# Tropical Cyclone Intensity Analysis and Forecasting

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## WMO RA-IV Virtual Workshop on Hurricane Forecasting and Warning
## 28 April 2021

# Outline

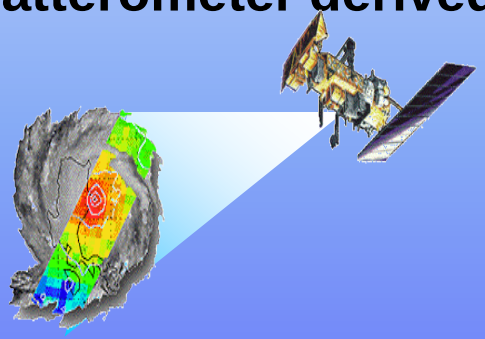
- Estimating the Current Intensity (with Exercise)
- Factors that Influence Intensity Change
- Intensity Forecasting Models
- Official Intensity Forecasts
- Intensity Forecast Exercise

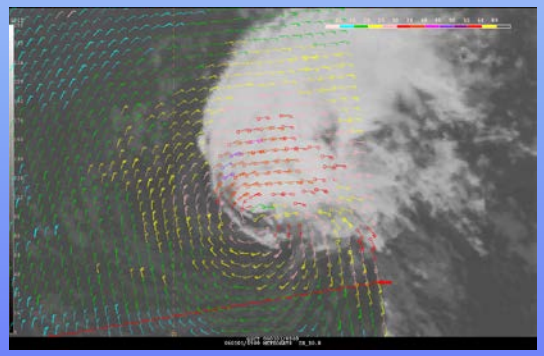
# Definition of Intensity

- 1-min maximum sustained surface winds (10 m) in open exposure
- Other intensity measures
  - Minimum sea-level pressure
  - Maximum 2-min winds, 10-min winds, etc
  - Integrated wind measures (IKE, etc)

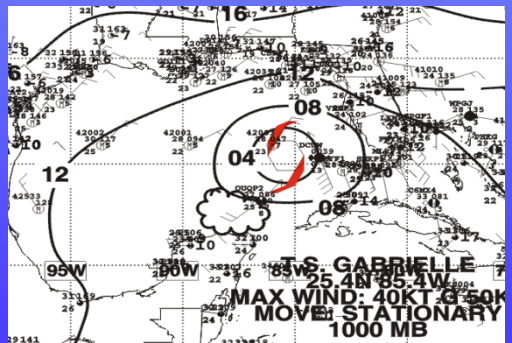
# How Do We Estimate Intensity?

- **Satellites (primary)**
  - Geostationary infrared & visible images (Dvorak Technique)
  - Microwave soundings (AMSU, ATMS)
  - Scatterometer derived surface winds (ASCAT)

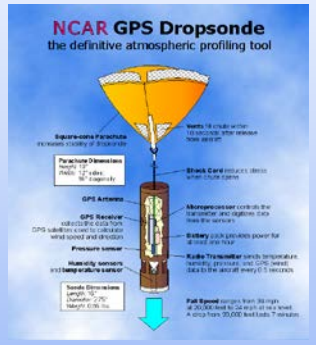


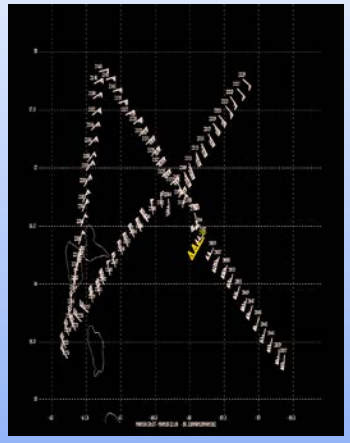
- **Surface observations**
  - Ships, buoys, land stations (limited)

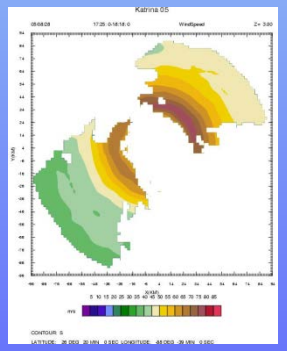



# How Do We Estimate Intensity?

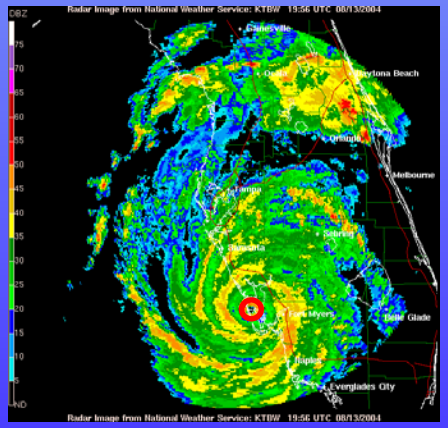
- **Aircraft reconnaissance**
  - **Flight-level winds**
  - **GPS dropsondes**
  - **Stepped-Frequency Microwave Radiometer (SFMR)**

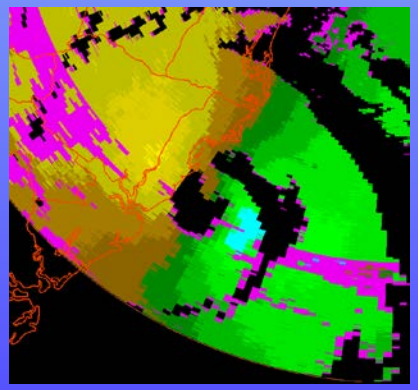


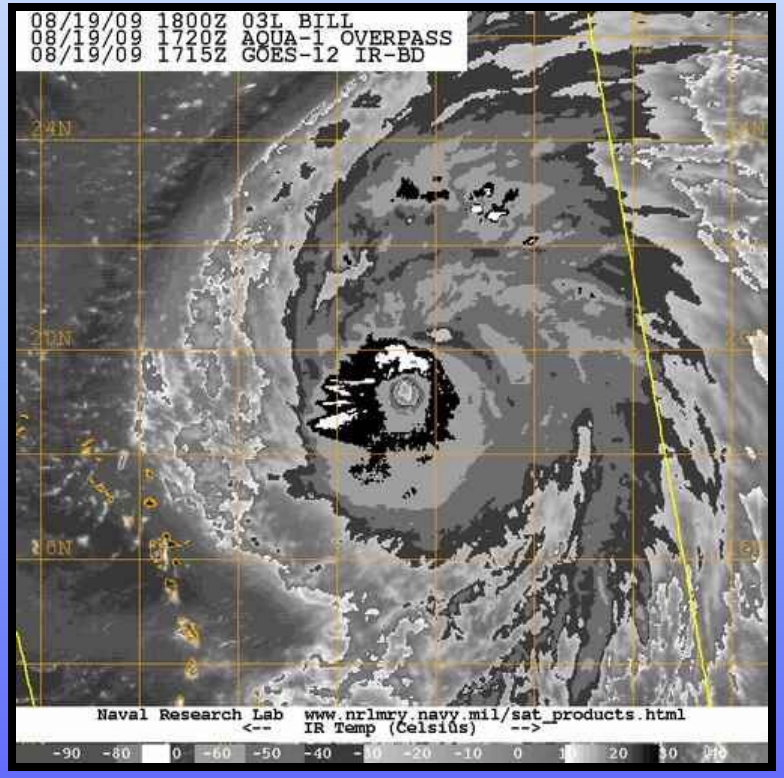


- **Doppler radar**
  - **Land-based (WSR-88D)**
  - **Airborne**



# Example: Estimating the Current Intensity of Hurricane Bill




## 19 August 1800 UTC

Dvorak classification:

TAFB: **T6.5** = 127 kt
SAB: **T6.0** = 115 kt

3-hr average ADT: **T6.4** = 125 kt

# Dvorak Scale

| CI Number | MWS (kt) | MSLP (Atlantic) | MSLP (NW Pacific) |
|---|---|---|---|
| 1.0 | 25 | | |
| 1.5 | 25 | | |
| 2.0 | 30 | 1009 mb | 1000 mb |
| 2.5 | 35 | 1005 mb | 997 mb |
| 3.0 | 45 | 1000 mb | 991 mb |
| 3.5 | 55 | 994 mb | 984 mb |
| 4.0 | 65 | 987 mb | 976 mb |
| 4.5 | 77 | 979 mb | 966 mb |
| 5.0 | 90 | 970 mb | 954 mb |
| 5.5 | 102 | 960 mb | 941 mb |
| 6.0 | 115 | 948 mb | 927 mb |
| 6.5 | 127 | 935 mb | 914 mb |
| 7.0 | 140 | 921 mb | 898 mb |
| 7.5 | 155 | 906 mb | 879 mb |
| 8.0 | 170 | 890 mb | 858 mb |

# Vortex Message

```
000
URNT12 KNHC 191819 CCA
VORTEX DATA MESSAGE   AL032009
A. 19/17:57:30Z
B. 19 deg 16 min N
   056 deg 55 min W
C. 700 mb 2665 m
D. 102 kt
E. 056 deg 24 nm
F. 134 deg 135 kt
G. 055 deg 27 nm
H. 947 mb
I. 11 C / 3045 m
J. 19 C / 3047 m
K. 6 C / NA
L. OPEN SW
M. C32
N. 12345 / 07
O. 0.02 / 0.5 nm
P. AF303 0203A BILL                OB 12 CC
MAX FL WIND 135 KT NE QUAD 17:48:30Z
;
```

**SFMR surface wind**

**90% from 700 mb**
**Surface estimate =**
**0.9 × 135 kt = 122 kt**

A) Date/Time of center fix

B) Center position

C) Std surface/min height

D) Max sfc wind (visually observed or SFMR)

E) Bearing/range of (D) from center

F) Max flt-lvl wind on inbound leg

G) Bearing/range of (F)

H) Minimum pressure

I) Max flt-lvl temp outside eyewall/PA

J) Max flt-lvl temp inside eye/PA

K) DPT/SST at (J)

L) Eyewall character (e.g., CLOSED)

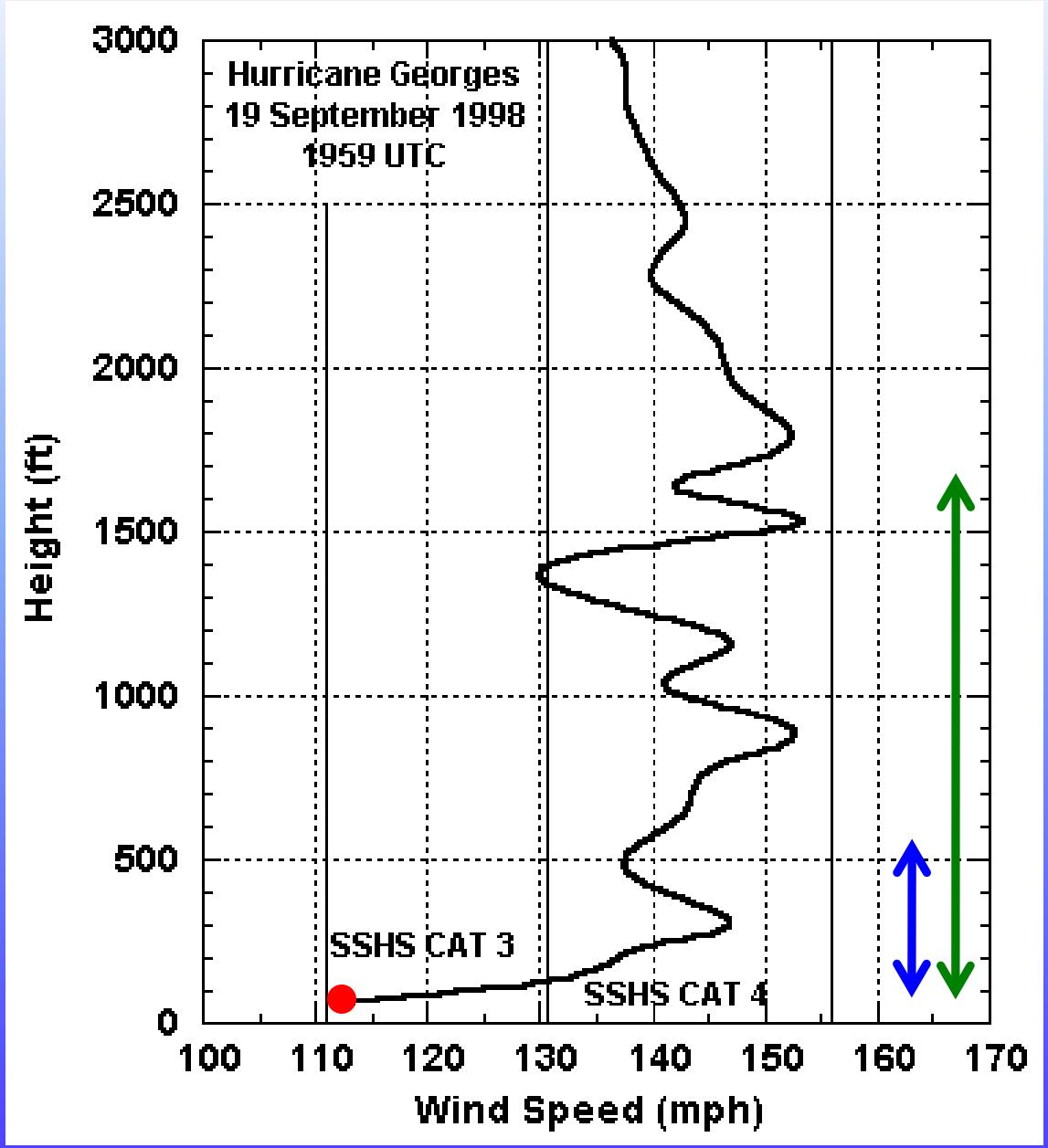
M) Eye diameter (nm)

N) Method of fix

O) Fix accuracy (NAV/MET)

P) Remarks (includes outbound max)

# Dropsonde




**MBL Wind**
(average of lowest 500 m)

**WL150 Wind**
(average of lowest 150 mb)

**Surface Wind**

# Dropsonde

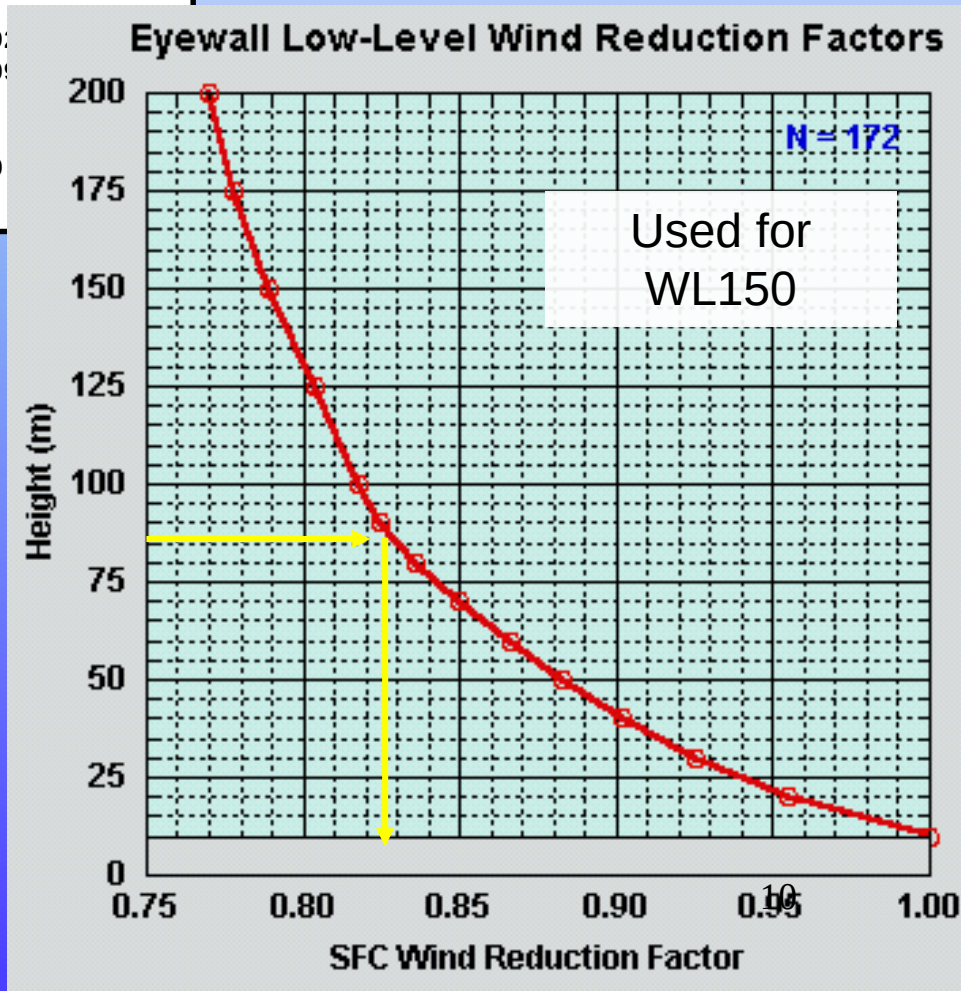
```
000
UZNT13 KNHC 192344
XXAA  69237 99203 70578 07807 99955 25600 09122 00912 ///// /////
92277 23801 10140 85016 20600 11641 70686 148// 14599 88999 77999
31313 09608 82322
61616 NOAA3 WX03A BILL4 OB 11
62626 REL 2033N05779W 232240 SPG 2042N05793W 232707 WL150 09134 0
86 DLM WND 12128 954696 MBL WND 10139 LST WND 011=
XXBB  69238 99203 70578 07807 00955 25600 11941 24400 22920 23802
33741 17000 44719 16001 55695 146//
21212 00955 09122 11952 08618 22943 09640 33938 09646 449
55916 10646 66896 11139 77749 13635 88740 14618 99695 150
31313 09608 82322
61616 NOAA3 WX03A BILL4 OB 11
62626 REL 2033N05779W 232240 SPG 2042N05793W 232707 WL150
86 DLM WND 12128 954696 MBL WND 10139 LST WND 011=
```

**Northeast eyewall:**

**Surface = 122 kt (gust?)**

**MBL (lowest 500 m) =**
**139 × 0.8 = 111 kt**

**WL150 (lowest 150 mb) =**
**134 × 0.83 = 111 kt**



# Determine the Official Intensity

- Subjective Dvorak: **127 / 115 kt**
- Objective ADT: **125 kt**
- SFMR surface wind **102 kt**
- Recon sfc-adjusted flight-level wind: **122 kt**
- Dropsonde surface value: **122 kt**
- Drop sfc-adjusted WL150: **111 kt**
- Drop sfc-adjusted MBL: **111 kt**

