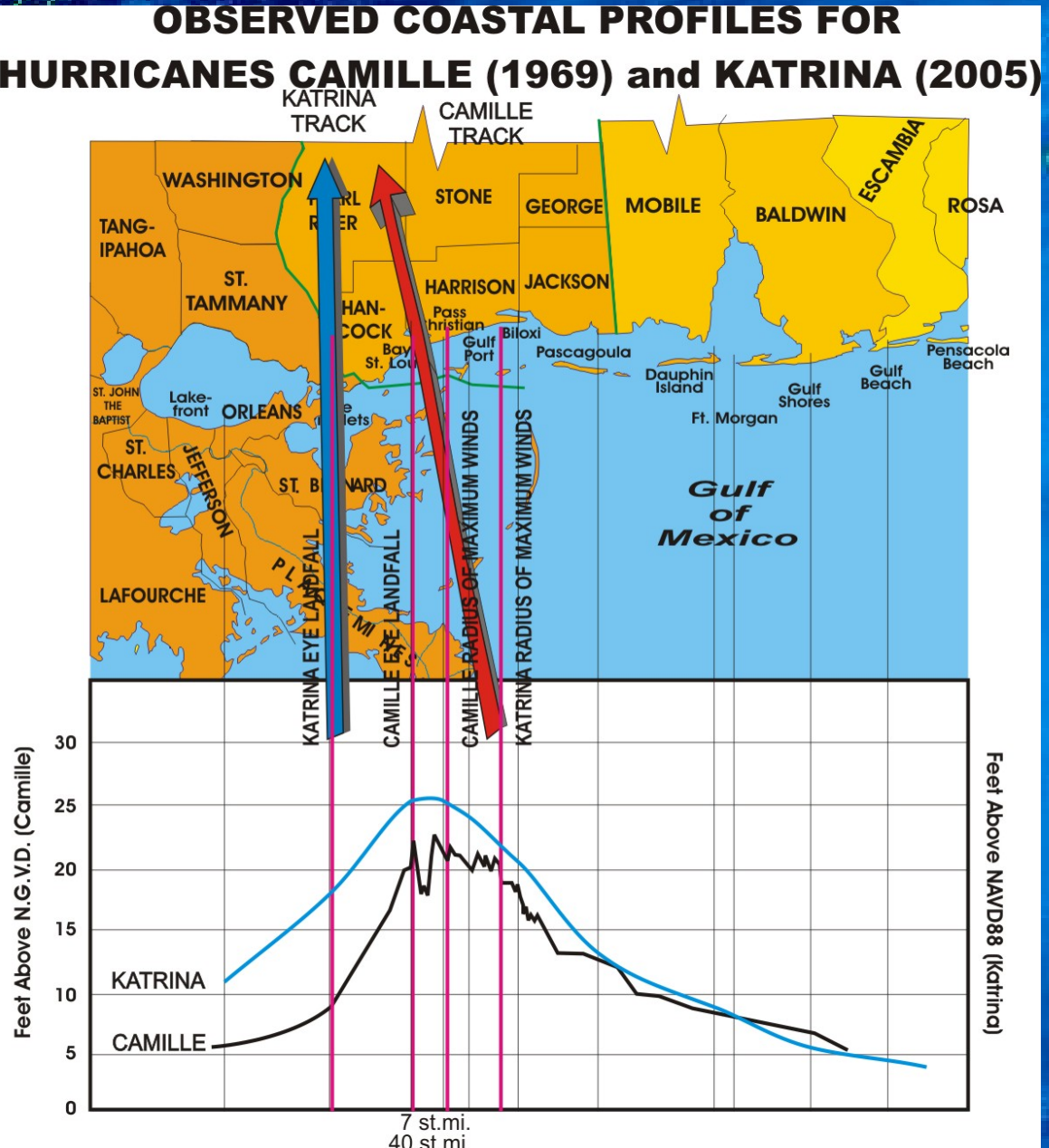


Figure 5. Total Precipitation (inches) from Hurricane Floyd, September 13-17, 1999.

Hurricane Frances' Tornadoes



Katrina's Storm Surge in Mississippi



It is possible today to destroy/weaken hurricane before they strike.

Project STORMFURY: A Scientific Chronicle 1962–1983

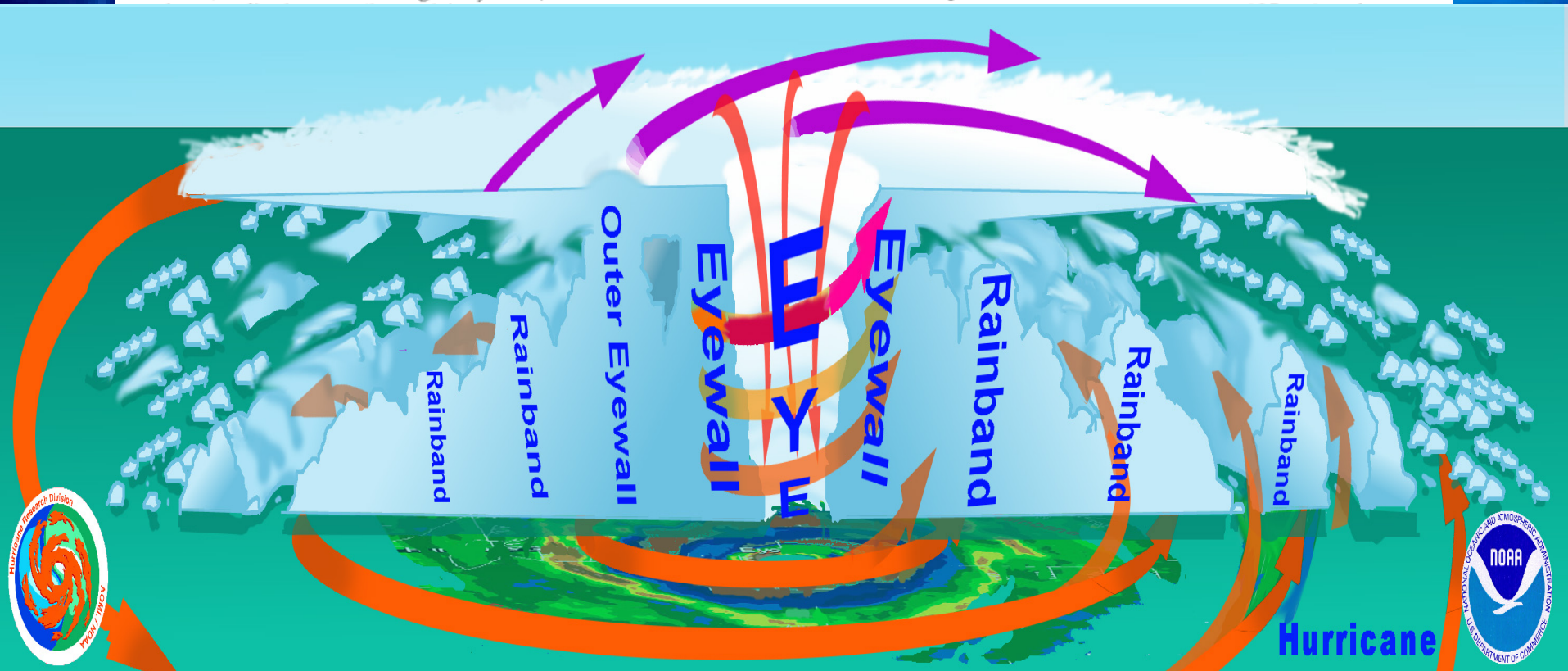
H. E. Willoughby, D. P. Jorgensen[1], R. A. Black, and S. L. Rosenthal