- OFCL at 1800 UTC: **115 kt**

**We can only sample a *part* of the TC**

**Each observation has strengths and weaknesses**

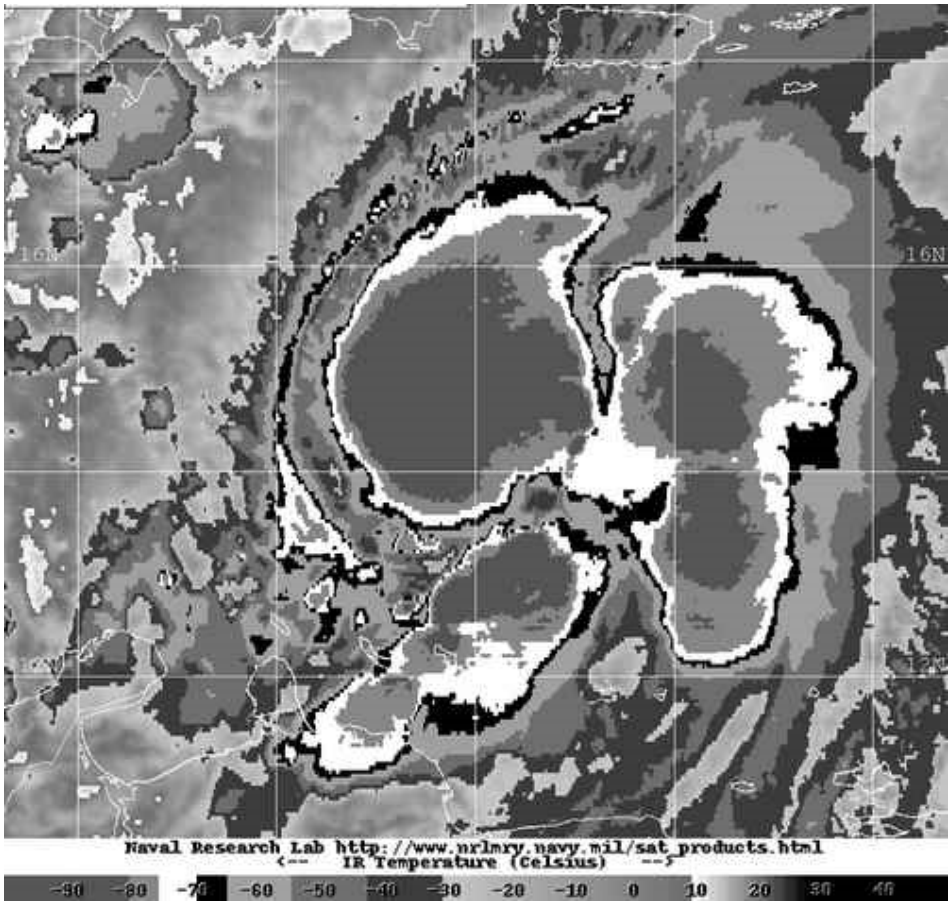
**We want a value that is**

***representative* of the TC's circulation**

# EXERCISE 1
# Intensity Estimation

# Part 1: What is the initial intensity?

## 15/0600 UTC




**Dvorak Classifications:**

**TAFB: T4.5**
**SAB: T4.5**

**3-hr average ADT: T4.4**

# Dvorak Scale

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| 7.0 | 140 | 921 mb | 898 mb |
| 7.5 | 155 | 906 mb | 879 mb |
| 8.0 | 170 | 890 mb | 858 mb |

# Part 1: What is the initial intensity given the following estimates?

| | |
|---|---|
| Subjective Dvorak | 77 kt |
| Objective Dvorak (ADT) | 75 kt |
| SFMR Surface Wind | 65 kt |
| Recon-adjusted Flight-level Wind | 60 kt |
| Dropsonde Surface Wind | 63 kt |
| Dropsonde Surface-adjusted MBL | 50 kt |
| Dropsonde Surface-adjusted WL150 | 55 kt |
| Official Intensity at 0600 UTC | ? |

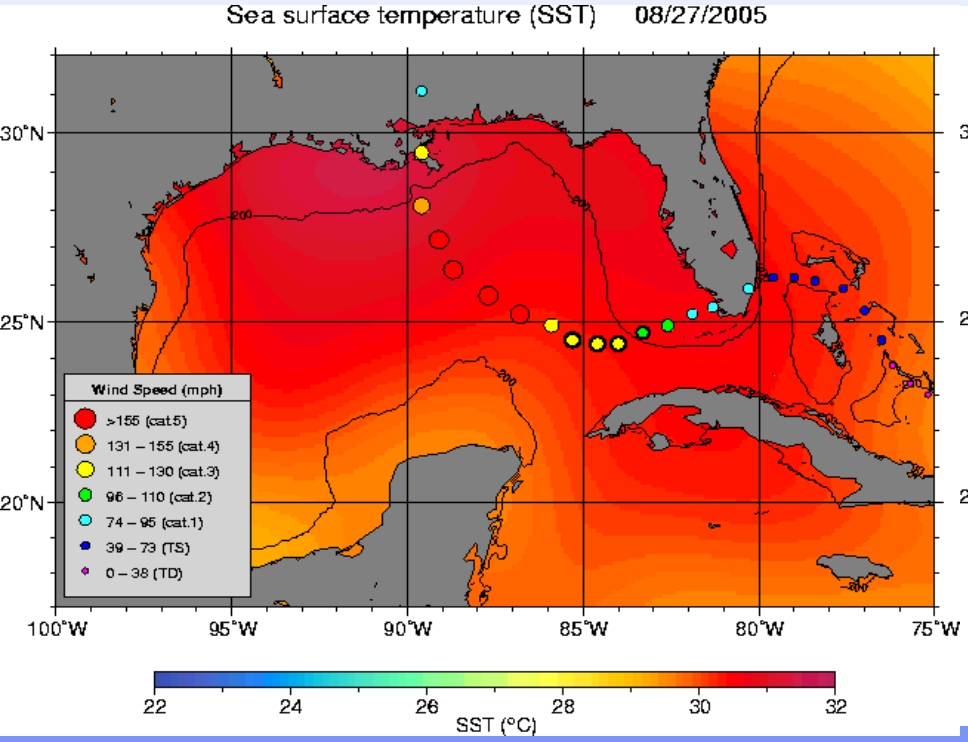
# Part 1: What is the initial intensity given the following estimates?

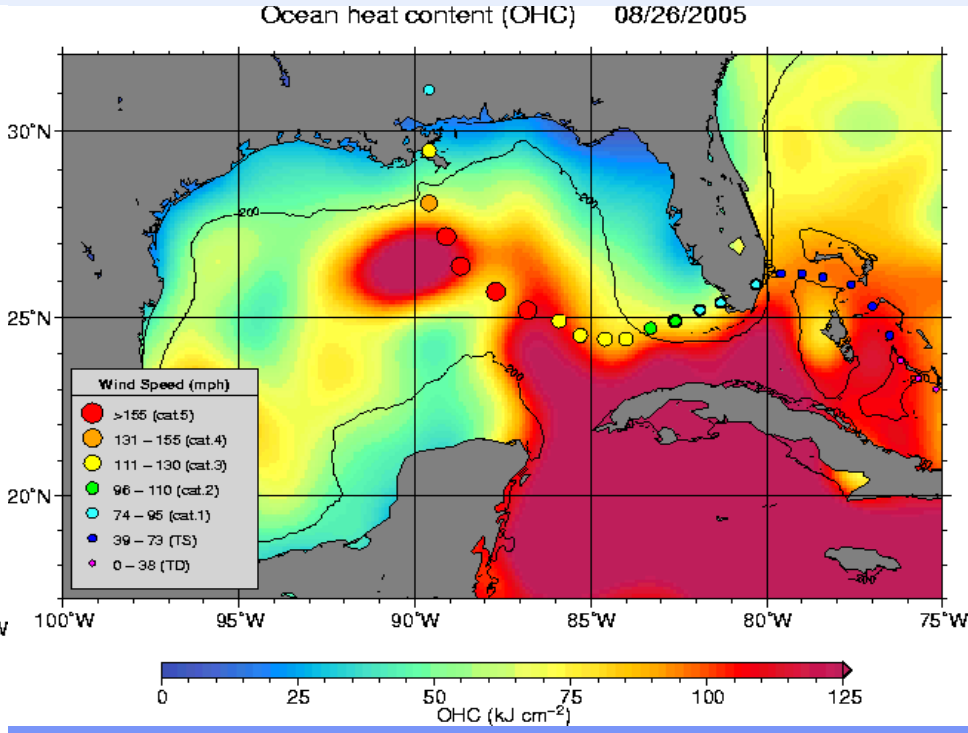
| | |
|---|---|
| Subjective Dvorak | 77 kt |
| Objective Dvorak (ADT) | 75 kt |
| SFMR Surface Wind | 65 kt |
| Recon-adjusted Flight-level Wind | 60 kt |
| Dropsonde Surface Wind | 63 kt |
| Dropsonde Surface-adjusted MBL | 50 kt |
| Dropsonde Surface-adjusted WL150 | 55 kt |
| Official Intensity at 0600 UTC | 65 kt |

# Factors Affecting Tropical Cyclone Intensity Changes

- Sea surface temperature (SST) / upper ocean heat content (OHC)
- Environmental winds, esp. vertical wind shear
- Trough interactions
- Temperature and moisture patterns in the storm environment
- Internal effects (e.g. eyewall replacement cycles)
- Interaction with land

# SST vs. OHC




## Sea Surface Temperatures

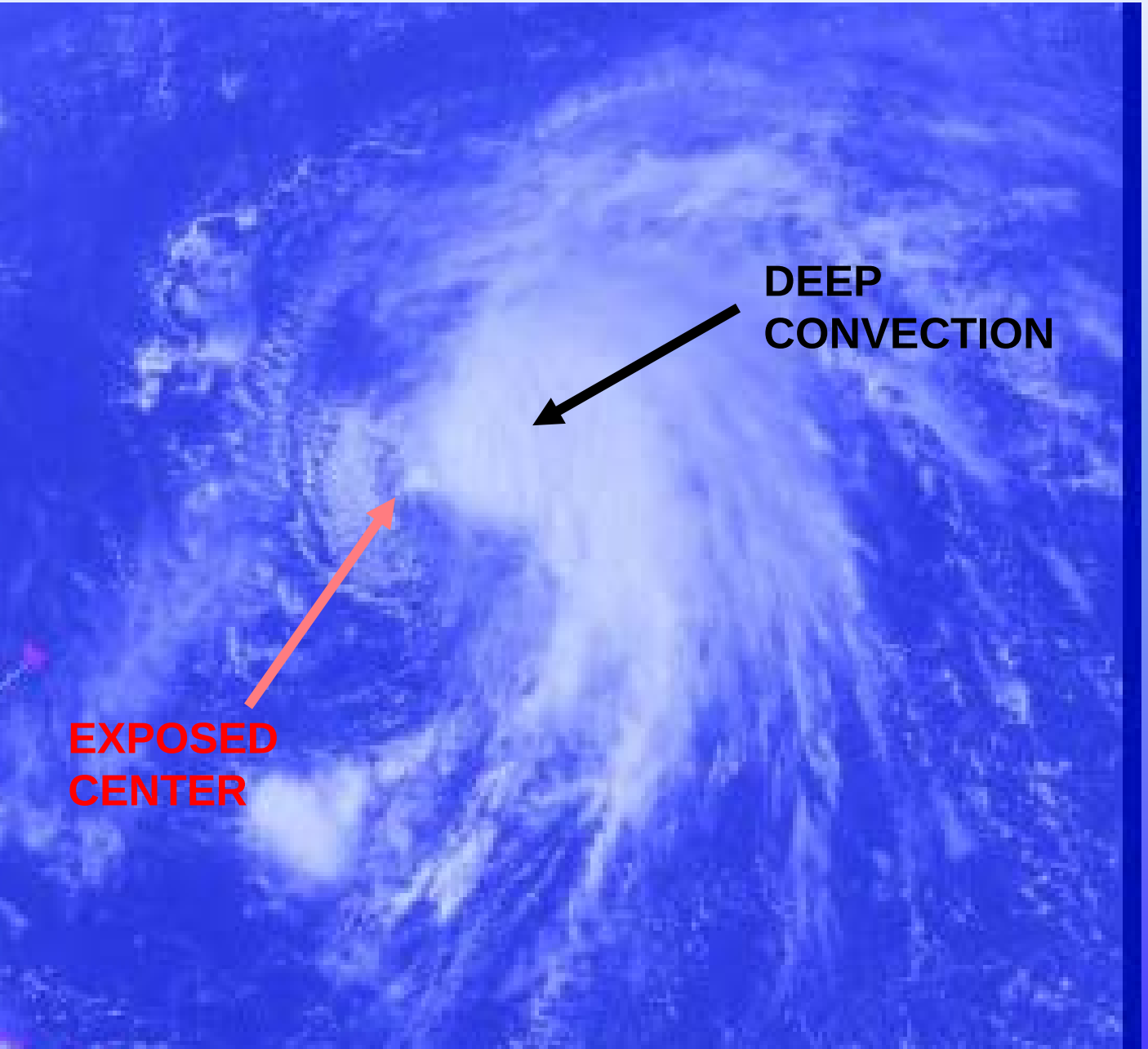
**only provides a view of the very top layer of the ocean.**

## Ocean Heat Content

**estimates the amount of heat available over a depth of warm water.**

**the greater the depth the more available heat that can be potentially converted to energy**

# Vertical Wind Shear




45000 ft

30000 ft

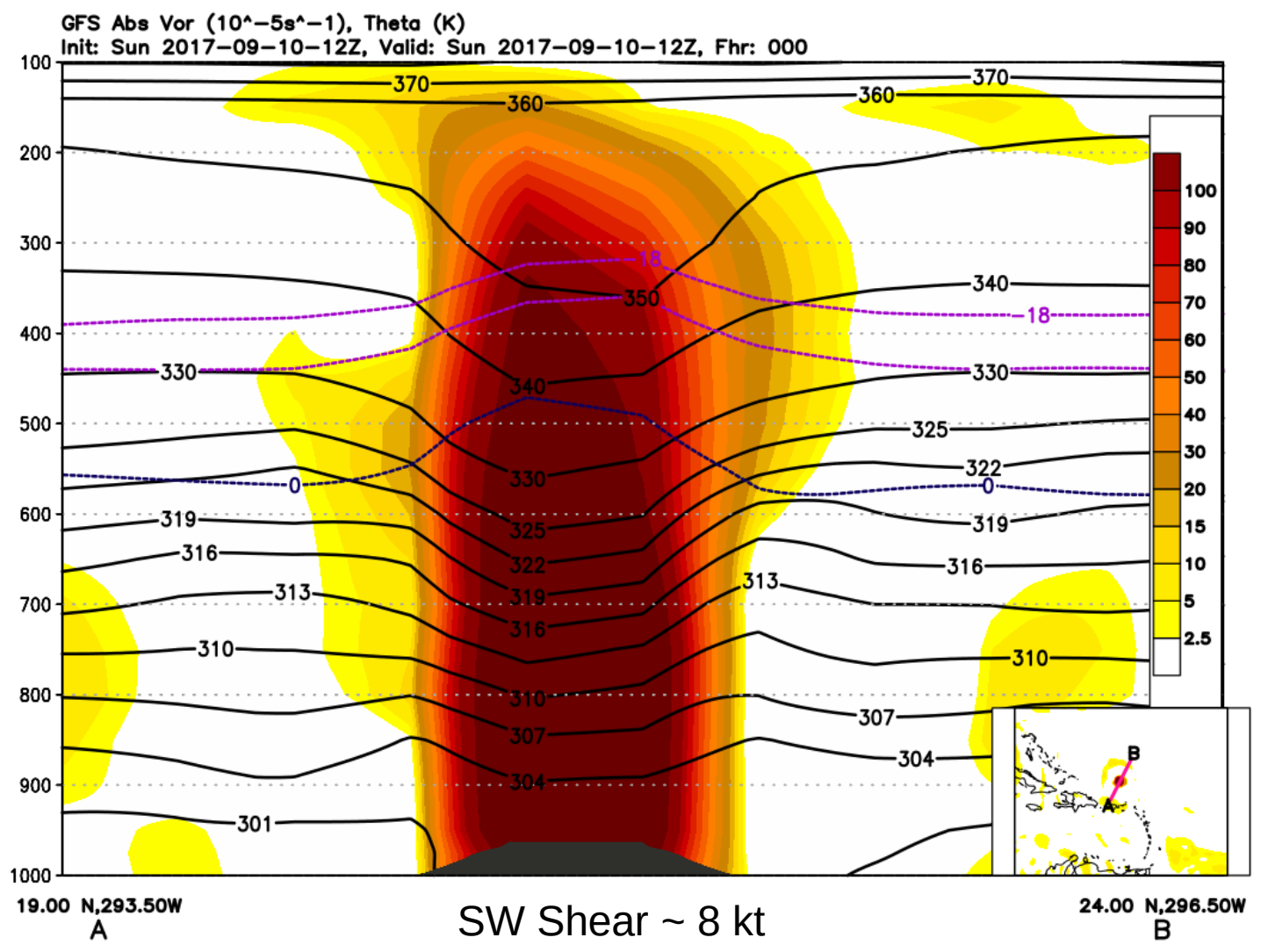
20000 ft

10000 ft

5000 ft

1000 ft

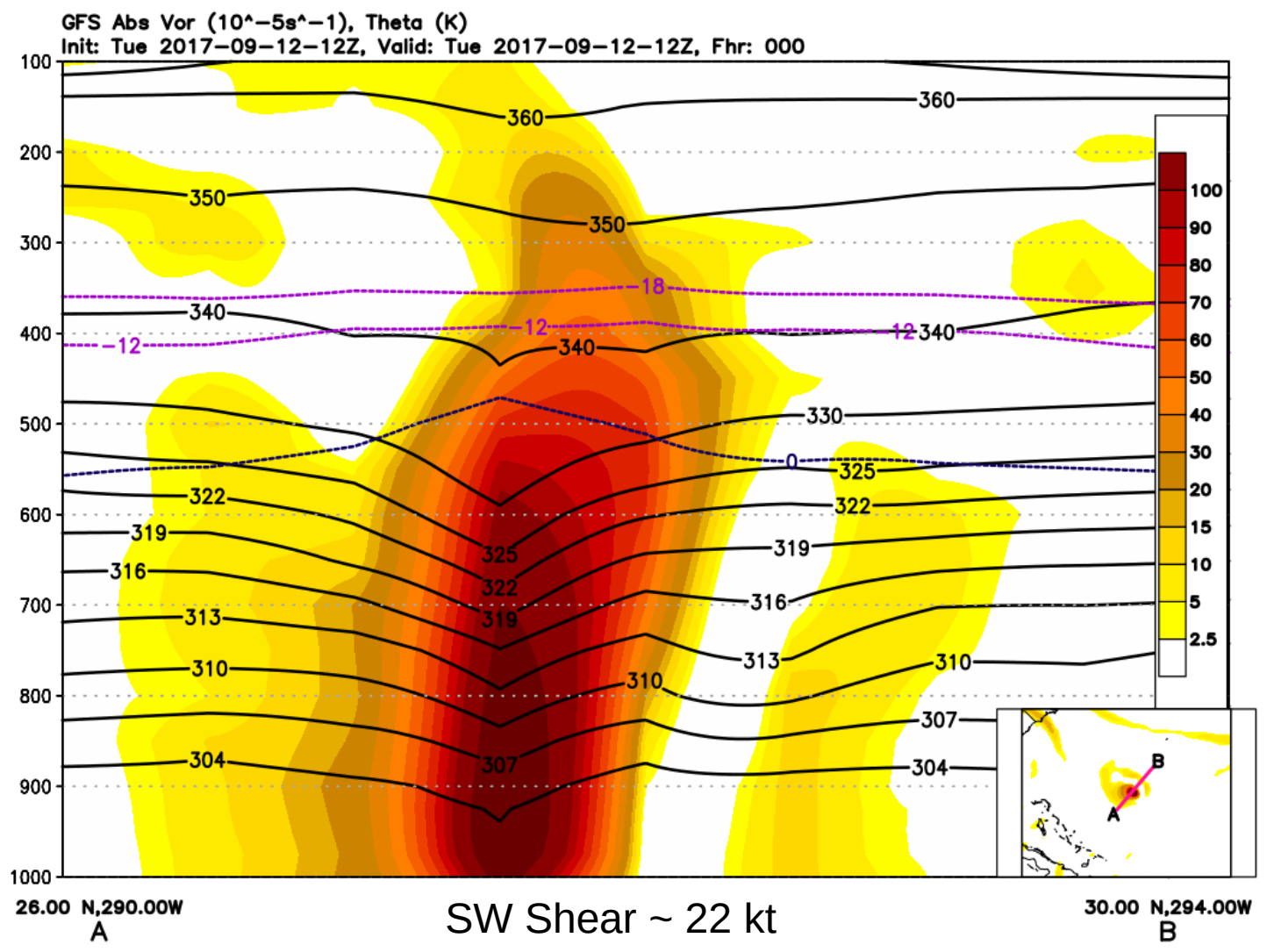
# Hurricane Jose 12 UTC 10 Sept 2017




SW Shear ~ 8 kt

Vertical cross-section of vorticity and potential temperature anomaly from the GFS model for the initialization of the 1200 UTC forecast on September 10