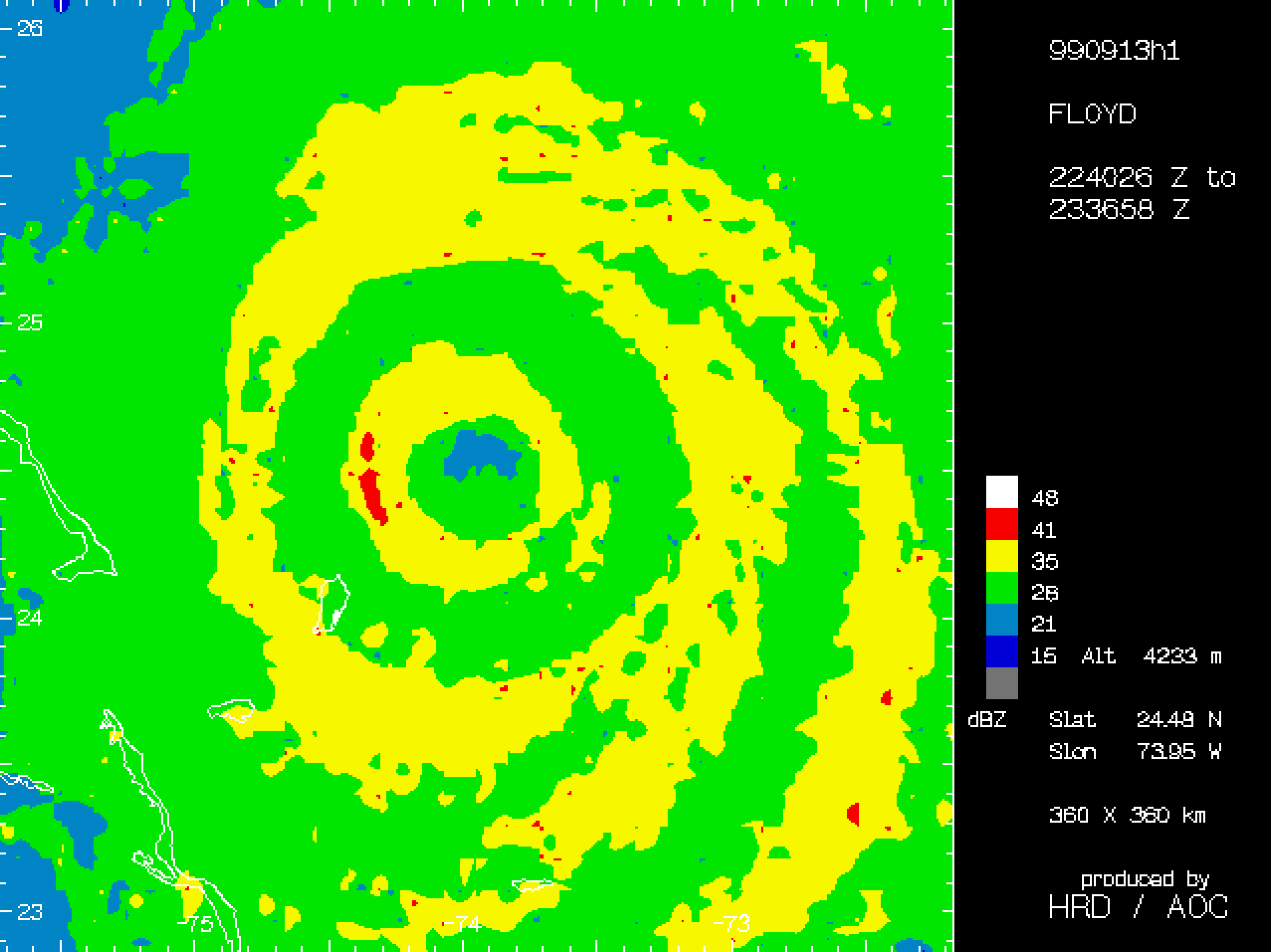
Hurricane Research Division, AOML/NOAA
4301 Rickenbacker Causeway
Miami, FL 33149

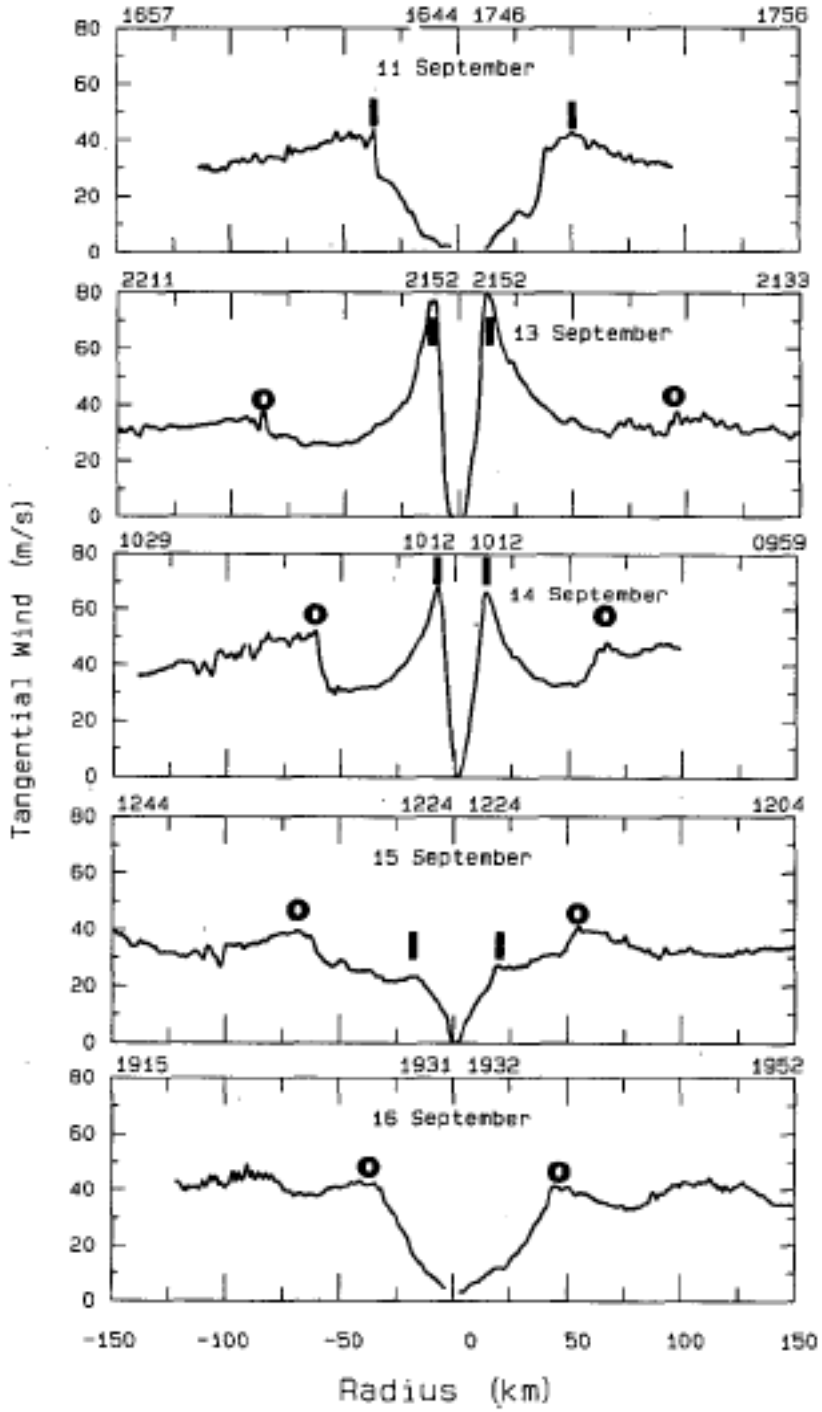
Abstract

Between 1962 and 1983, research in hurricane modification centered on an ambitious experimental program, Project STORMFURY. The proposed modification technique involved artificial stimulation of convection outside the eye wall through seeding with silver iodide. The artificially invigorated convection, it was argued, would compete with the convection in the original eye wall, lead to reformation of

of Georgia and North Florida. After seeding, observers aboard the experimental aircraft noted changes in the visual appearance of the clouds, but they could not demonstrate any other effects on structure or intensity. The one indisputable change—although apparently not the result of seeding (Mook *et al.*, 1957)—was a reversal of track toward the west, which ultimately led to landfall on the coasts of Georgia and