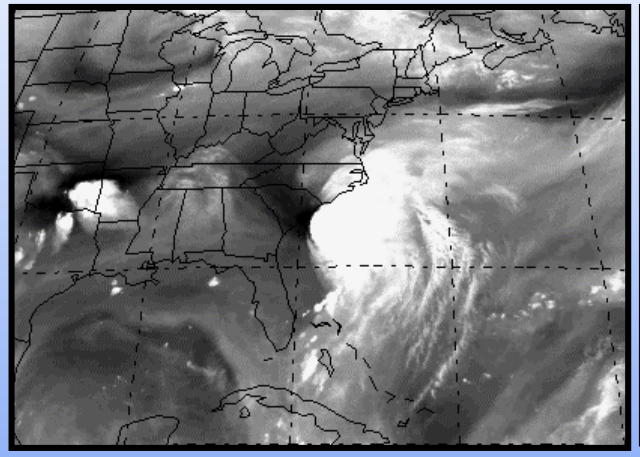
# Hurricane Jose 12 UTC 12 Sept 2017

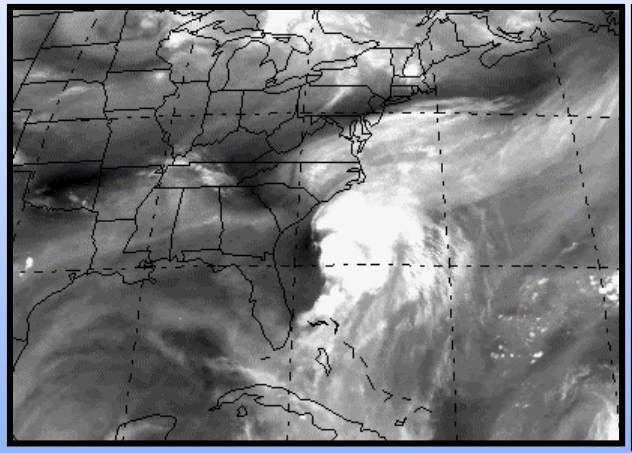


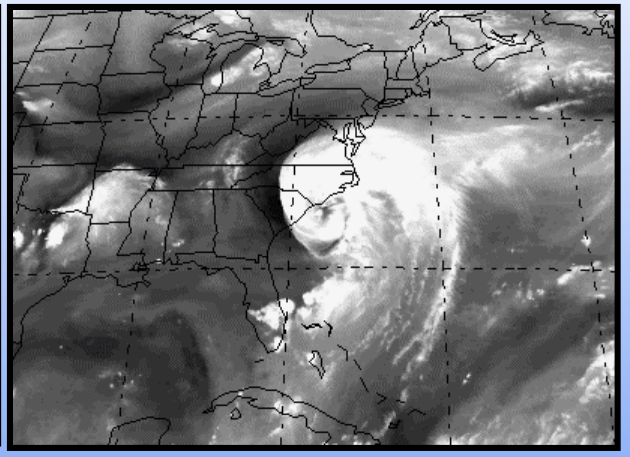

Vertical cross-section of vorticity and potential temperature anomaly from the GFS model for the initialization of the 1200 UTC forecast on September 10

# Hurricane-Trough Interaction

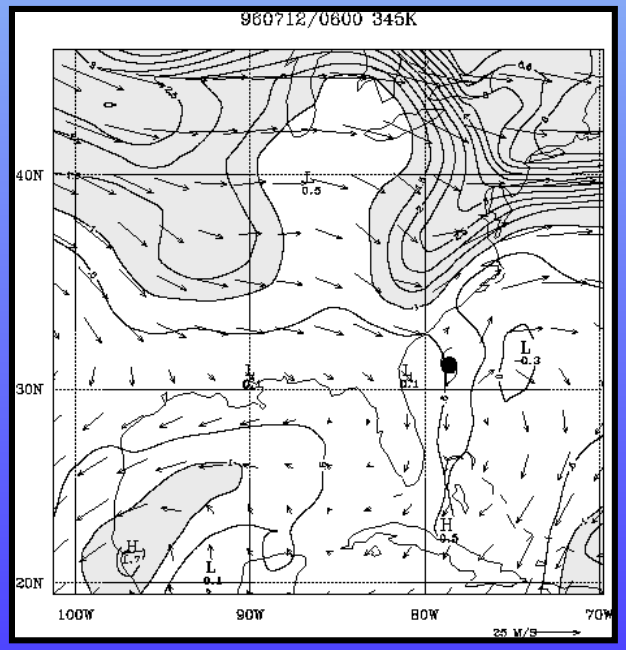
## Hurricane Bertha (1996)