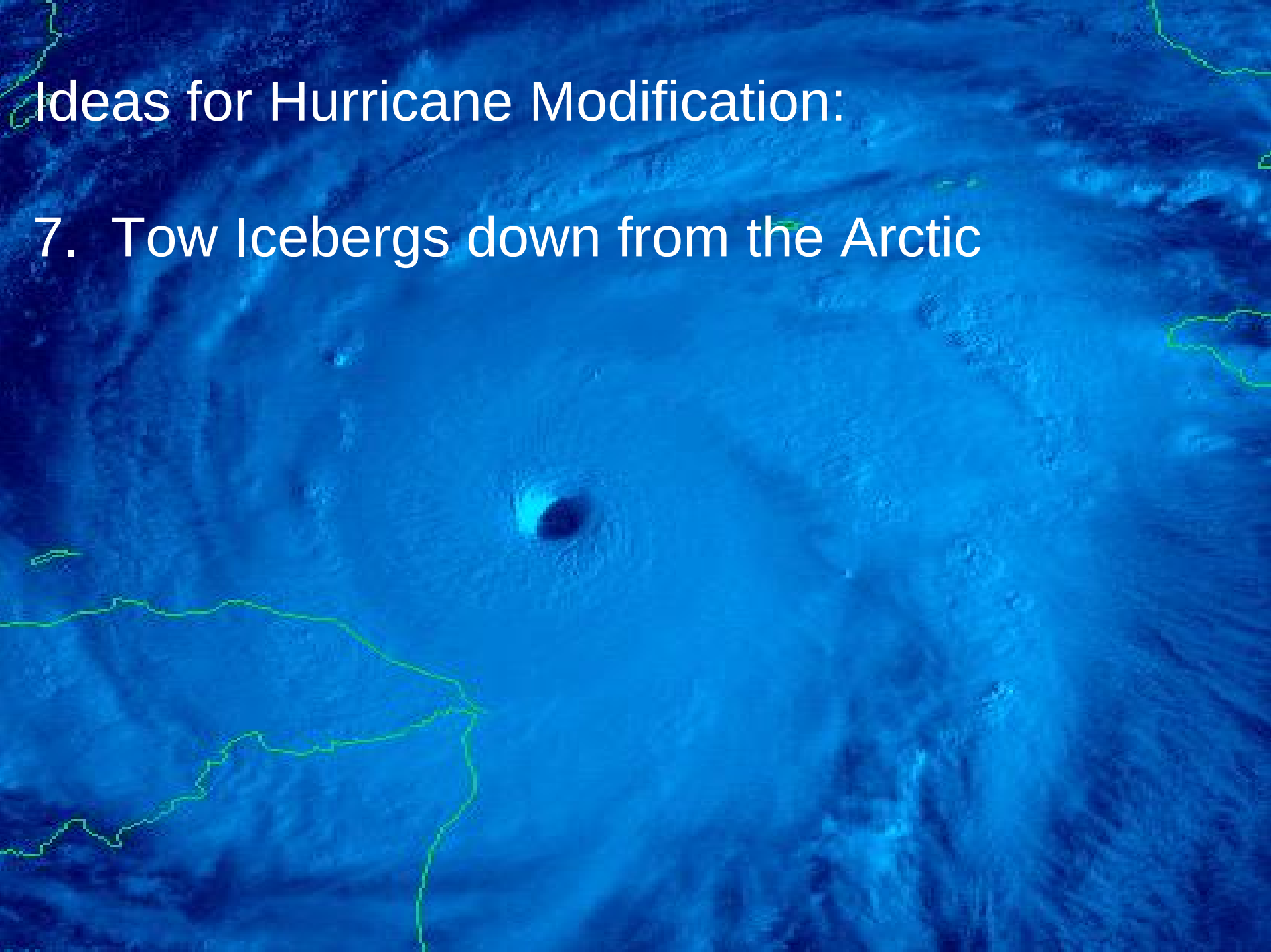



26
25
24
23
-75
-74
-73
990913h1
FLOYD
224026 Z to
233658 Z
48
41
35
28
21
15 Alt 4233 m
dBZ
Slat 24.49 N
Slon 73.95 W
360 X 360 km
produced by
HRD / AOC



Concentric Eyewall Cycle

Black & Willoughby (1992)



Ideas for Hurricane Modification:

7. Tow Icebergs down from the Arctic

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7. Tow Icebergs down from the Arctic
6. Bring up Cool Water to the Ocean’s Surface from Below

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2. Blow Hurricanes back to Sea with Giant Fans

Ideas for Hurricane Modification:

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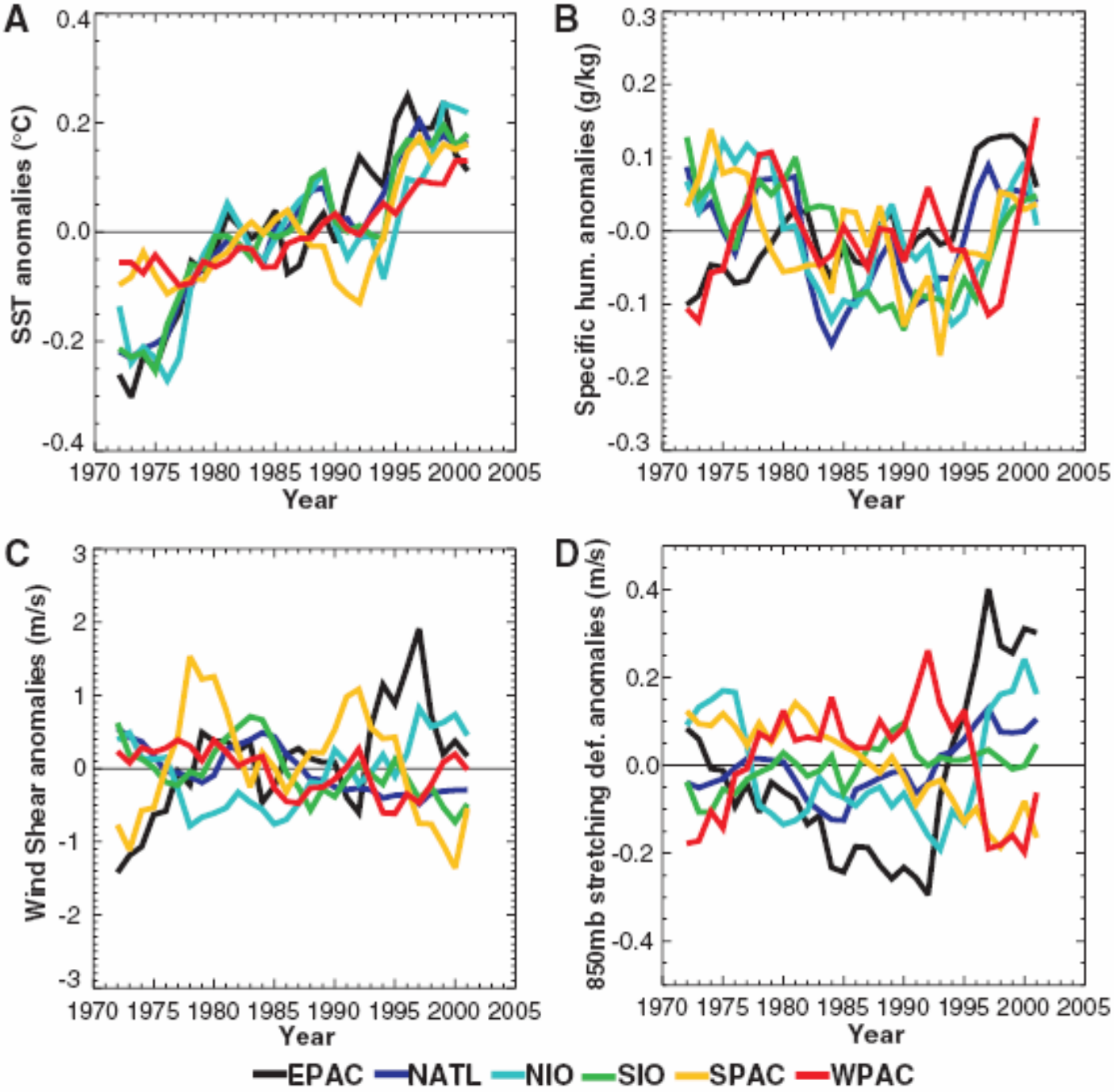
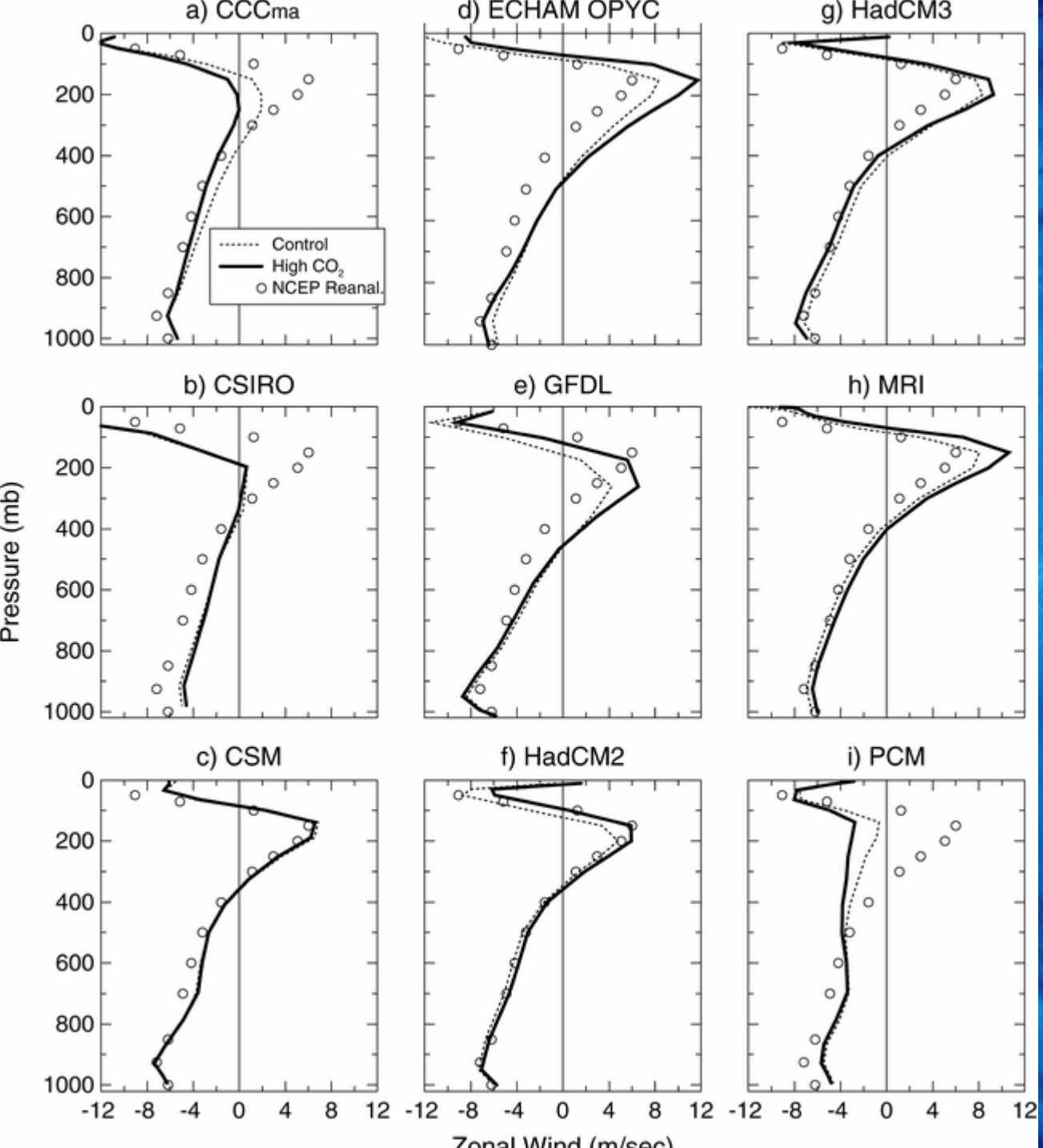
4. Seed them with Carbon Black
3. Seed them with Water Absorbing Substances
2. Blow Hurricanes back to Sea with Giant Fans
1. Hit them with a Nuclear Bomb

Mitigate instead of Modify



New Results from Hoyos et al.



How does the wind shear change in doubled CO2?

(Knutson & Tuleya 2004)

Atlantic Hurricane Database Re-Analysis Project

http://www.aoml.noaa.gov/hrd/data_sub/re_anal.html

1851 through 1914 changes accepted and officially adopted by NHC. 1915 through 1930 have been submitted to NHC. Remainder of 20th Century currently being reanalyzed.

RE-ANALYSES NEED TO BE CONDUCTED GLOBALLY!!!

"Florida's Hurricane History"

Effects of Anthropogenic Global Warming On Tropical Cyclones Around 2100

Frequency? +/-10%
Maximum intensity? +5%
Average intensity? +5%
Rainfall? +5%
Area of formation/occurrence? No change
Size? ???

JHT Website

www.nhc.noaa.gov/jht/index.shtml

USWRP

Joint Hurricane Testbed

- JHT Home
- Terms of Reference (PDF)
- Staff
- Steering Committee
- Main Activities
- Highlights - 2001 to present
- Current Projects (2005-2007)
- Past Projects
- Administrative Presentations and Information

Mission Statement

The mission of the Joint (National Oceanic and Atmospheric Administration - NOAA, Navy, and National Aeronautics and Space Administration - NASA) Hurricane Test Bed is to transfer more rapidly and smoothly new technology, research results, and observational advances of the United States Weather Research Program (USWRP), its sponsoring agencies, the academic community and other groups into improved tropical cyclone analysis and prediction at operational centers.