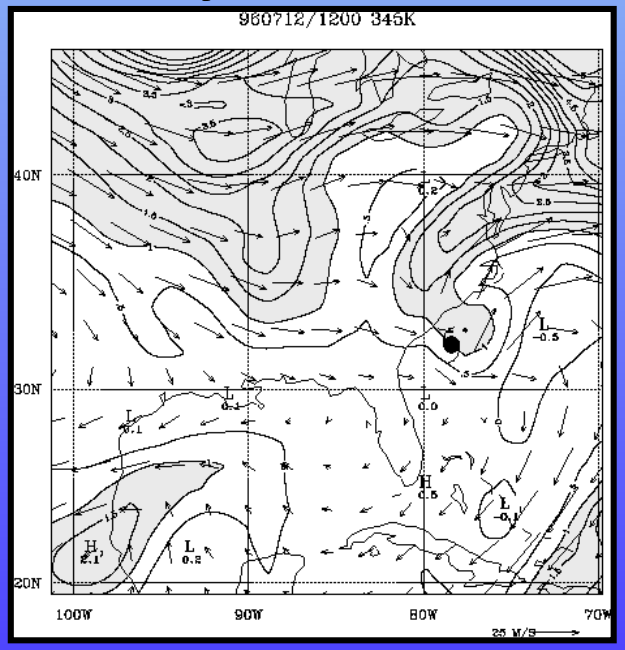




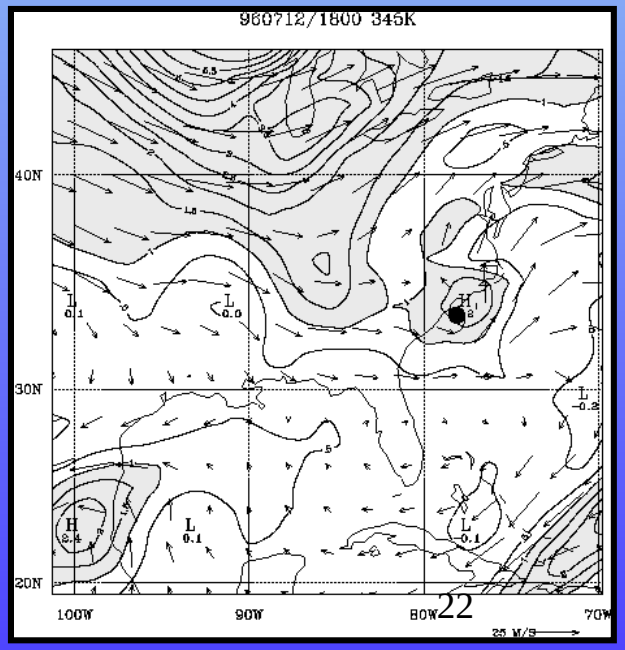
**12 July 1995 06 UTC**



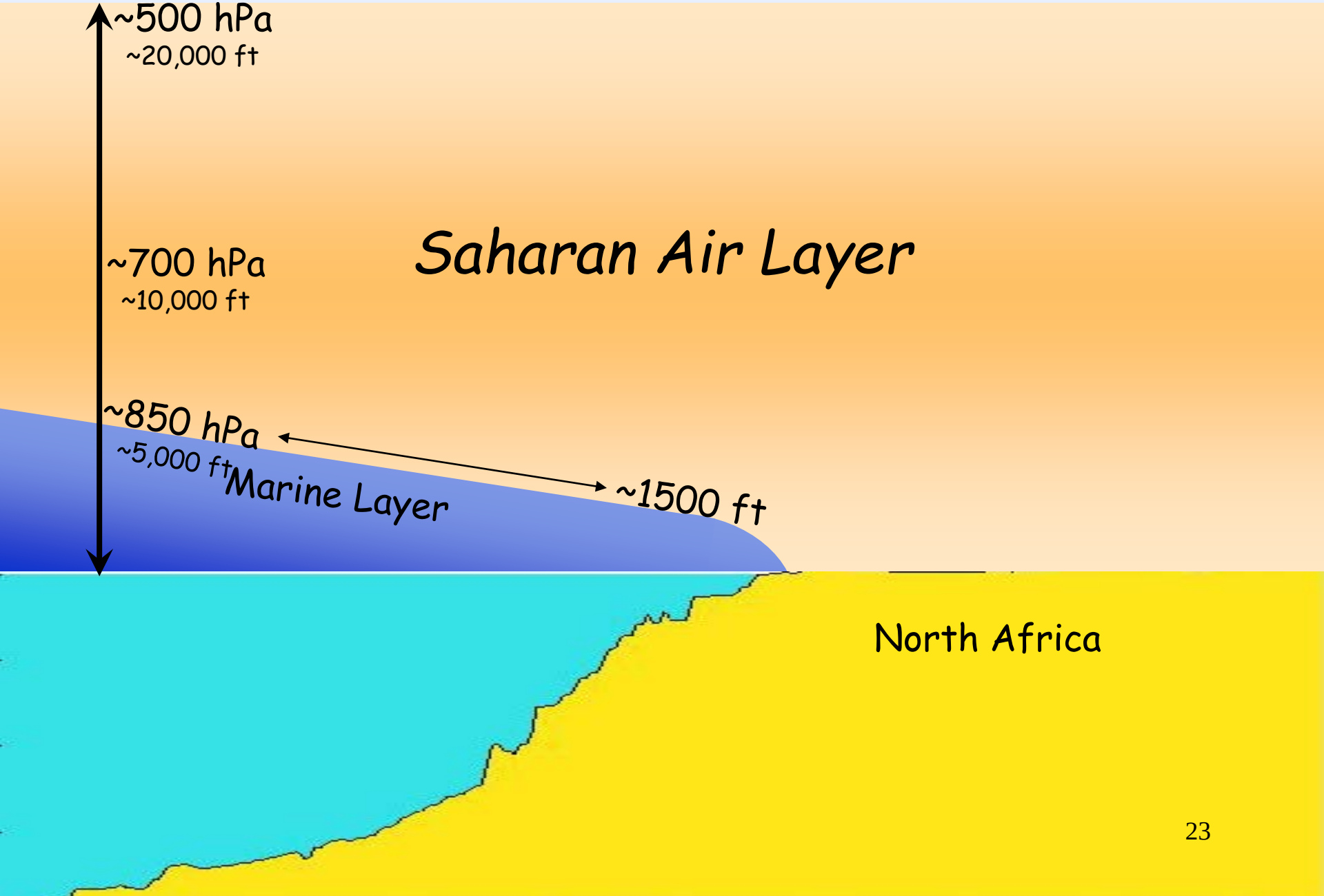

**12 July 1995 12 UTC**



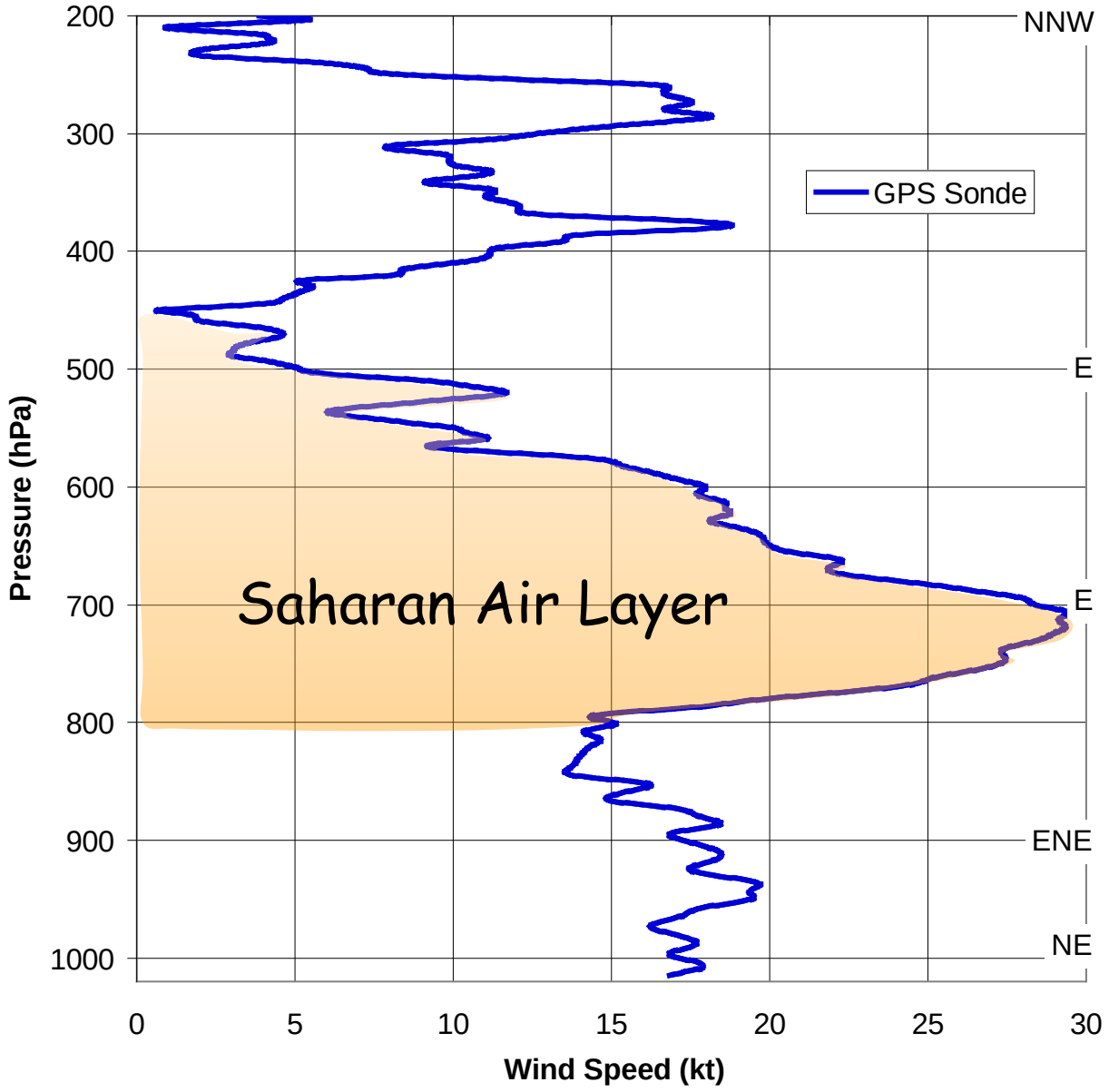

**12 July 1995 18 UTC**



# Saharan Air Layer

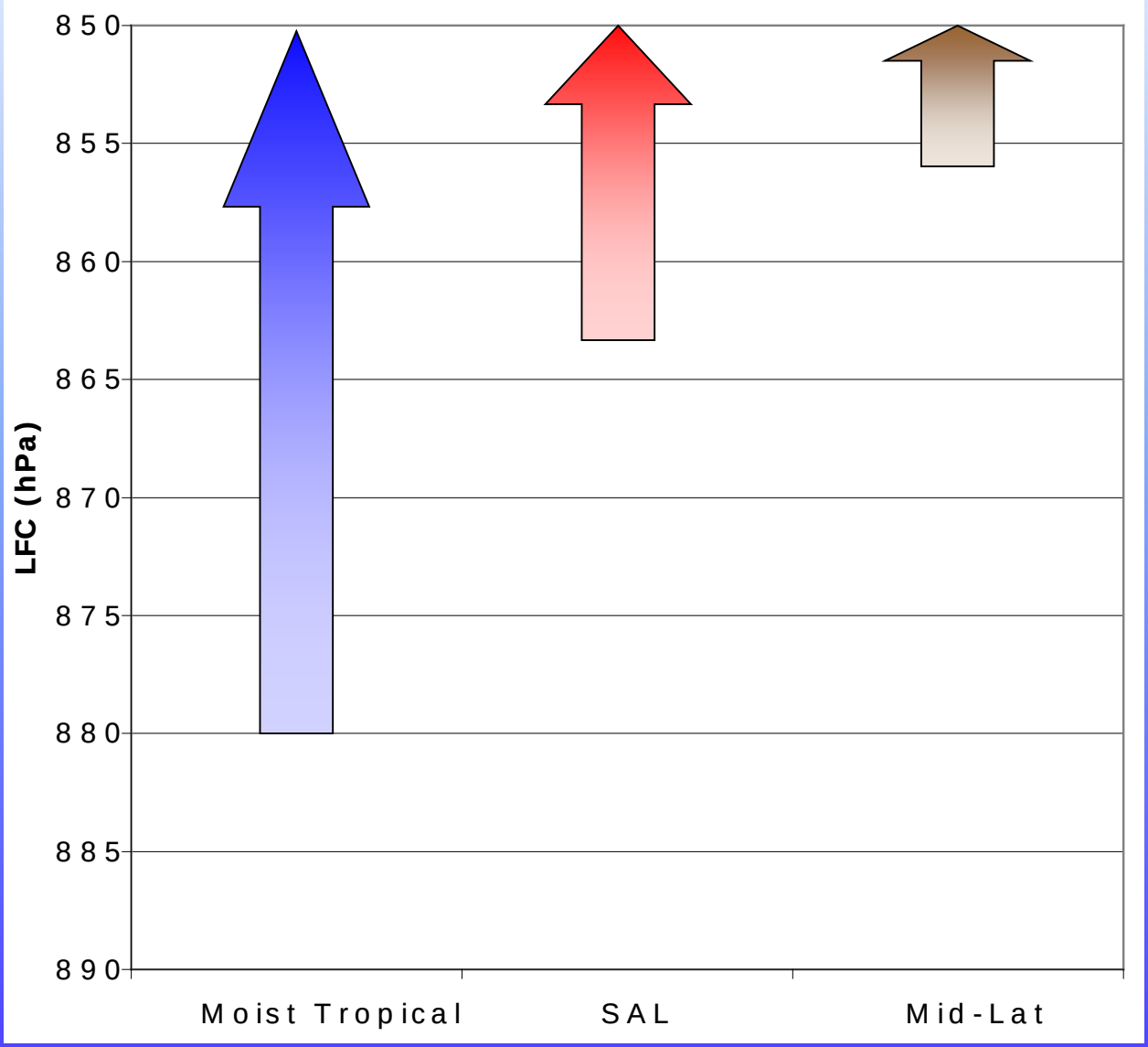


# Getting Dry Air into the TC Circulation

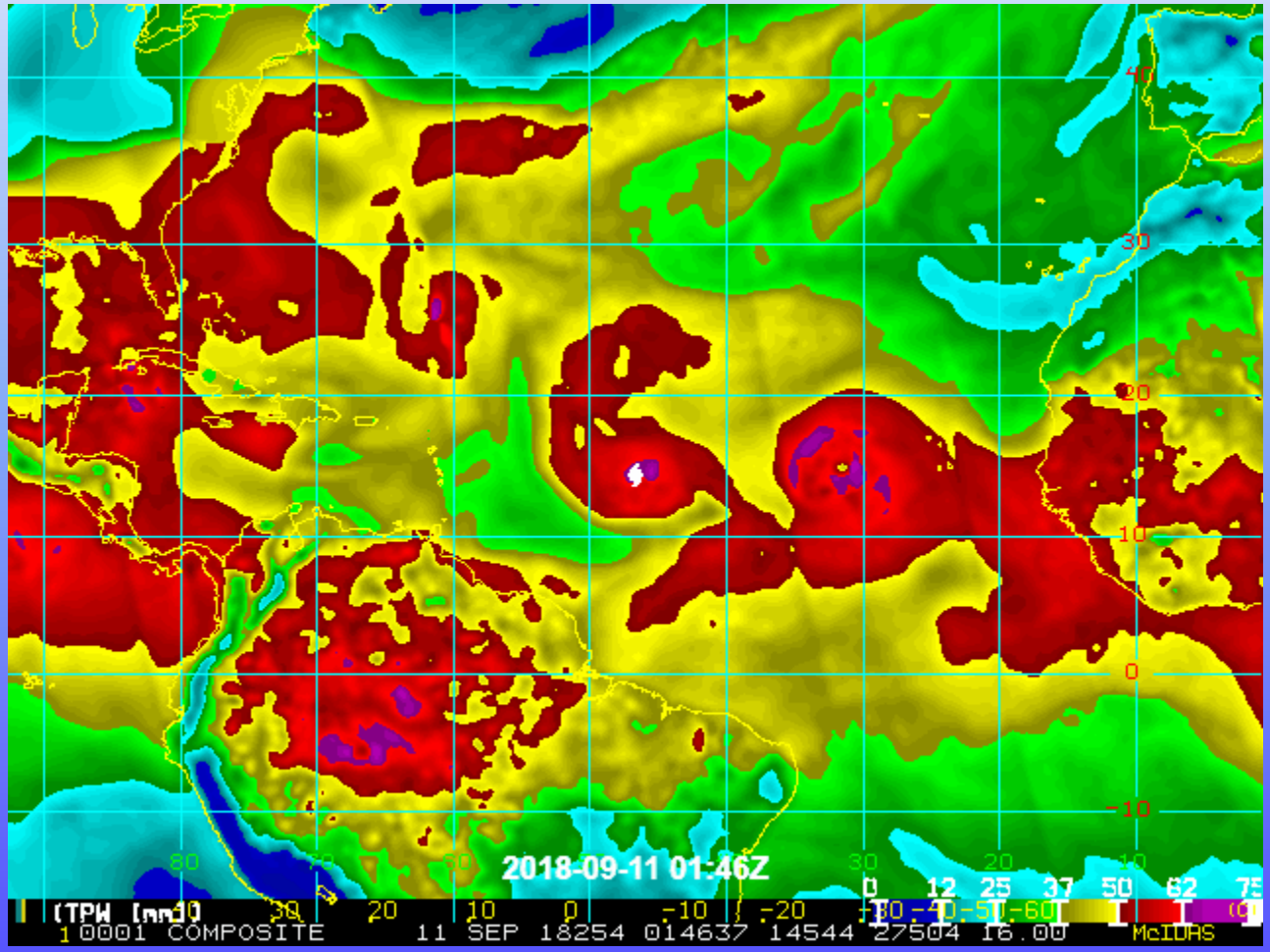


# How Moisture Affects Stability

## LCL and LFC



# Satellite TPW Products Useful for Tracking Dry Air Intrusions




**TC-centered TPW Loop for Hurricane Isaac Sept 2018**

# Eyewall Replacement Cycles

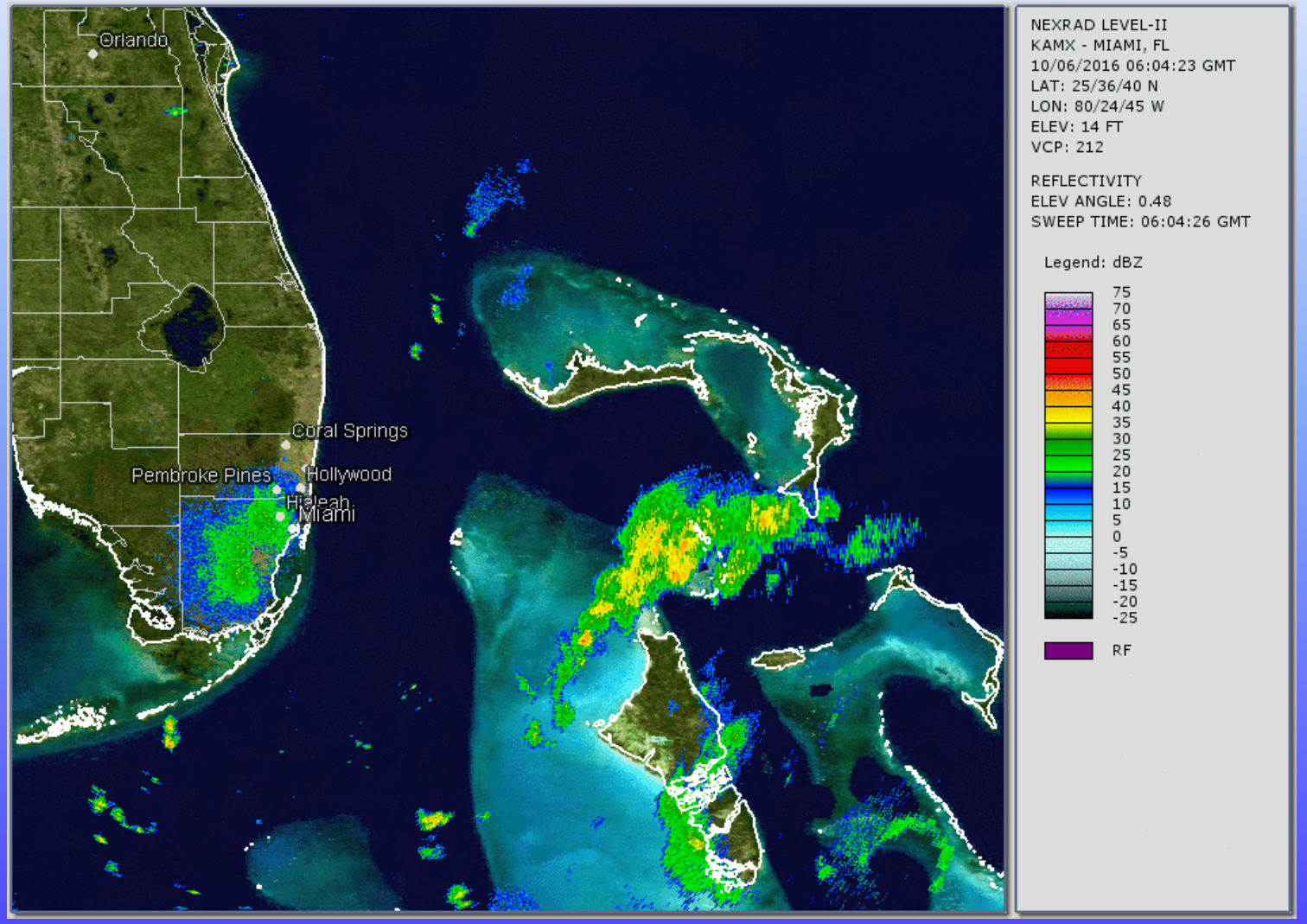
In addition to large-scale environmental influences, tropical cyclone intensity change can be caused by inner-core processes, such as eyewall replacement cycles:

In stronger hurricanes, we often see a concentric eyewall develop at a larger distance from the center than the radius of the original eyewall.

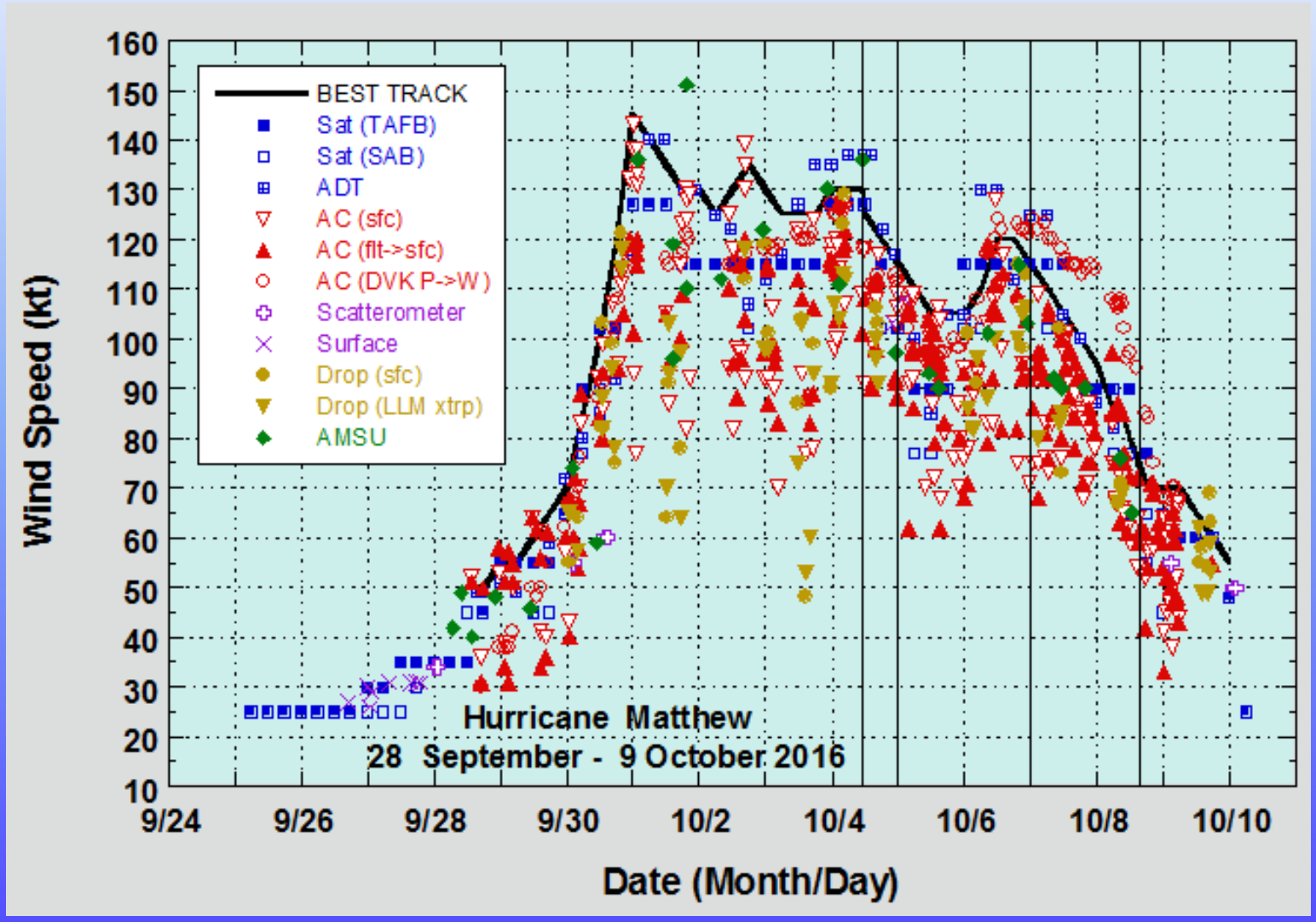
When this outer eyewall becomes dominant, some weakening usually occurs.

However, this outer eyewall could contract, in which case the hurricane would re-intensify.

# Hurricane Matthew Radar Loop



# Hurricane Matthew Maximum Wind



# Land Interaction

- In general, winds weaken over land due to lack of latent heating and increased friction
- Strong winds move inland farther if the TC is moving faster
- Terrain can cause significant local “speed-ups” (sometimes by more than 10 – 30%) over hills, valleys, etc.
- Higher elevations in mountainous areas can have stronger winds than at sea level – common on Caribbean islands


# Weather Forecast Methods[1]

- Classical Statistical Models
  - Use observable parameters to statistical predict future evolution
- Numerical Weather Prediction (NWP)
  - Physically based forecast models
- Statistical-Dynamical Models
  - Use NWP forecasts and other input for statistical prediction of desired variables
    - Station surface temperature, precipitation, hurricane intensity changes



[1]From Wilks (2006) and Kalnay (2003)

# Tropical Cyclone Intensity Forecast Models

- **Statistical Models:**
  - **Decay SHIFOR** (Statistical Hurricane Intensity FORecast with inland decay).
    - Based on historical information - climatology and persistence (uses CLIPER track).
    - Baseline for skill of intensity forecasts
  - **Trajectory CLIPER**
    - Statistically estimate track and intensity tendency instead of change over fixed time
      - e.g., dV/dt instead of V(t)-V(0)
- **Statistical-Dynamical Models:**
  - **SHIPS** and **DSHIPS** (Statistical Hurricane Intensity Prediction Scheme):
    - Based on climatology, persistence, and statistical relationships to current and forecast environmental conditions (with inland decay applied in DSHIPS)
  - **LGEM** (Logistic Growth Equation Model):
    - Uses same inputs as SHIPS, but environmental conditions are variable over the length of the forecast (SHIPS averages over the entire forecast)
    - More sensitive to environmental changes
- **Dynamical Models:**
  - **HWRF, HMON, COAMPS-TC, GFS, UKMET, NOGAPS, ECMWF**

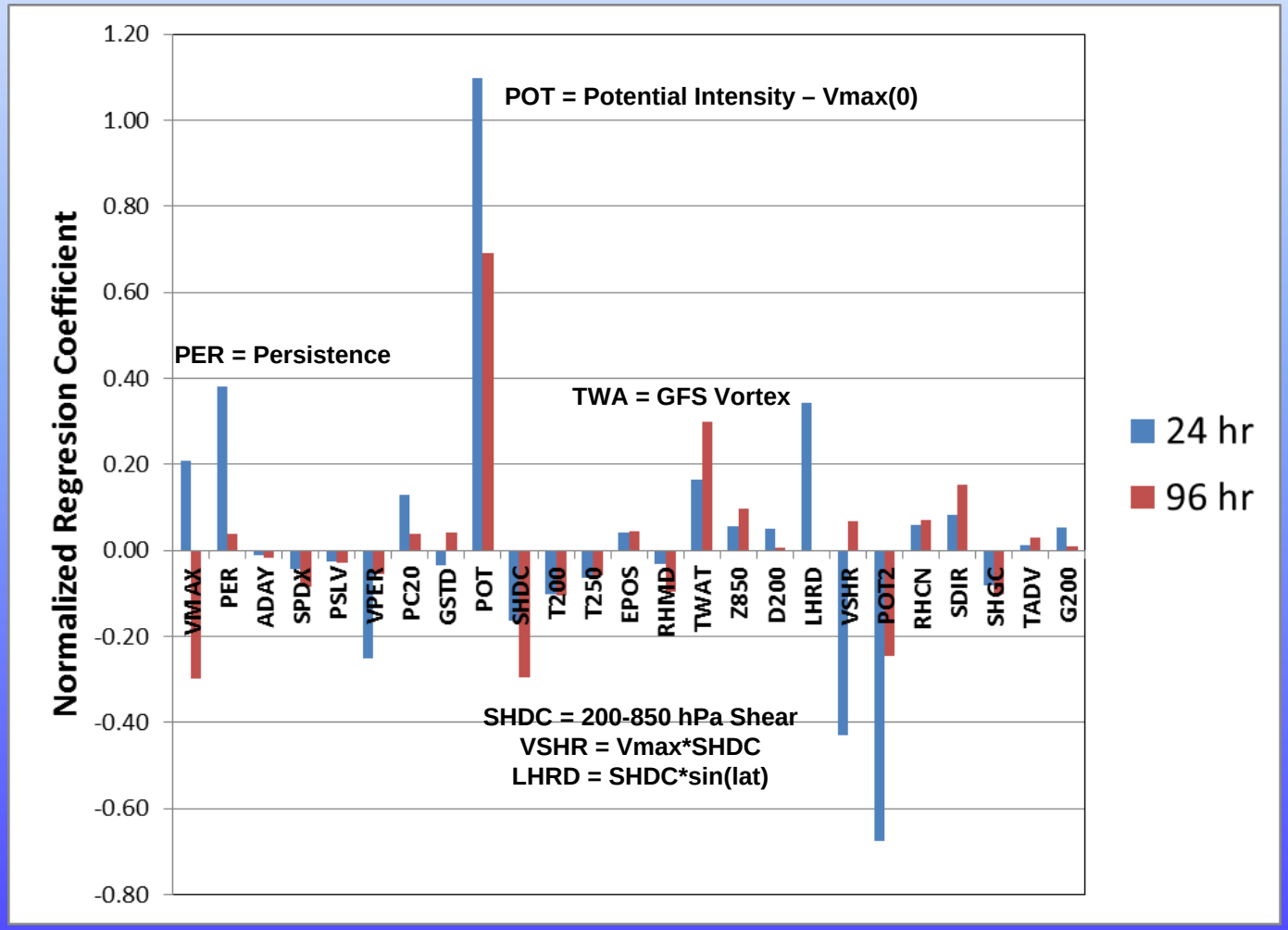
# Overview of the SHIPS Model

- Multiple linear regression
  - $y = a_0 + a_1x_1 + \ldots a_Nx_N$
    - y = intensity change at given forecast time
      - $(V_6\text{-}V_0)$, $(V_{12}\text{-}V_0)$, …, $(V_{120}\text{-}V_0)$
    - $x_i$ = predictors of intensity change
    - $a_i$ = regression coefficients
- Different coefficients for each forecast time
- Predictors $x_i$ averaged over forecast period
- x,y normalized by subtracting sample mean, dividing by standard deviation

# SHIPS Predictors

1. Climatology (days from peak)
2. $V_0$ ($V_{max}$ at t= 0 hr)
3. Persistence ($V_0$-$V_{-12}$)
4. $V_0$ * Per
5. Zonal storm motion
6. Steering layer pressure
7. %IR pixels < -20°C
8. IR pixel standard deviation
9. Max Potential Intensity – $V_0$
10. Square of No. 9
11. Ocean heat content
12. T at 200 hPa
13. T at 250 hPa
14. RH (700-500 hPa)
15. $\theta_e$ of sfc parcel - $\theta_e$ of env
16. 850-200 hPa env shear
17. Shear * $V_0$
18. Shear direction
19. Shear*sin(lat)
20. Shear from other levels
21. 0-1000 km 850 hPa vorticity
22. 0-1000 km 200 hPa divergence
23. GFS vortex tendency
24. Low-level T advection
25. GFS vortex warm core

# SHIPS Regression Coefficients at 24 and 96 hr



# Impact of Land

- Detect when forecast track crosses land
- Replace multiple regression prediction with

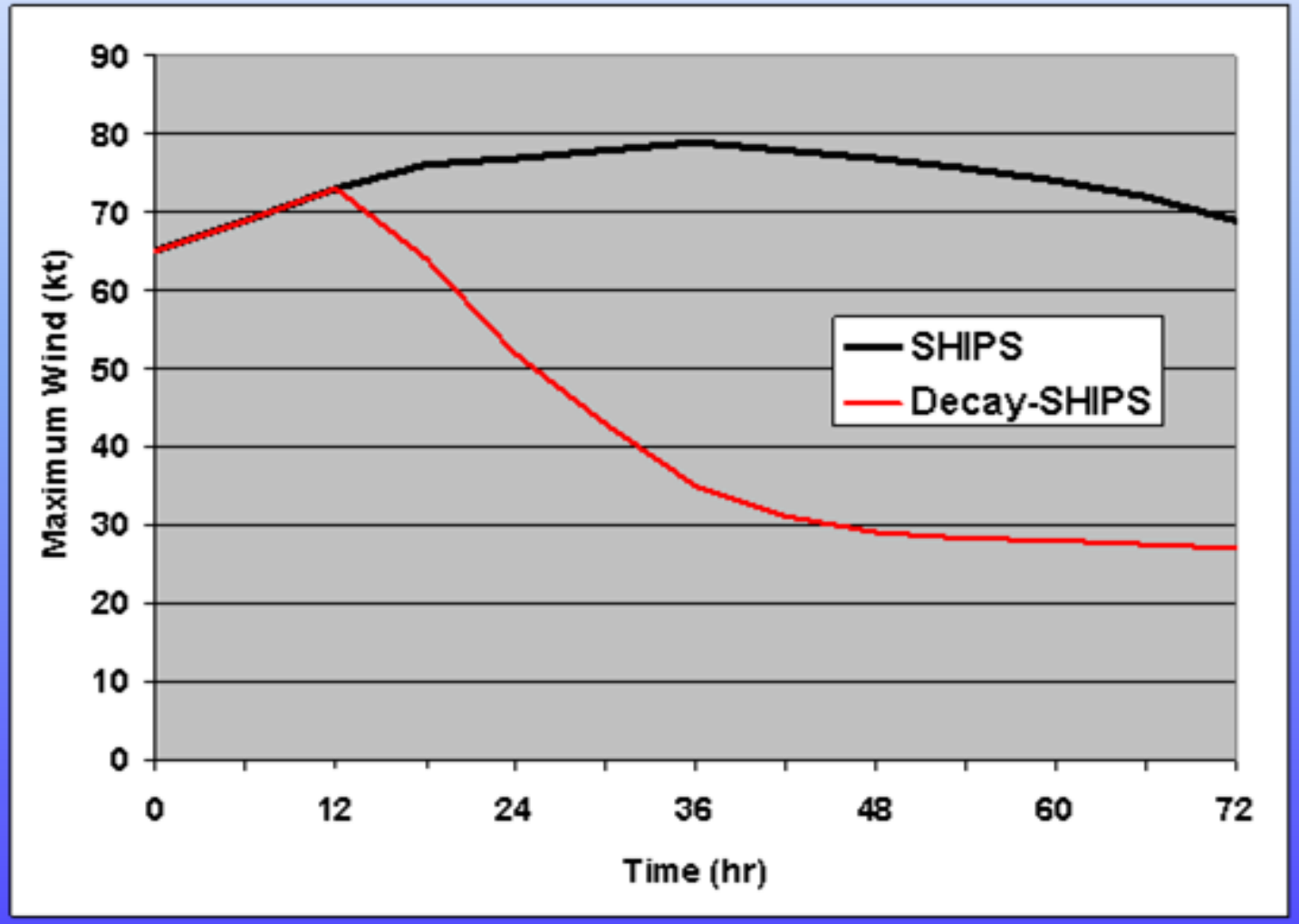
$$dV/dt = - \mu(V-V_b)$$

$\mu$ = climatological decay rate ~ 1/10 $hr^{-1}$

$V_b$ = background intensity over land

- Decay rate reduced if area within 1 deg lat is partially over water

# Example of Land Effect



# Limitations of SHIPS

- V predictions can be negative
- Most predictors averaged over entire forecast period
  - Slow response to changing synoptic environment
- Strong cyclones that move over land and back over water can have low bias
- Logistic Growth Equation Model (LGEM) relaxes these assumptions

# Operational LGEM Intensity Model

$$dV/dt = \kappa V - \beta(V/V_{mpi})^n V$$
$$\text{(A)} \qquad \text{(B)}$$

$V_{mpi}$ = Maximum Potential Intensity estimate

$\kappa$ = Max wind growth rate (from SHIPS predictors)

$\beta$, $n$ = empirical constants = 1/24 hr, 2.5

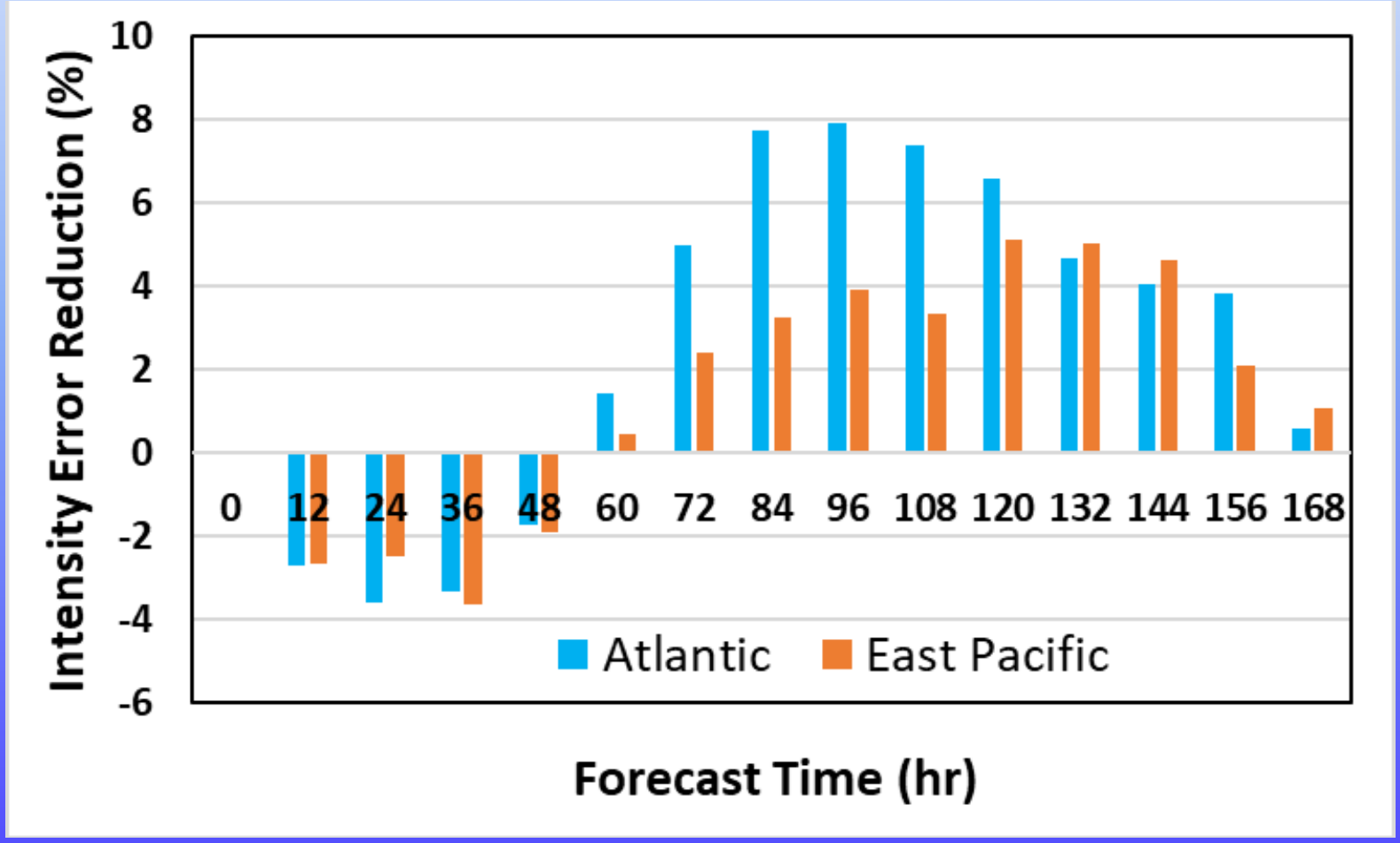
Steady State Solution: $V_s = V_{mpi}(\beta/\kappa)^{1/n}$

# LGEM versus SHIPS

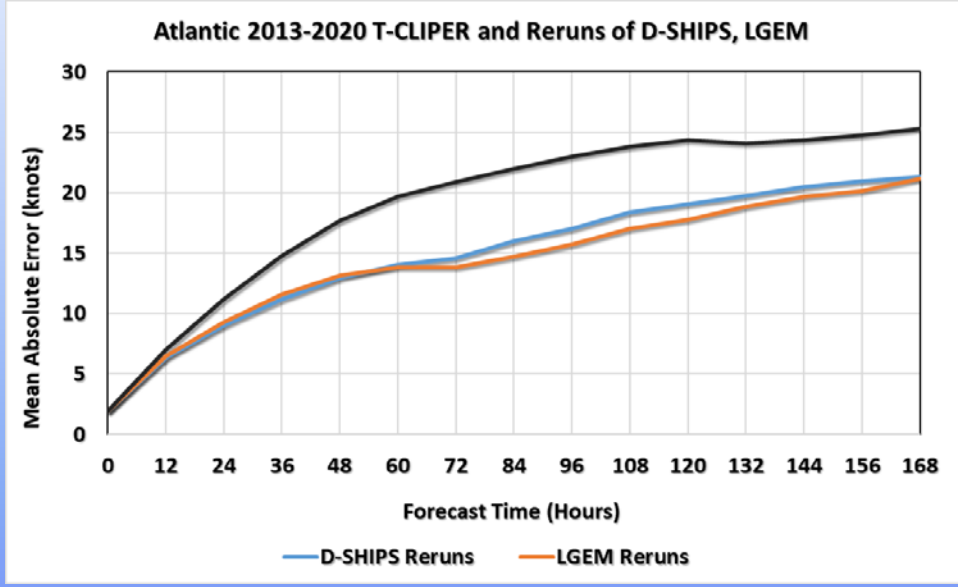
- Advantages
  - Prediction equation bounds the solution between 0 and $V_{mpi}$
  - Time evolution of predictors (Shear, etc) better accounted for
  - Movement between water and land handled better because of time stepping
- Disadvantages
  - Model fitting more involved
  - Inclusion of persistence more difficult

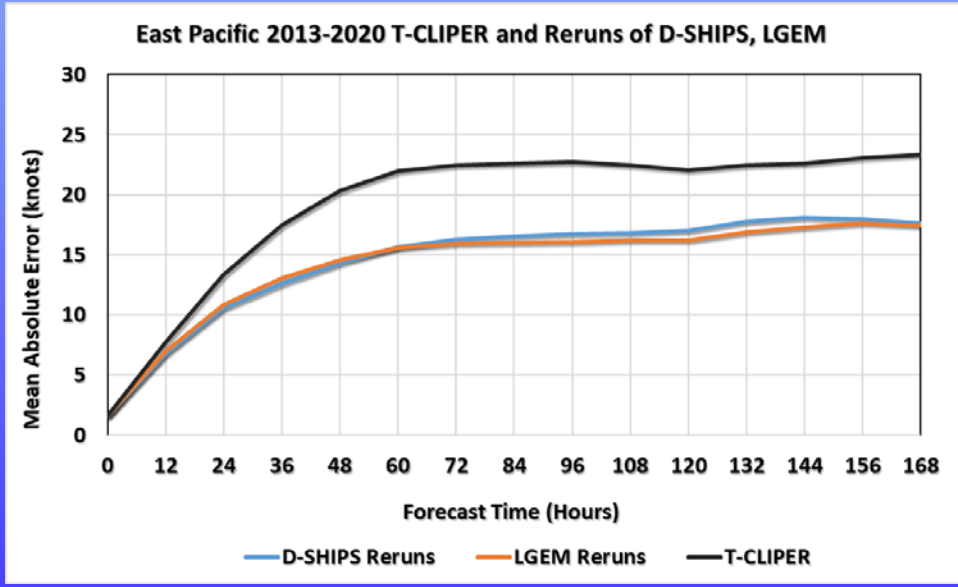
# LGEM Improvement over SHIPS

## Retrospective runs with 2021 Models
## 2013-2020 Sample



# SHIPS/LGEM extended from 5 to 7days starting in 2020



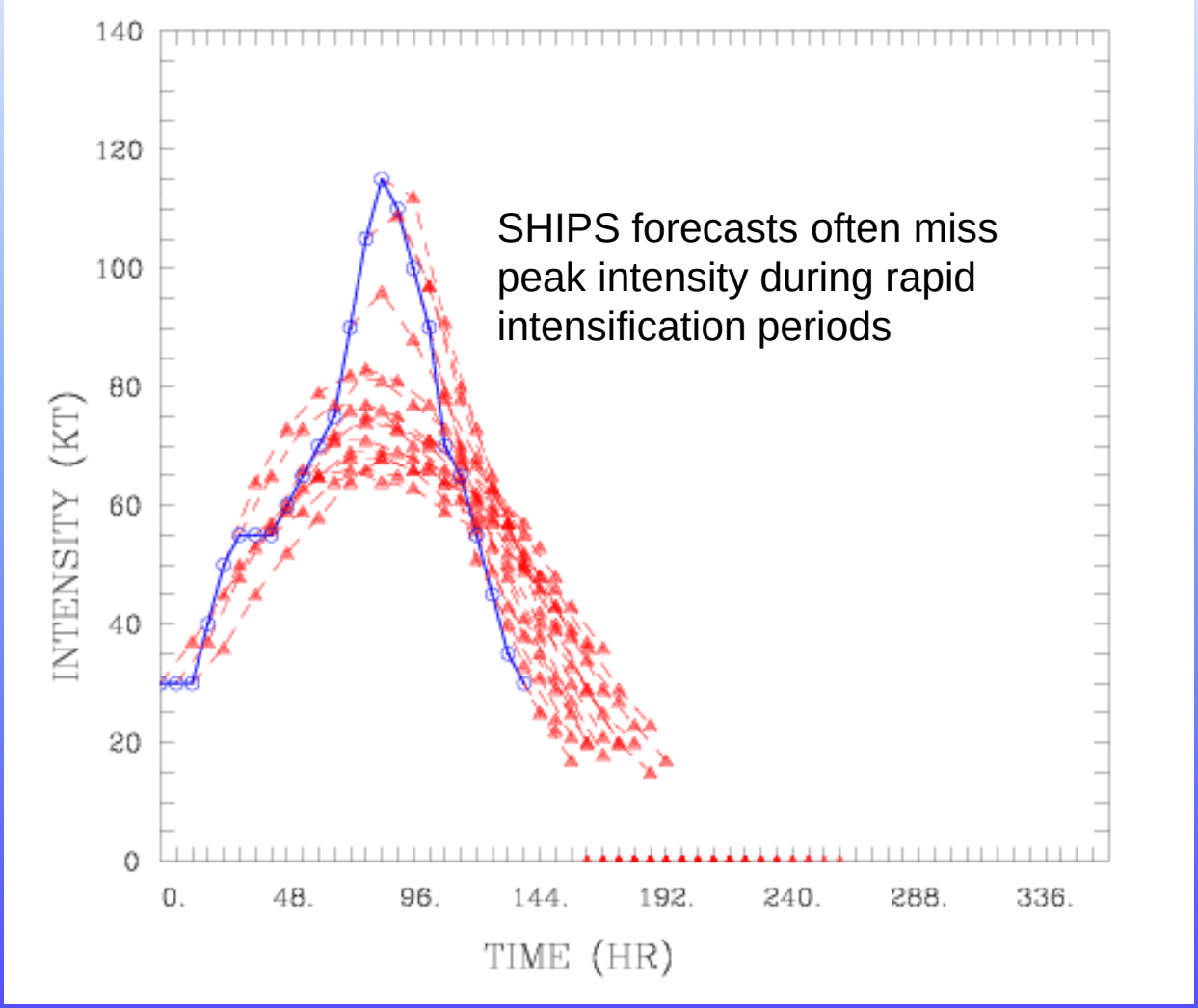



# SHIPS Diagnostic File

```
                          * ATLANTIC     2021 SHIPS INTENSITY FORECAST     *
                          * IR SAT DATA AVAILABLE,       OHC AVAILABLE     *
                          *  DORIAN      AL052019  08/30/19  00 UTC        *

TIME (HR)          0     6    12    18    24    36    48    60    72    84    96   108   120   132   144   156   168
V (KT) NO LAND    80    83    87    90    94    97   102   102   105   102   106   103   103    97    95    91    90
V (KT) LAND       80    83    87    90    94    97   102   102   105   102   106    62    40    31    28    27    27
V (KT) LGEM       80    83    86    89    92    99   105   105   104   104   103    62    39    31    28    27    27
Storm Type      TROP  TROP  TROP  TROP  TROP  TROP  TROP  TROP  TROP  TROP  TROP  TROP  TROP  TROP  TROP  TROP  TROP

SHEAR (KT)         9     8     4     3     8    12    12    15    11    11    11    16    15    16    16    14    21
SHEAR ADJ (KT)    -1    -2    -1    -1    -4    -1    -5    -2    -4     0     0     0    -2     2     1     3     2
SHEAR DIR        200   232   250   243   275   334   299   320   290   293   266   289   267   279   252   255   212
SST (C)         29.4  29.4  29.3  29.4  29.4  29.3  29.3  29.5  29.8  29.9  29.8  29.9  29.7  29.8  29.6  29.4  29.6
POT. INT. (KT)   159   159   157   158   158   156   156   159   164   166   163   165   161   164   159   156   159
ADJ. POT. INT.   147   144   141   142   141   138   136   138   141   141   137   138   135   137   131   127   129
200 MB T (C)   -53.3 -53.3 -53.4 -53.1 -53.0 -53.2 -52.8 -52.9 -52.6 -52.5 -52.1 -52.0 -51.7 -52.1 -51.8 -52.2 -51.4
200 MB VXT (C)  -0.1   0.1   0.2   0.2   0.6   0.6   0.6   0.7   1.0   0.9   1.0   1.3   0.9   0.8   0.7   0.7   0.6
TH_E DEV (C)       11    10    10    10    10    10    10     9     9     9     9     9    10     8    10     7     8
700-500 MB RH      56    56    57    59    59    58    63    61    68    64    65    60    62    56    55    50    50
MODEL VTX (KT)     12    13    14    14    16    17    20    21    23    22    27    26    28    26    27    27    28
850 MB ENV VOR    -43   -46   -45   -32   -22   -24     9    -1    23    -2    17   -15    11   -25    -2    -4    31
200 MB DIV         36    30    14    49    30    13    14    -3    25    -3    25    10    60    23    63    49    89
700-850 TADV        0     1     0     2     1    -6     0    -1    -1    -1    -1    -1     2     4     1     6     0
LAND (KM)         397   444   513   565   622   617   503   332   184    84     4   -46   -78   -77   -61   -46   -77
LAT (DEG N)      22.8  23.6  24.3  24.9  25.4  26.1  26.5  26.8  27.0  27.2  27.5  27.9  28.5 xx.x  xx.x  xx.x  xx.x
LONG(DEG W)      68.0  68.8  69.5  70.4  71.3  73.2  75.0  76.7  78.2  79.3  80.3  81.0  81.5 xxx.x xxx.x xxx.x xxx.x
STM SPEED (KT)     11    10    10    10     9     9     8     7     6     5     4     4     5     5     4     4     4
HEAT CONTENT       45    45    50    58    46    50    57    53    53    56    44    40    32    15    10    16     7

  FORECAST TRACK FROM OFCI      INITIAL HEADING/SPEED (DEG/KT):330/ 11      CX,CY:  -4/ 10
  T-12 MAX WIND:  75            PRESSURE OF STEERING LEVEL (MB):  623  (MEAN=620)
  GOES IR BRIGHTNESS TEMP. STD DEV.  50-200 KM RAD:  14.5 (MEAN=14.5)
  % GOES IR PIXELS WITH T < -20 C    50-200 KM RAD:  65.0 (MEAN=65.0)
  PRELIM RI PROB (DV .GE. 35 KT IN 36 HR):          18.7

                    INDIVIDUAL CONTRIBUTIONS TO INTENSITY CHANGE
                     6    12    18    24    36    48    60    72    84    96   108   120   132   144   156   168
                    ------------------------------------------------------------------------------------------
  SAMPLE MEAN CHANGE   1.    2.    3.    4.    6.    8.    9.   10.   11.   12.   12.   13.   14.   15.   15.   16.
  SST POTENTIAL        1.    3.    4.    5.    4.    2.   -1.   -2.   -3.   -4.   -4.   -5.   -7.   -8.  -10.  -11.
  VERTICAL SHEAR MAG  -0.    0.    1.    1.    1.    3.    4.    5.    7.    8.    8.    8.    9.    9.    9.    8.
  VERTICAL SHEAR ADJ   0.    0.    1.    1.    2.    3.    4.    5.    4.    4.    3.    3.    3.    2.    2.    1.
  VERTICAL SHEAR DIR  -0.   -0.   -0.   -0.   -0.   -0.   -0.   -0.   -0.   -0.    0.    0.    0.    1.    1.    1.
  PERSISTENCE          1.    1.    1.    0.    0.    0.    0.    0.   -0.   -0.   -0.   -0.   -0.   -0.   -0.   -0.
  200/250 MB TEMP.    -0.   -1.   -1.   -1.   -1.   -1.   -1.   -2.   -2.   -2.   -3.   -3.   -4.   -4.   -4.   -5.
  THETA_E EXCESS       0.    0.    0.    1.    1.    1.    1.    1.    1.    0.    0.    0.   -0.   -0.   -0.   -0.
  700-500 MB RH       -0.   -0.   -0.   -0.   -0.   -1.   -1.   -2.   -3.   -3.   -3.   -4.   -4.   -4.   -4.   -3.
  MODEL VTX TENDENCY   0.    1.    1.    2.    3.    7.    8.   11.   10.   15.   14.   15.   11.   11.   10.   10.
  850 MB ENV VORTICITY -0.   -1.   -1.   -1.   -1.   -2.   -2.   -2.   -2.   -2.   -2.   -3.   -3.   -3.   -3.   -3.
  200 MB DIVERGENCE   -0.   -0.   -0.   -0.   -0.   -0.   -1.   -1.   -1.   -1.   -0.    0.    0.    0.    0.   -0.
  850-700 T ADVEC      0.   -0.   -0.   -0.   -0.   -0.   -0.   -0.   -0.   -0.   -0.   -0.   -0.   -0.   -0.   -0.
  ZONAL STORM MOTION  -0.   -0.    0.    0.    0.    0.    0.   -0.   -0.   -0.   -0.   -0.   -1.   -1.   -1.   -1.
  STEERING LEVEL PRES -0.   -0.   -0.   -0.   -0.   -0.   -0.   -0.   -0.   -0.   -0.   -0.   -0.   -0.   -0.   -0.
  DAYS FROM CLIM. PEAK 0.   -0.   -0.   -0.    0.    0.    0.    0.    0.   -0.   -0.   -0.   -0.   -0.   -1.   -0.
  GOES PREDICTORS     -0.   -0.   -0.   -0.   -0.    0.    1.    1.    1.    1.    1.    1.    0.   -0.   -0.   -0.
  OCEAN HEAT CONTENT   0.    0.    0.    0.    0.    0.   -0.   -0.   -0.   -0.   -0.   -0.   -0.   -0.   -0.   -0.
  RI POTENTIAL         0.    1.    2.    2.    3.    3.    2.    1.    0.   -1.   -1.   -2.   -2.   -2.   -2.   -2.
                    ------------------------------------------------------------------------------------------
  TOTAL CHANGE         3.    7.   10.   14.   17.   22.   22.   25.   22.   26.   23.   23.   17.   15.   11.   10.
```