WHAT'S NEW

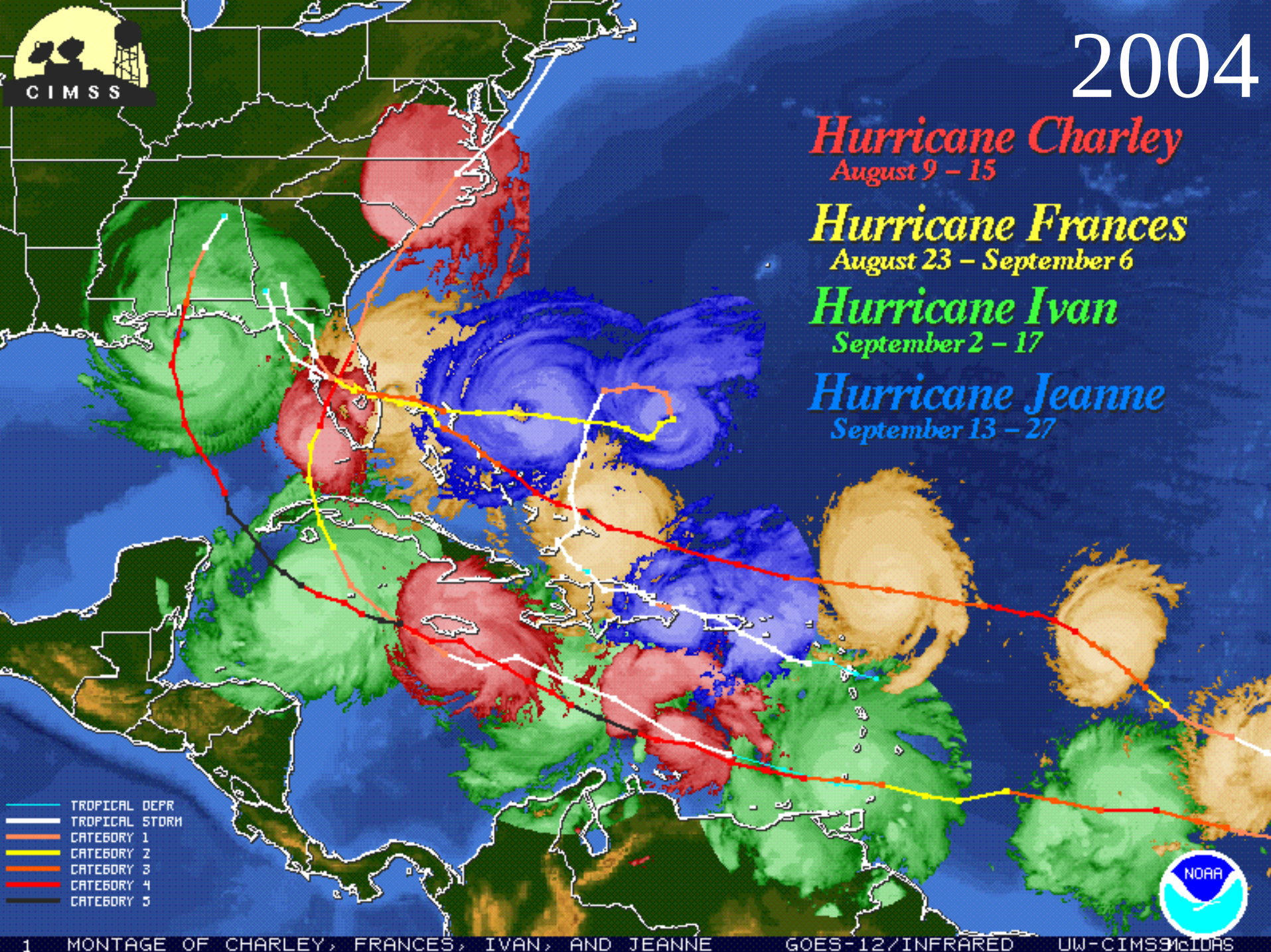
Updated January 31, 2006:

- 2005-2007 Projects and Goals
- The 2005 Midyear Reports are available in the Project Table

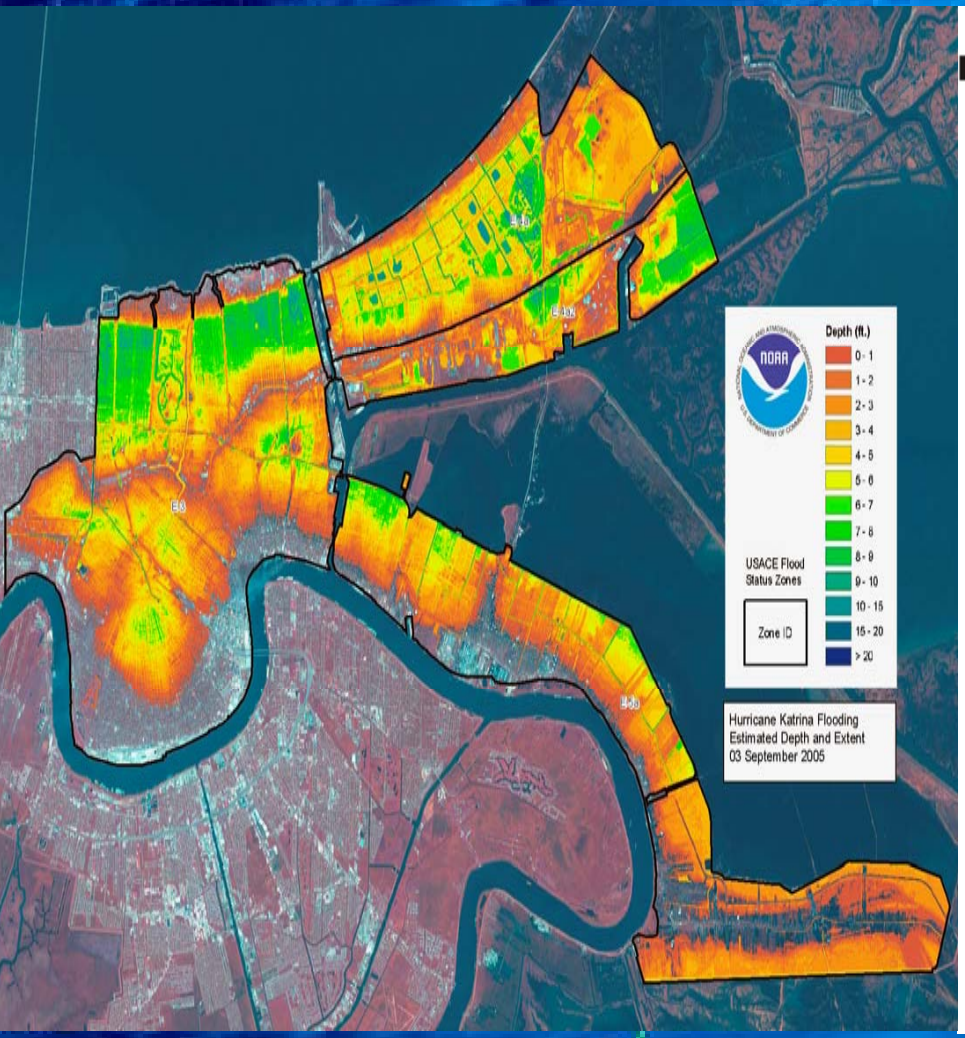
Added February 10, 2006:

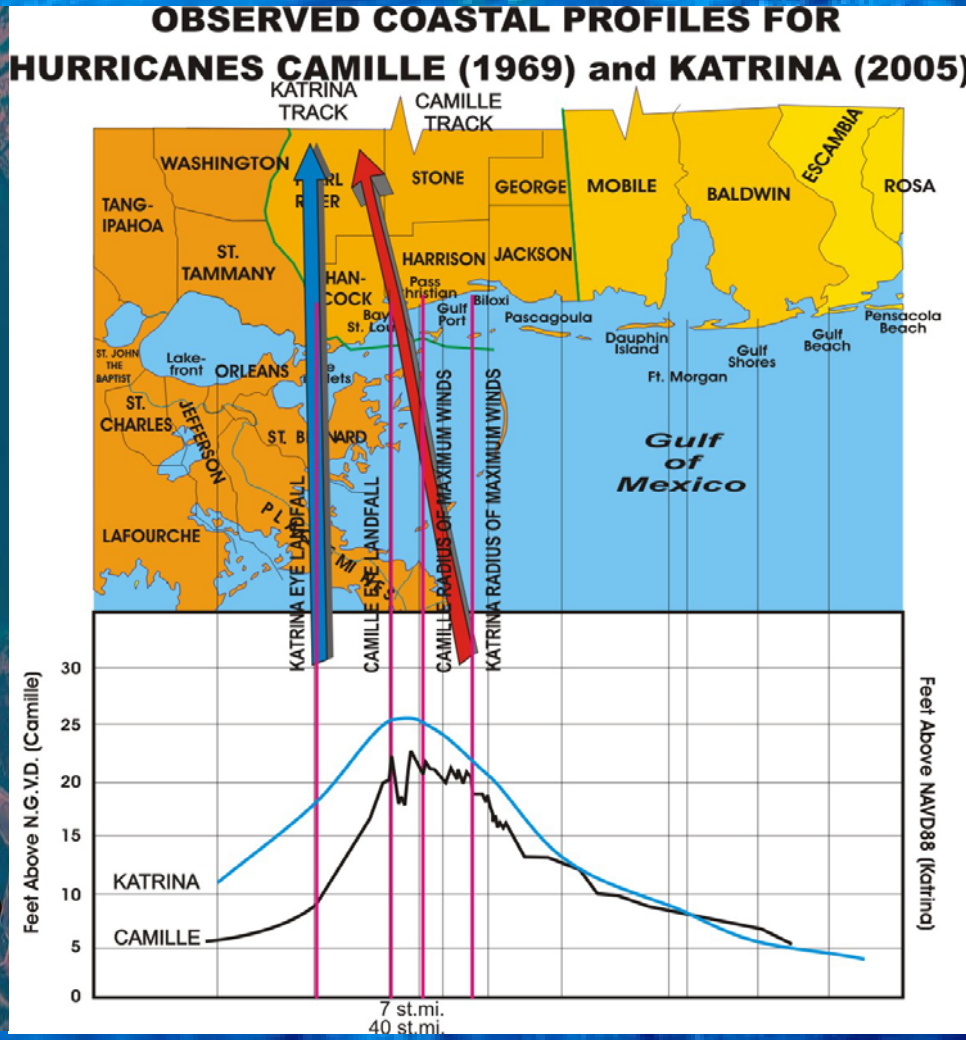
- The Joint Hurricane Testbed (JHT): Progress and Future Plans, Chris Landsea (TPC/NHC) - American Meteorological Society's Annual Meeting, February 2006 presentation.
(PDF format)