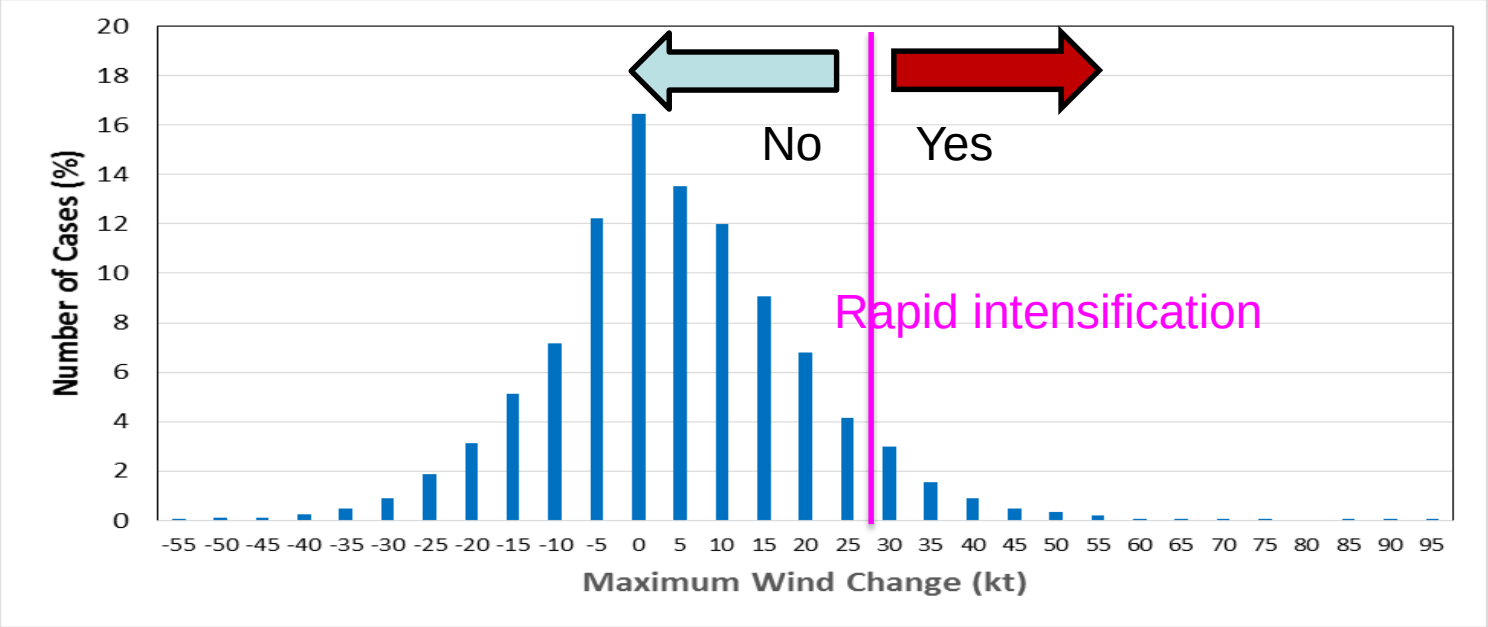
Available in real time from ftp://ftp.nhc.noaa.gov/atcf/stext

# SHIPS Forecasts For East Pacific Hurricane Georgette (2016)



# 24 hr Intensity Change PDF

## Atlantic Over-Water Cases




Mean: 4.3 kt Std Dev: 15 kt Range -55 kt to +95 kt

4th percentile: -25 kt 96th percentile: +30 kt

# The Rapid Intensification Index

- Define RI as 30 kt or greater intensity increase in 24 hr
- Find subset of SHIPS predictors that separate RI and non-RI cases
- Use training sample to convert discriminant function value to a probability of RI
- AL and EP/CP versions include more thresholds (25, 30, 35, 40 kt changes, etc)

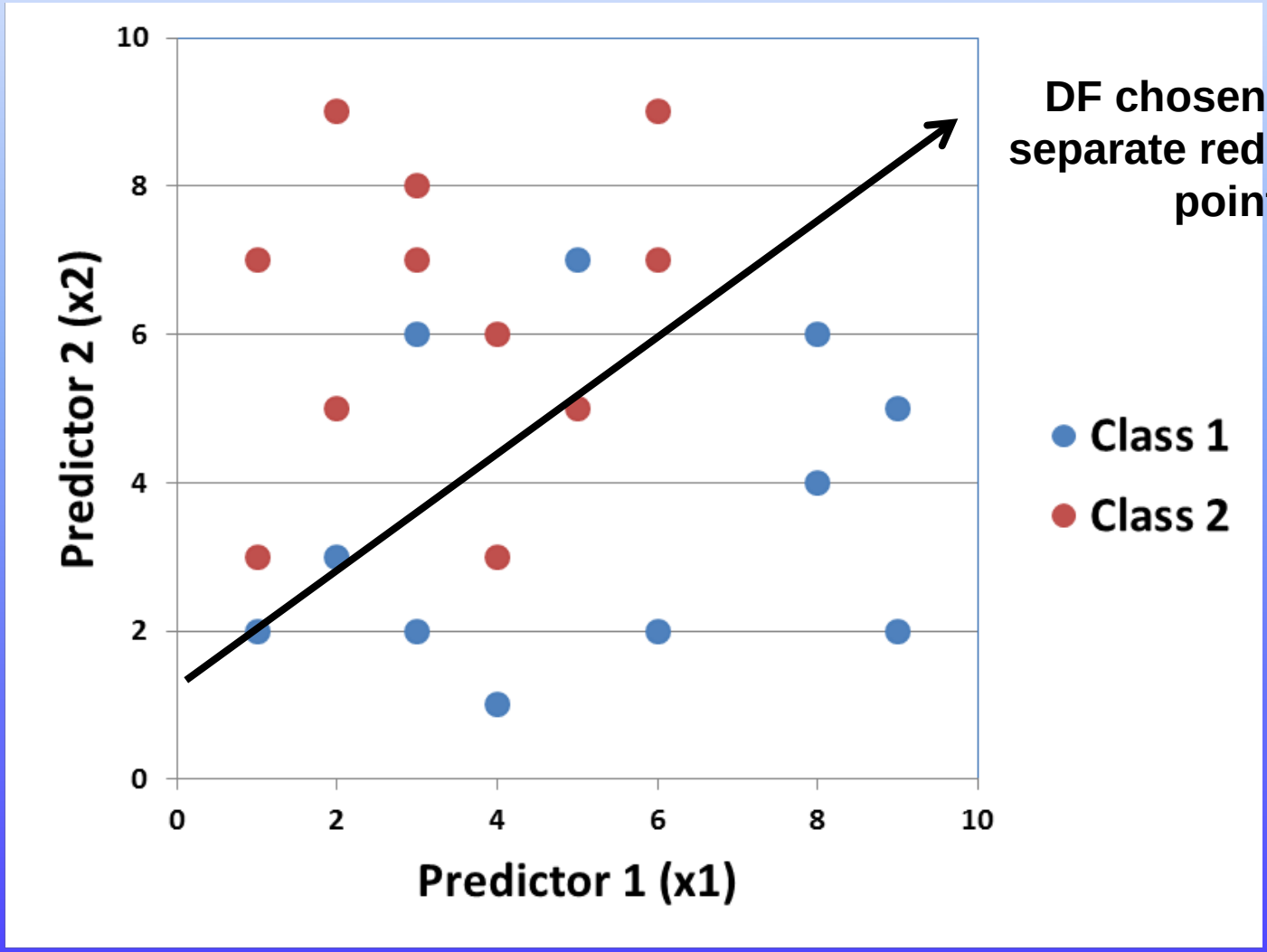
# Linear Discriminant Analysis

- 2 class example
  - Objectively determine which of two classes a data sample belongs to
    - Rapid intensifier or non-rapid intensifier
  - Predictors for each data sample provide input to the classification
- Discriminant function (DF) linearly weights the inputs

$$DF = a_0 + a_1x_1 + \ldots a_Nx_N$$

- Weights chosen to maximize separation of the classes

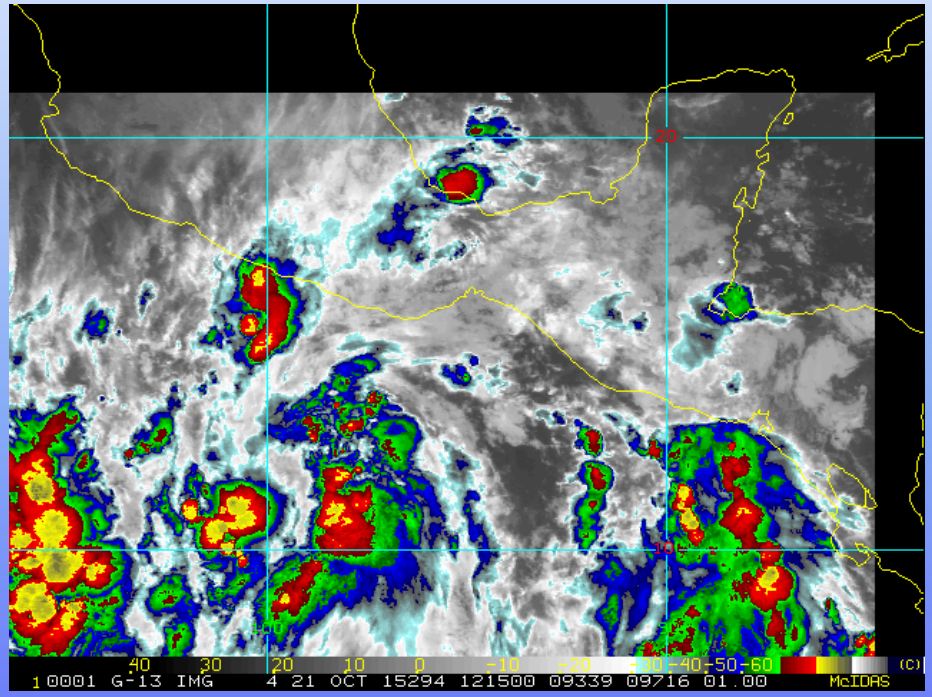
# Graphical Interpretation of the Discriminant Function



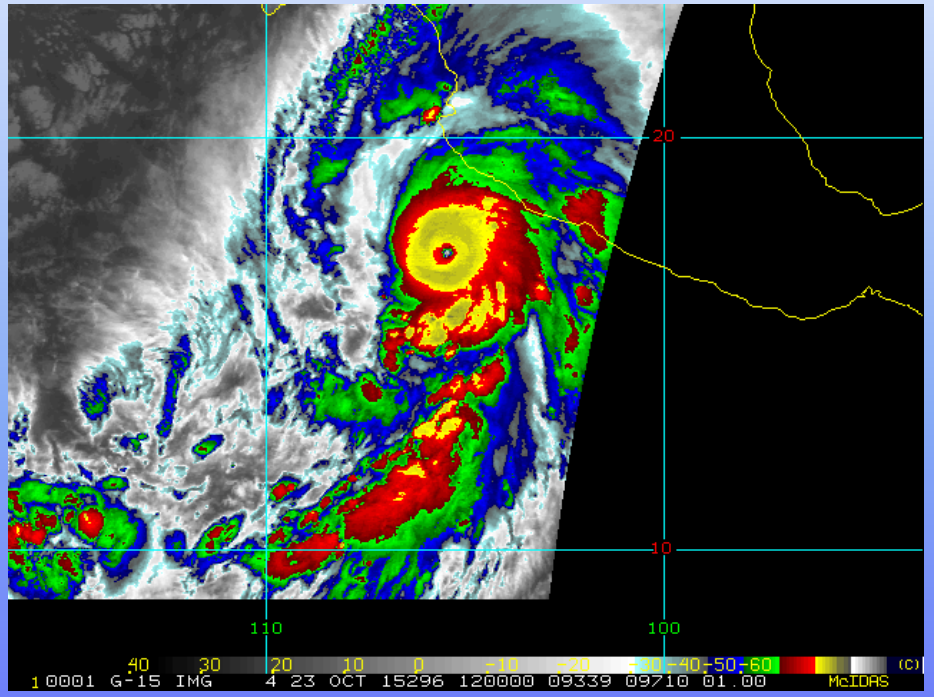
# RII Discriminators

1. Previous 12 h max wind change (persistence)
2. Maximum Potential Intensity – Current intensity
3. Oceanic Heat Content
4. 200-850 hP shear magnitude (0-500 km)
5. 200 hPa divergence (0-1000 km)
6. 850-700 hPa relative humidity (200-800 km)
7. 850 hPa tangential wind (0-500 km)
8. IR pixels colder than -30$^{o}$C
9. Azimuthal standard deviation of IR brightness temperature

# PATRICIA INTENSIFIED FROM 40 KT TO 185 KT IN 48 HOURS!




21 OCT 2015 12 UTC




23 OCT 2015 12 UTC

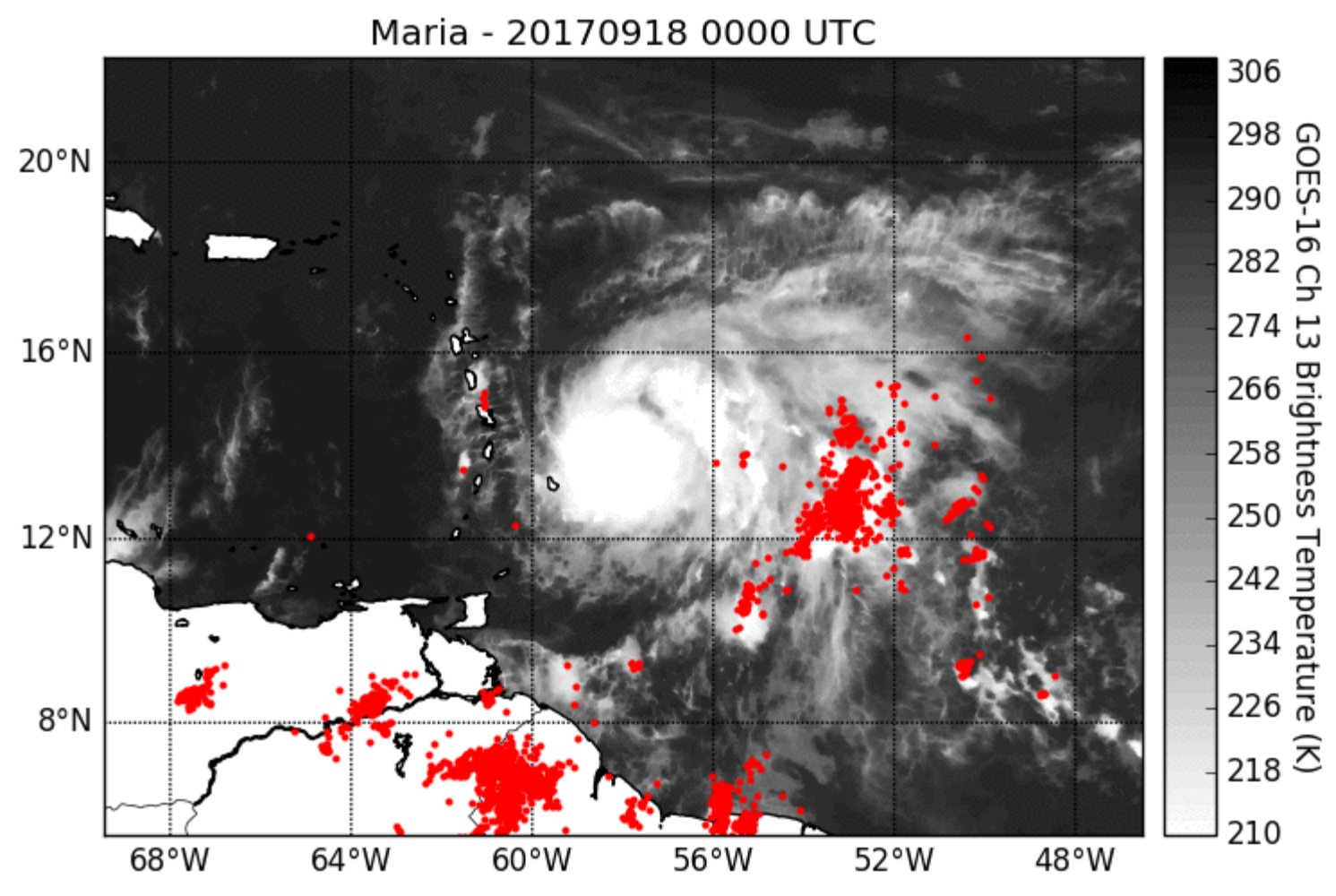
# RI Guidance

## Hurricane Patrica (2015 - East Pacific)

```
                    * EAST PACIFIC 2021 SHIPS INTENSITY FORECAST     *
                    * IR SAT DATA AVAILABLE,       OHC AVAILABLE     *
                    *  PATRICIA    EP202015  10/22/15  06 UTC        *

TIME (HR)          0     6    12    18    24    36    48    60    72    84    96   108   120   132   144   156   168
V (KT) NO LAND    70    82    94   105   113   124   117    89    70    59    50    44    41    38    35    32    28
V (KT) LAND       70    82    94   105   113   124    95    52    35    29    28    27    27    27    27    27    27
V (KT) LGEM       70    83    95   106   115   122    91    50    34   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A
Storm Type      TROP  TROP  TROP  TROP  TROP  TROP  TROP  TROP  TROP   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A

SHEAR (KT)         2     1     6    11    11    12    24    31    46   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A
SHEAR ADJ (KT)     0     0    -3    -5    -5    -2     4     1     1   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A
SHEAR DIR         42   229   228   197   178   189   195   219   232   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A
SST (C)         30.3  30.4  30.5  30.3  30.1  30.5  30.6  28.5  28.6   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A
```

```
     ** 2021 E. Pacific RI INDEX EP202015 PATRICIA   10/22/15  06 UTC **
(SHIPS-RII PREDICTOR TABLE for 30 KT OR MORE MAXIMUM WIND INCREASE IN NEXT 24-h)

    Predictor                  Value   RI Predictor Range  Scaled Value(0-1) % Contribution
POT = MPI-VMAX (KT)          :  98.7     40.5  to  149.3         0.53           13.6
12 HR PERSISTENCE (KT)       :  25.0    -22.0  to   44.0         0.71           20.8
D200 (10**7s-1)              : 116.8    -33.0  to  159.5         0.78           18.5
850-200 MB SHEAR (KT)        :   6.3     19.6  to    1.3         0.73           16.6
MAXIMUM WIND (KT)            :  70.0     22.5  to  132.0         0.83           14.9
STD DEV OF IR BR TEMP        :   6.3     37.8  to    2.1         0.88           14.2
BL DRY-AIR FLUX (W/M2)       : 120.8    800.8  to  -82.5         0.77          -13.8
HEAT CONTENT (KJ/CM2)        :  61.6      2.7  to  106.7         0.57            7.6
%area of TPW <45 mm upshear  :   0.0     56.6  to    0.0         1.00            5.0
2nd PC OF IR BR TEMP         :  -0.3      2.2  to   -2.3         0.55            1.6

SHIPS Prob RI for 20kt/ 12hr RI threshold= 100% is  15.9 times climatological mean ( 6.3%)
SHIPS Prob RI for 25kt/ 24hr RI threshold= 100% is   8.0 times climatological mean (12.5%)
SHIPS Prob RI for 30kt/ 24hr RI threshold=  99% is  11.6 times climatological mean ( 8.6%)
SHIPS Prob RI for 35kt/ 24hr RI threshold=  98% is  16.1 times climatological mean ( 6.2%)
SHIPS Prob RI for 40kt/ 24hr RI threshold=  82% is  19.5 times climatological mean ( 4.2%)
SHIPS Prob RI for 45kt/ 36hr RI threshold=  94% is  14.0 times climatological mean ( 6.7%)
SHIPS Prob RI for 55kt/ 48hr RI threshold=  58% is   9.9 times climatological mean ( 5.9%)
SHIPS Prob RI for 65kt/ 72hr RI threshold=  13% is   2.7 times climatological mean ( 4.7%)
```