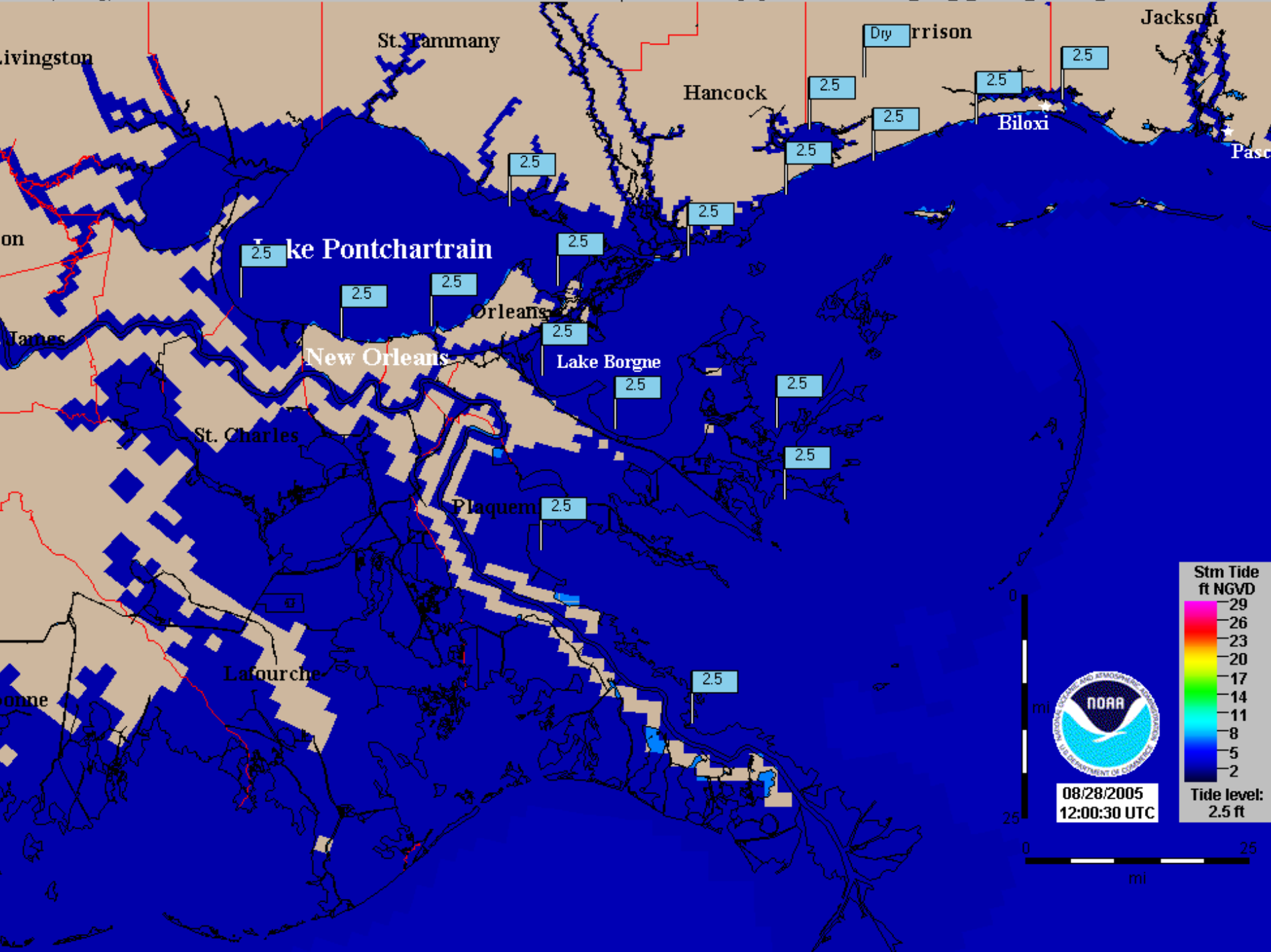
Return to NHC Home – Contact NHC

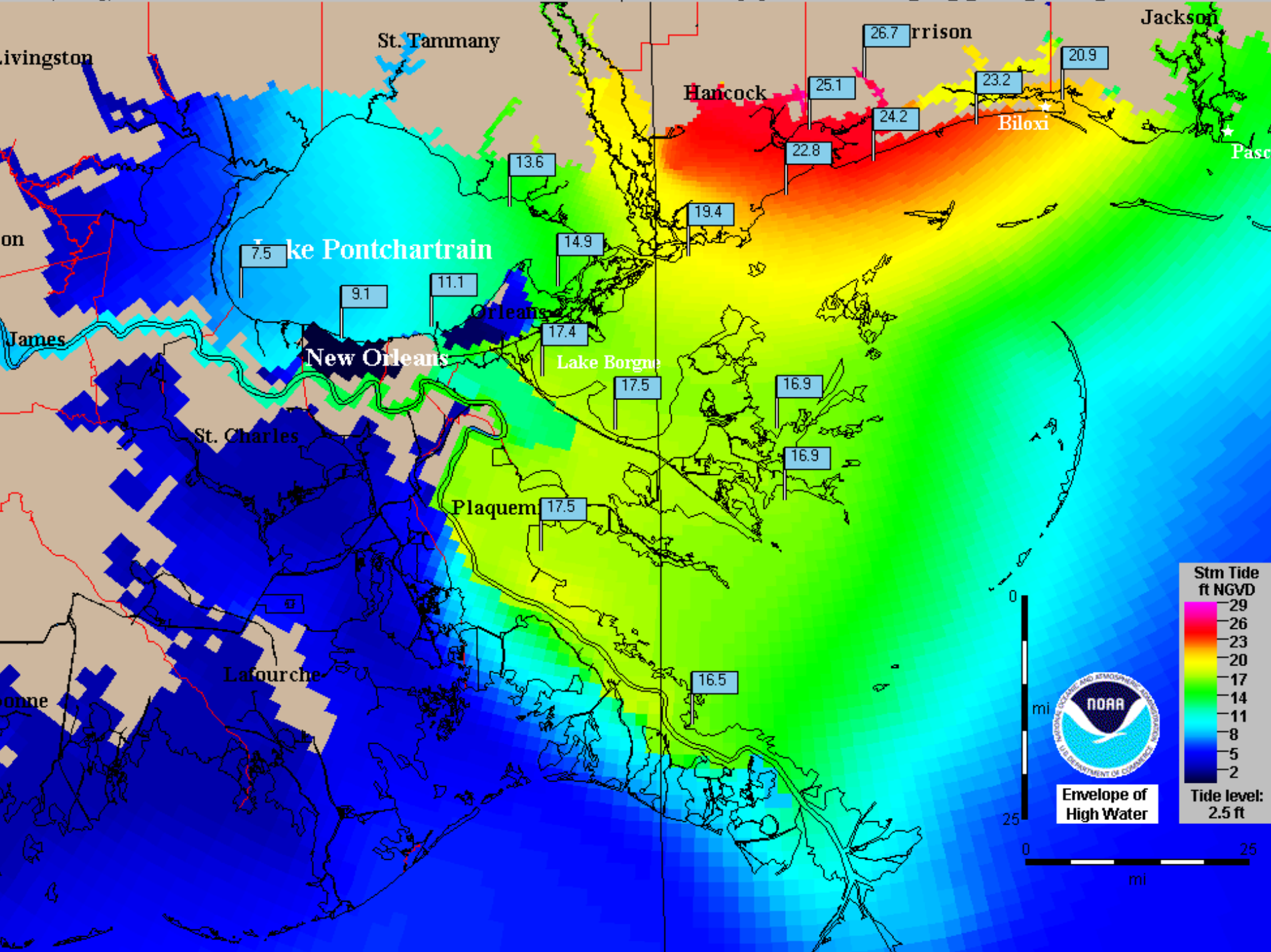

2004
CIMSS
Hurricane Charley
August 9 – 15
Hurricane Frances
August 23 – September 6
Hurricane Ivan
September 2 – 17
Hurricane Jeanne
September 13 – 27
TROPICAL DEPR
TROPICAL STORM
CATEGORY 1
CATEGORY 2
CATEGORY 3
CATEGORY 4
CATEGORY 5
NOAA
1 MONTAGE OF CHARLEY, FRANCES, IVAN, AND JEANNE GOES-12/INFRARED UW-CIMSS McIDAS

Katrina Storm Surge






St. Tammany
Hancock
Biloxi
Jackson
Lake Pontchartrain
Orleans
New Orleans
Lake Borgne
St. Charles
Plaquemines
Lafourche
Dry
2.5
Stm Tide
ft NGVD
29
26
23
20
17
14
11
8
5
2
Tide level:
2.5 ft
08/28/2005
12:00:30 UTC
NOAA
0
25
mi


Livingston
St. Tammany
Hancock
Jackson
Biloxi
Lake Pontchartrain
Orleans
New Orleans
Lake Borgne
St. Charles
Plaquemines
Lafourche
James
26.7
25.1
23.2
20.9
24.2
22.8
13.6
19.4
14.9
7.5
9.1
11.1
17.4
17.5
16.9
16.9
17.5
16.5
Stm Tide
ft NGVD
29
26
23
20
17
14
11
8
5
2
Tide level:
2.5 ft
Envelope of
High Water
0
mi
25
0
25
mi