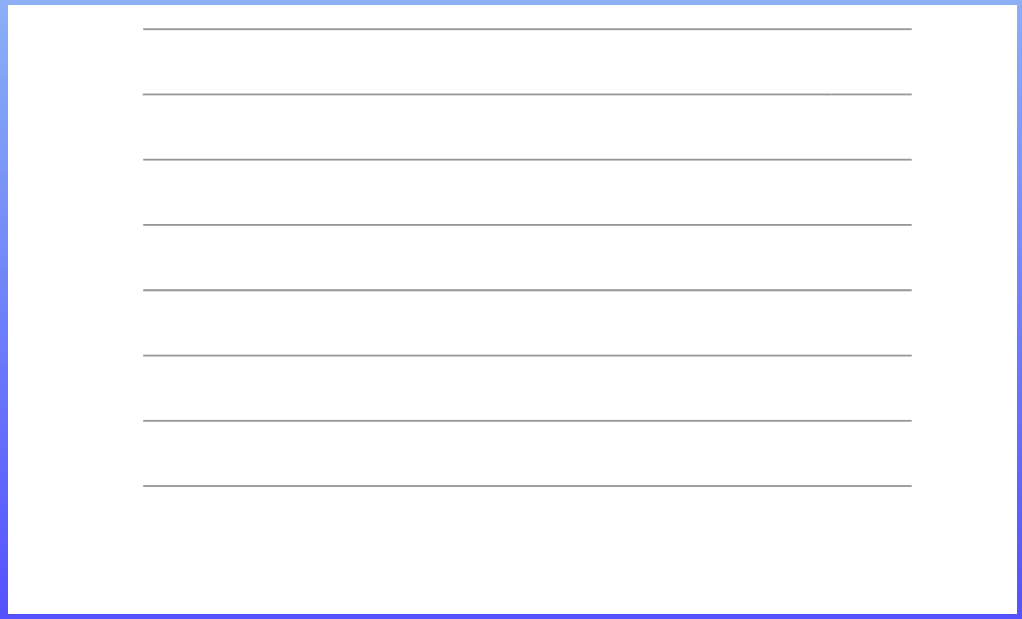
# GOES-16 Imagery and Lightning Locations



# Using GLM to Improve the RII

- Experimental tests using lightning in RII show improved skill
- Plan to run real-time experimental version this season

**RII PREDICTORS**
*POT*: SST Potential
*SHDC*: Shear
*D200*: Divergence
*PER*: Persistence
*PC30*: % IR pixels < -30°C
*TBSTDo*: GOES IR brightness temp standard deviation
*OHC*: Ocean heat content
*RHLO*: Relative humidity
*LM02*: Inner-core lightning
*LM24*: Outer-rainband lightning



Stevenson et al. (2014, MWR)

# Tropical Cyclone Intensity Dynamical Forecast Models

- Regional Models: HWRF, HMON, COAMPS-TC
- Global Models: NCEP GFS, UKMET, ECMWF, Navy NAVGEM, Canadian
- These models have forecast errors due to…
  - sparse observations
  - inadequate resolution (need to go down to a few km grid spacing; the HMON and HWRF, our highest-resolution operational hurricane models, are currently 1-2 km).
  - incomplete understanding and simulation of basic physics of intensity change.
  - problems with representation of shear.
- Steady improvements over past few years to due improved resolution, physics and data assimilation

# Consensus Forecasts

- **ICON – Consensus that is computed by averaging the forecast intensities from Decay-SHIPS, LGEM, HWRF, HMON, COAMPS-TC.**
- **IVCN – Consensus that requires at least 2 of Decay-SHIPS, LGEM, HWRF, HMON and COAMPS-TC.**
- **FSSE (Florida State Superensemble) – Consensus that uses dynamical models and the previous NHC forecast. The FSSE learns from past performances of its member models in a "training phase", then accounts for the model biases.**
- **HCCA (HFIP Corrected Consensus Approach) – FSSE approach adapted to NHC operations**

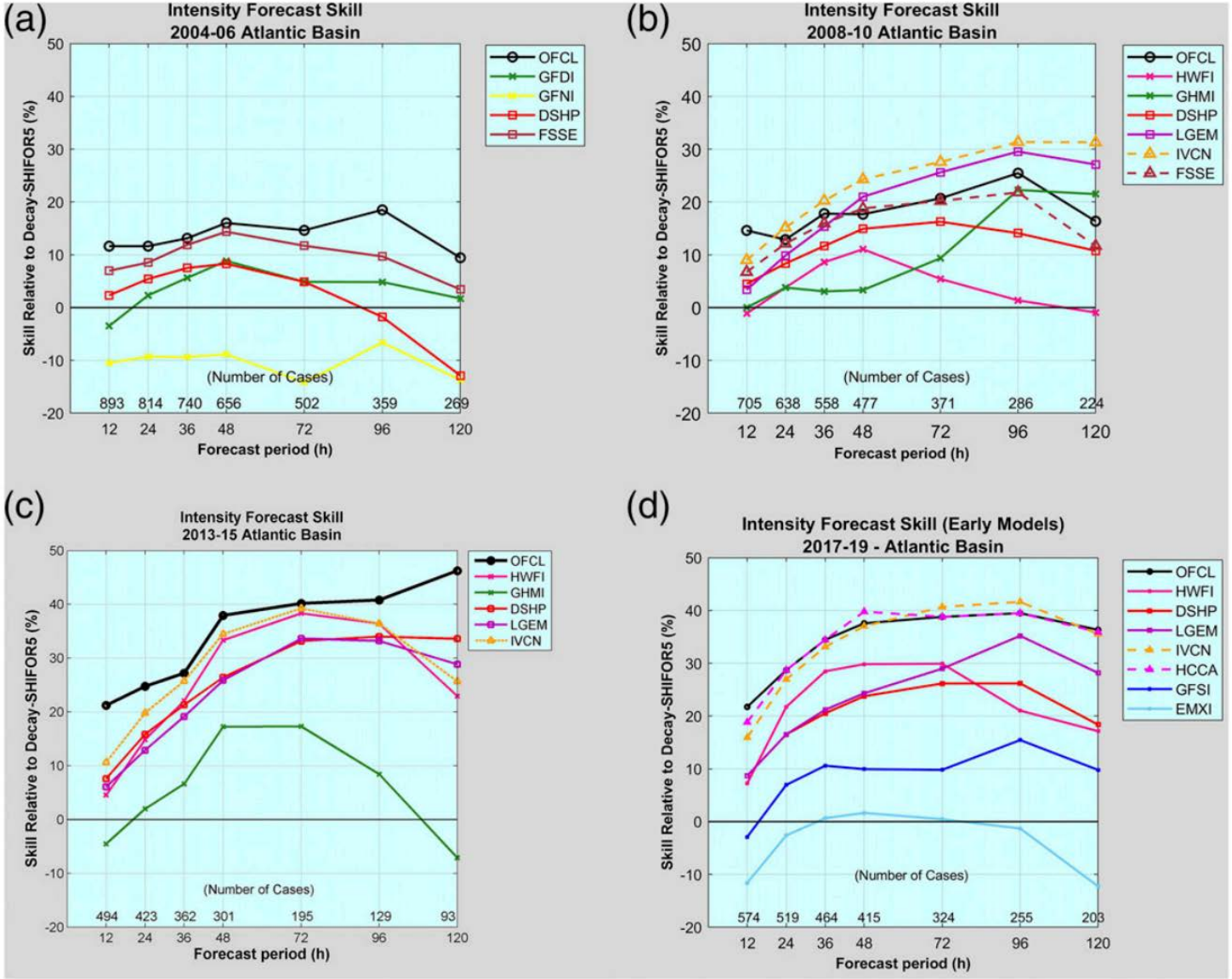
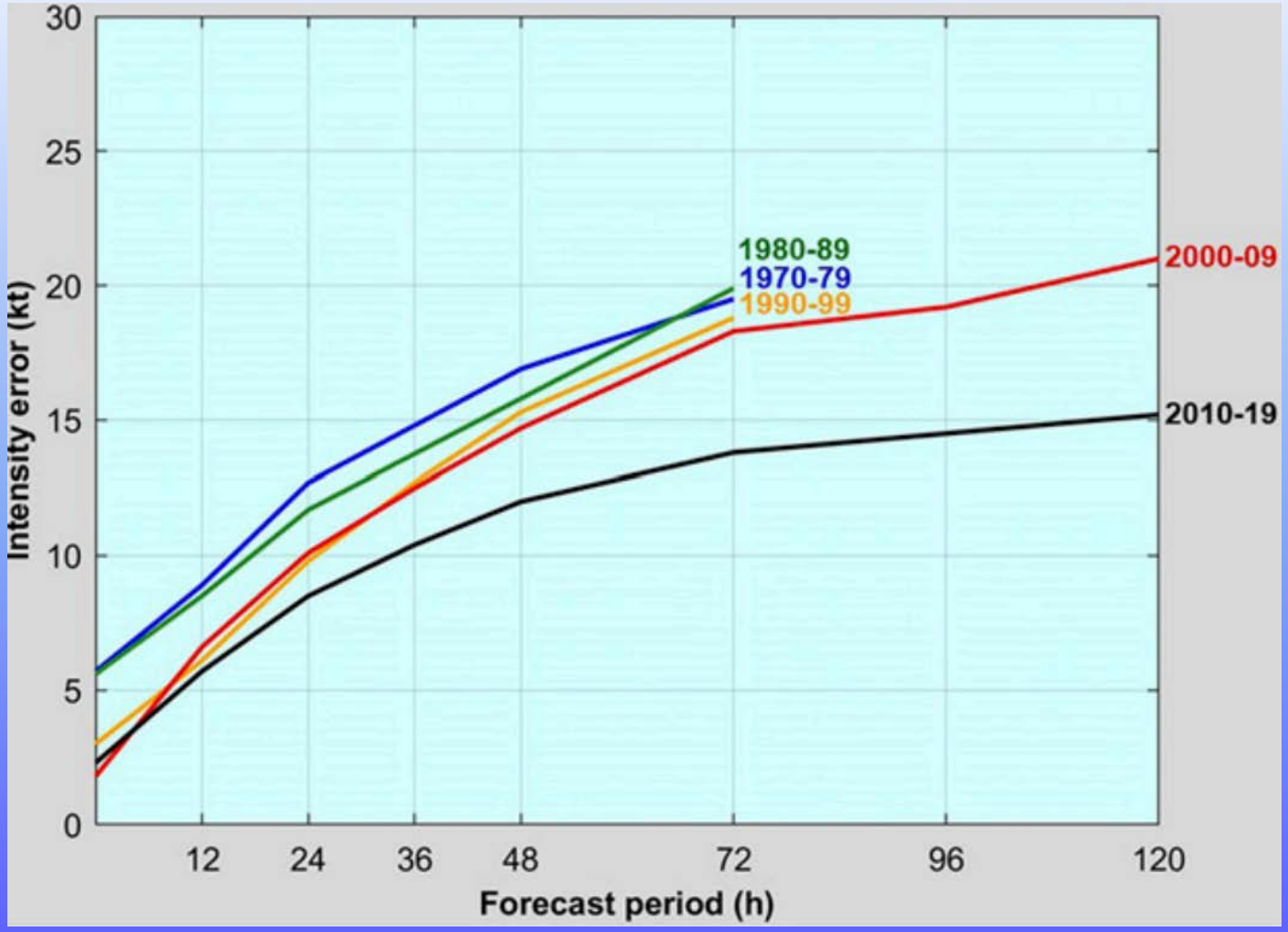



FIG. 5. NHC and intensity model skill for (a) 2004–06, (b) 2008–10, (c) 2013–15, and (d) 2017–19. NHC skill is shown in black, and the various models are depicted in the other colors. The number of verifying events at each forecast lead time is shown above the *x* axis. Models not previously defined: NHC forecasts (OFCL), HWRF interpolated forecasts (HWFI), GFDL interpolated forecasts (GFDI), GFDL run off the U.S. Navy Global Atmospheric Prediction System (GFNI), Florida State Super Ensemble (FSSE), GFS interpolated forecasts (GFSI), and ECMWF interpolated forecasts (EMXI).

# NHC Official Intensity Forecast

- Based on statistical guidance from SHIPS and D-SHIFOR, qualitative guidance from dynamical models and consensus.
- Dynamical models (HWRF and COTC) more skillful last few years
- Persistence is used quite a bit!
- Obvious signs in the environment, i.e. cooler waters, increasing upper-level winds, are taken into account.
- Generally corresponds to what is *normal* for a storm in any particular situation (e.g. the standard Dvorak development rate).
- Tends to be conservative; ***extreme events are almost never forecast.***
- For forecasts 24 h and beyond, the average error is roughly 1 SSHWS Category (15-20 knots).

# Atlantic Intensity Error Trends




*Only small improvements between 1970-2009, but errors have decreased more sharply this decade.*

*From Cangialosi et al 2020, Weather and Forecasting*

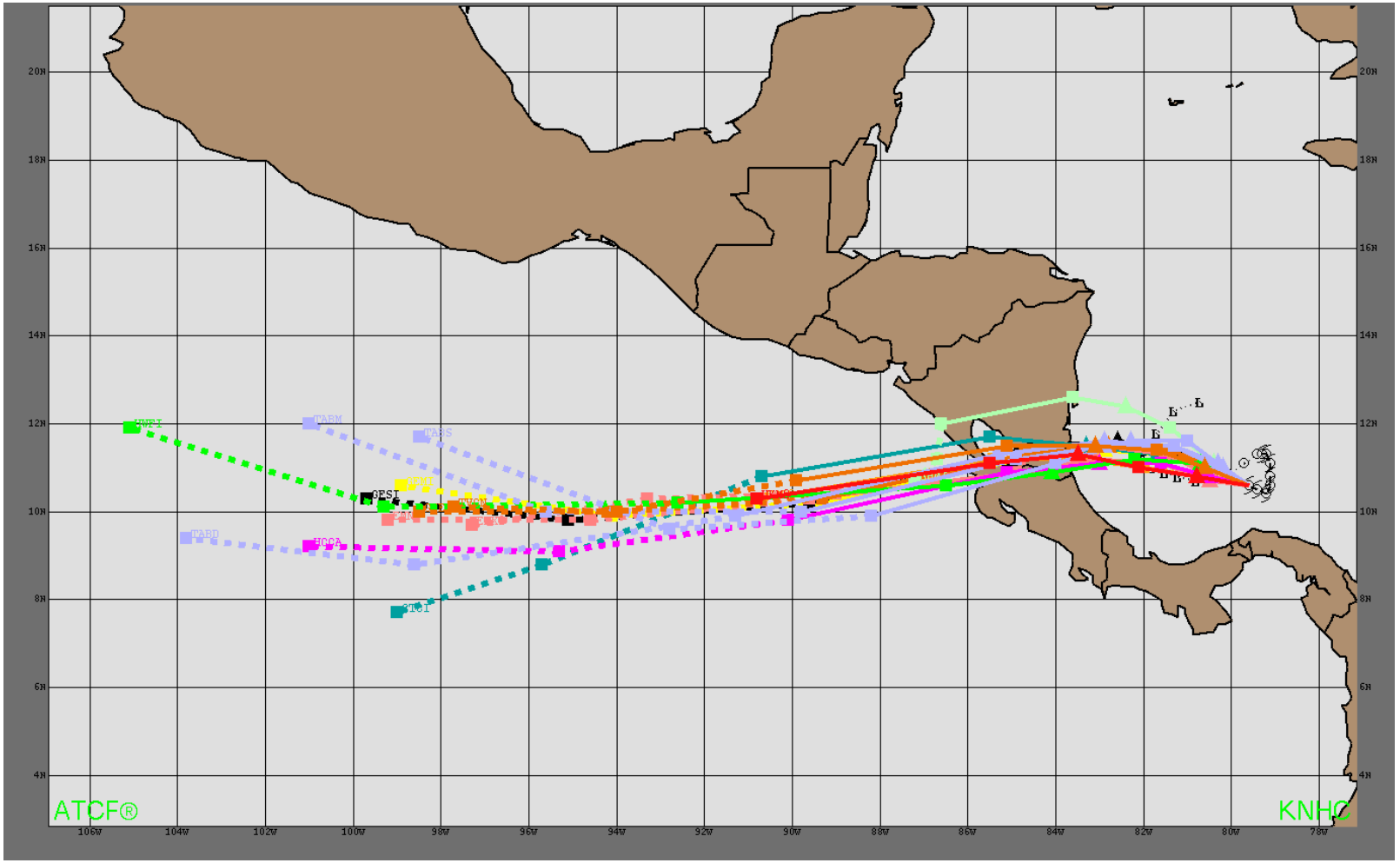
# Concluding Remarks

- Intensity forecasting is not as advanced as track forecasting.
- There is less skill for intensity forecasting than there is for track forecasting.
- Current guidance is provided mainly by HWRF, DSHIPS, LGEM, IVCN and more recently, COAMPS-TC, HMON, FSSE and HCCA
  - Dynamical models more skillful for basin-wide intensity forecasts
  - Statistical methods more skillful for identifying RI cases
- We still have significant difficulty in forecasting rapidly intensifying and rapidly weakening storms.
- The main hope for the future lies in improved dynamical models, coupled with enhanced observations and understanding of the hurricane's inner core - Hurricane Forecast Improvement Project (HFIP)
- GOES-16/-17 is providing new imagery and lightning data for dynamical and statistical-dynamical intensity models

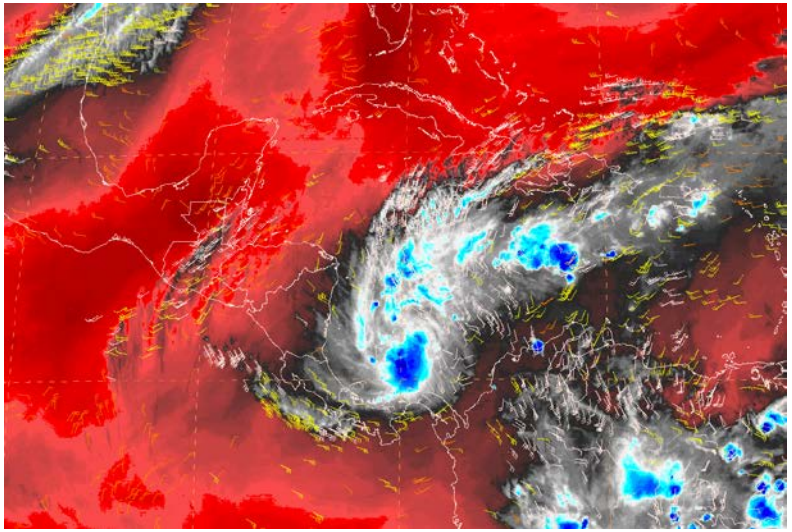
# EXERCISE 2
# Intensity Forecast

# Part 2: 36-Hour Forecast Intensity

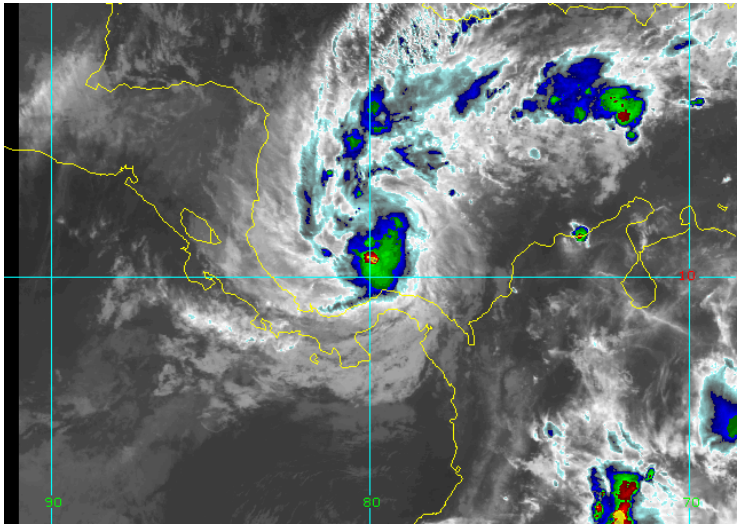
## Model Track Guidance

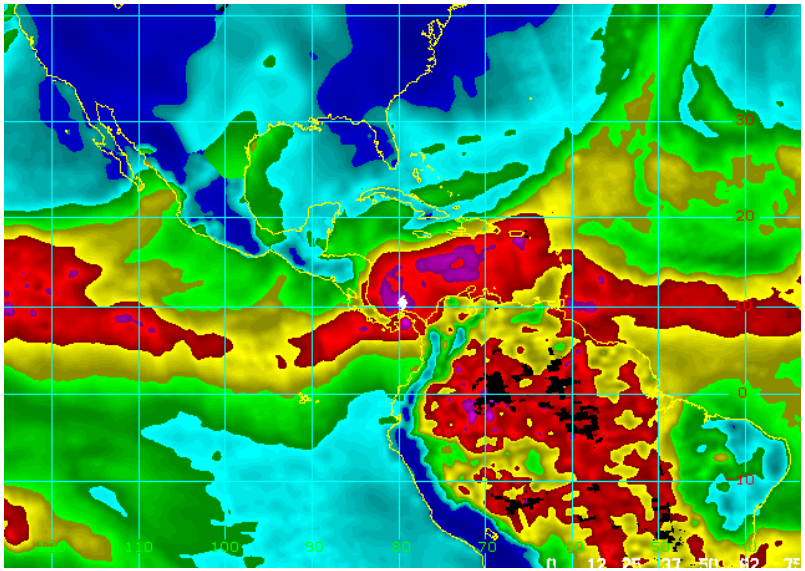


## Water Vapor Imagery and Mid- to Upper Level Winds

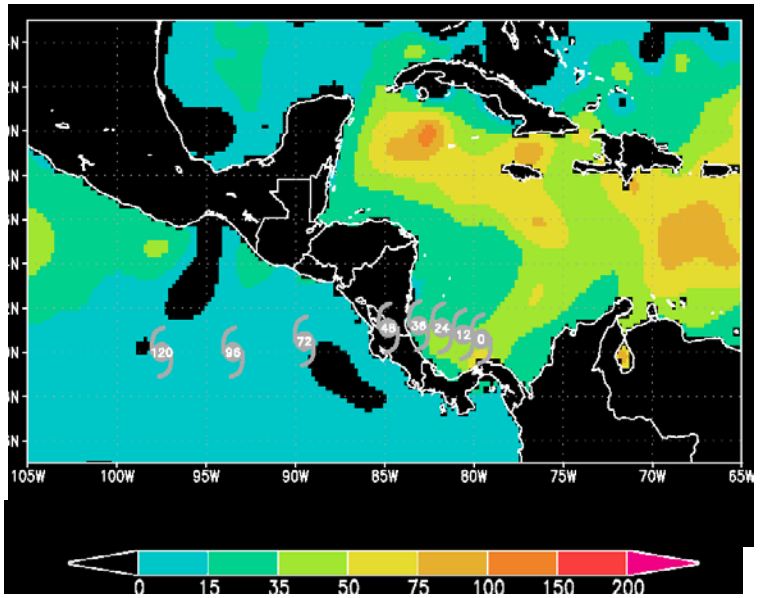


## Infrared Imagery (Window Channel)



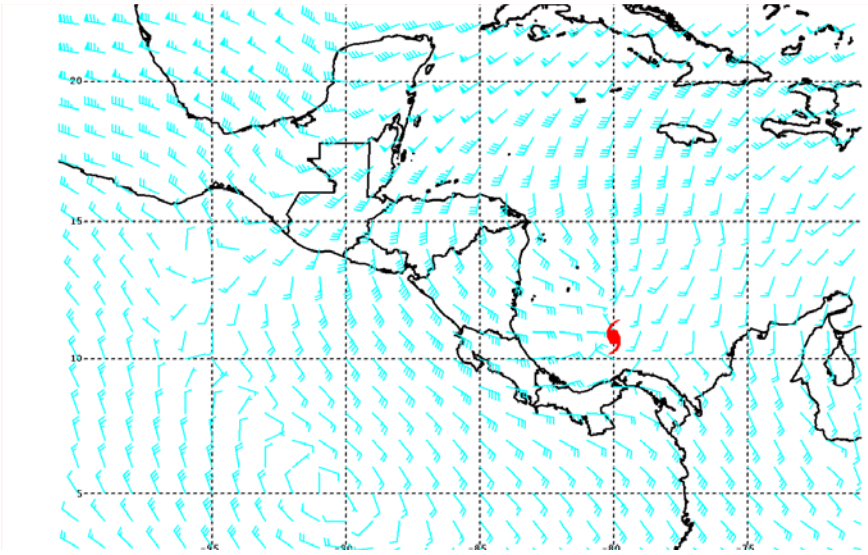


Total Precipitable Water

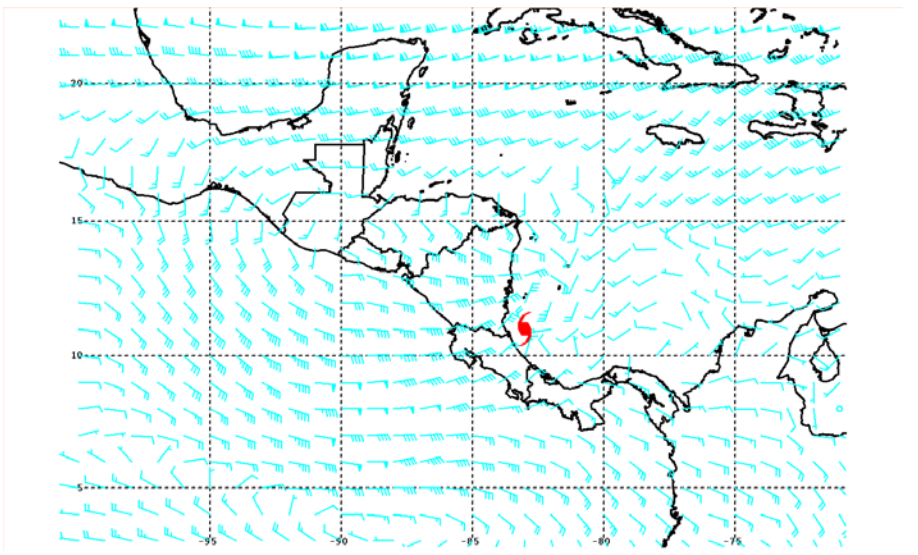


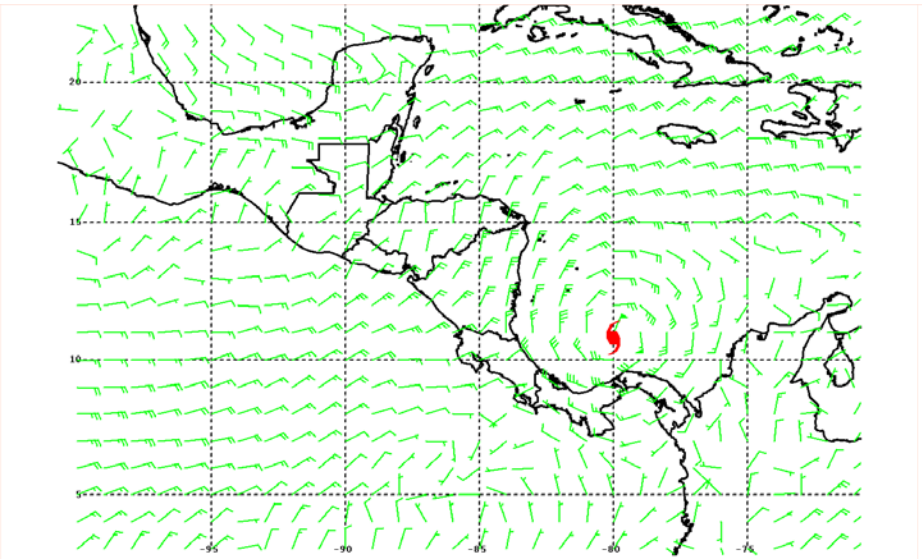

Oceanic Heat Content

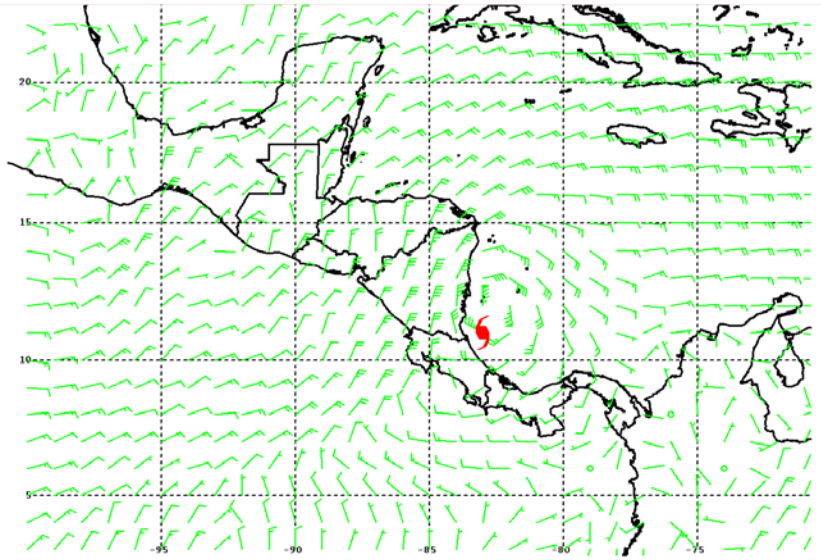
## 200 hPa Wind 6 hr GFS forecast



## 200 hPa Wind 42 hr GFS forecast



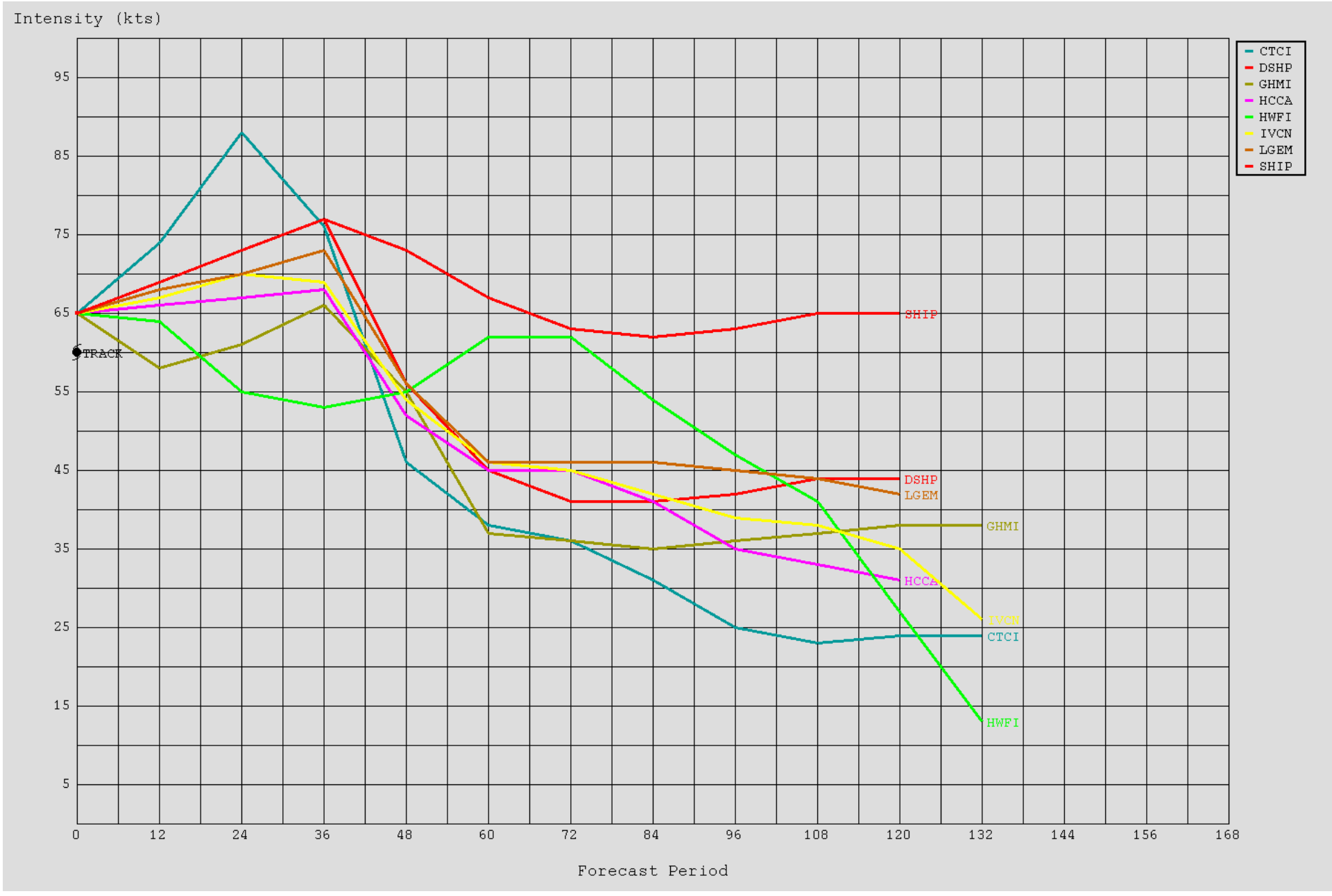




## 850 hPa Wind 6 hr GFS forecast

## 850 hPa Wind 42 hr GFS forecast

# Intensity Model Guidance



# SHIPS/LGEM Model Guidance

* ATLANTIC SHIPS INTENSITY FORECAST *
* IR SAT DATA AVAILABLE, OHC AVAILABLE *

| TIME (HR) | 0 | 6 | 12 | 18 | 24 | 36 | 48 | 60 | 72 | 84 | 96 | 108 | 120 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| V (KT) NO LAND | 65 | 67 | 69 | 71 | 73 | 77 | 73 | 67 | 63 | 62 | 63 | 65 | 65 |
| V (KT) LAND | 65 | 67 | 69 | 71 | 73 | 77 | 56 | 45 | 41 | 41 | 42 | 44 | 44 |
| V (KT) LGEM | 65 | 67 | 68 | 69 | 70 | 73 | 56 | 46 | 46 | 46 | 45 | 44 | 42 |
| Storm Type | TROP | TROP | TROP | TROP | TROP | TROP | TROP | TROP | TROP | TROP | TROP | TROP | TROP |
| SHEAR (KT) | 14 | 13 | 12 | 11 | 12 | 11 | 16 | 22 | 25 | 25 | 20 | 20 | 24 |
| SHEAR ADJ (KT) | 0 | -1 | -3 | -4 | -4 | -2 | -1 | -1 | 0 | 1 | 4 | 8 | 7 |
| SHEAR DIR | 136 | 151 | 151 | 123 | 116 | 119 | 133 | 135 | 125 | 125 | 115 | 108 | 89 |
| SST (C) | 29.0 | 29.0 | 29.0 | 29.0 | 29.1 | 29.2 | 28.7 | 28.1 | 28.1 | 28.7 | 29.1 | 29.1 | 28.6 |
| POT. INT. (KT) | 148 | 148 | 149 | 150 | 152 | 154 | 147 | 139 | 138 | 146 | 152 | 154 | 147 |
| ADJ. POT. INT. | 141 | 142 | 144 | 147 | 149 | 151 | 146 | 140 | 139 | 144 | 152 | 160 | 153 |
| 200 MB T (C) | -52.9 | -53.0 | -53.2 | -52.6 | -52.8 | -53.3 | -53.0 | -53.6 | -53.3 | -54.1 | -53.8 | -54.4 | -54.1 |
| 200 MB VXT (C) | -0.2 | -0.2 | -0.1 | 0.0 | 0.1 | 0.1 | 0.1 | 0.2 | 0.3 | 0.1 | 0.0 | 0.0 | 0.0 |
| TH_E DEV (C) | 6 | 5 | 4 | 5 | 5 | 4 | 5 | 4 | 5 | 4 | 4 | 4 | 5 |
| 700-500 MB RH | 63 | 66 | 67 | 69 | 70 | 74 | 75 | 74 | 71 | 65 | 67 | 60 | 58 |
| MODEL VTX (KT) | 17 | 18 | 18 | 18 | 17 | 20 | 15 | 11 | 8 | 10 | 11 | 11 | 10 |
| 850 MB ENV VOR | 51 | 63 | 64 | 66 | 62 | 62 | 61 | 46 | 48 | 28 | 8 | -6 | -7 |
| 200 MB DIV | 68 | 86 | 109 | 104 | 61 | 64 | 61 | 45 | 61 | 65 | 80 | 77 | 65 |
| 700-850 TADV | 0 | 1 | 0 | 0 | 1 | 1 | 6 | 10 | 9 | 10 | 8 | 5 | 1 |
| LAND (KM) | 111 | 135 | 163 | 212 | 196 | 85 | -55 | 83 | 311 | 412 | 463 | 559 | 695 |
| LAT (DEG N) | 10.6 | 10.8 | 10.9 | 11.0 | 11.1 | 11.1 | 11.1 | 10.8 | 10.3 | 10.0 | 9.9 | 9.8 | 9.5 |
| LONG(DEG W) | 79.6 | 79.9 | 80.2 | 80.8 | 81.5 | 82.9 | 84.4 | 86.6 | 89.1 | 91.1 | 92.2 | 94.3 | 97.1 |
| STM SPEED (KT) | 3 | 3 | 5 | 6 | 7 | 7 | 9 | 12 | 11 | 7 | 8 | 12 | 14 |
| HEAT CONTENT | 44 | 41 | 37 | 35 | 35 | 31 | 24 | 3 | 12 | 4 | 6 | 7 | 3 |

FORECAST TRACK FROM OFCI INITIAL HEADING/SPEED (DEG/KT):290/ 2 CX,CY: -1/ 1
T-12 MAX WIND: 60 PRESSURE OF STEERING LEVEL (MB): 591 (MEAN=618)
GOES IR BRIGHTNESS TEMP. STD DEV. 50-200 KM RAD: 10.1 (MEAN=14.5)
% GOES IR PIXELS WITH T < -20 C 50-200 KM RAD: 74.0 (MEAN=65.0)
PRELIM RI PROB (DV .GE. 30 KT IN 24 HR): 10.4

# Rapid Intensification Index

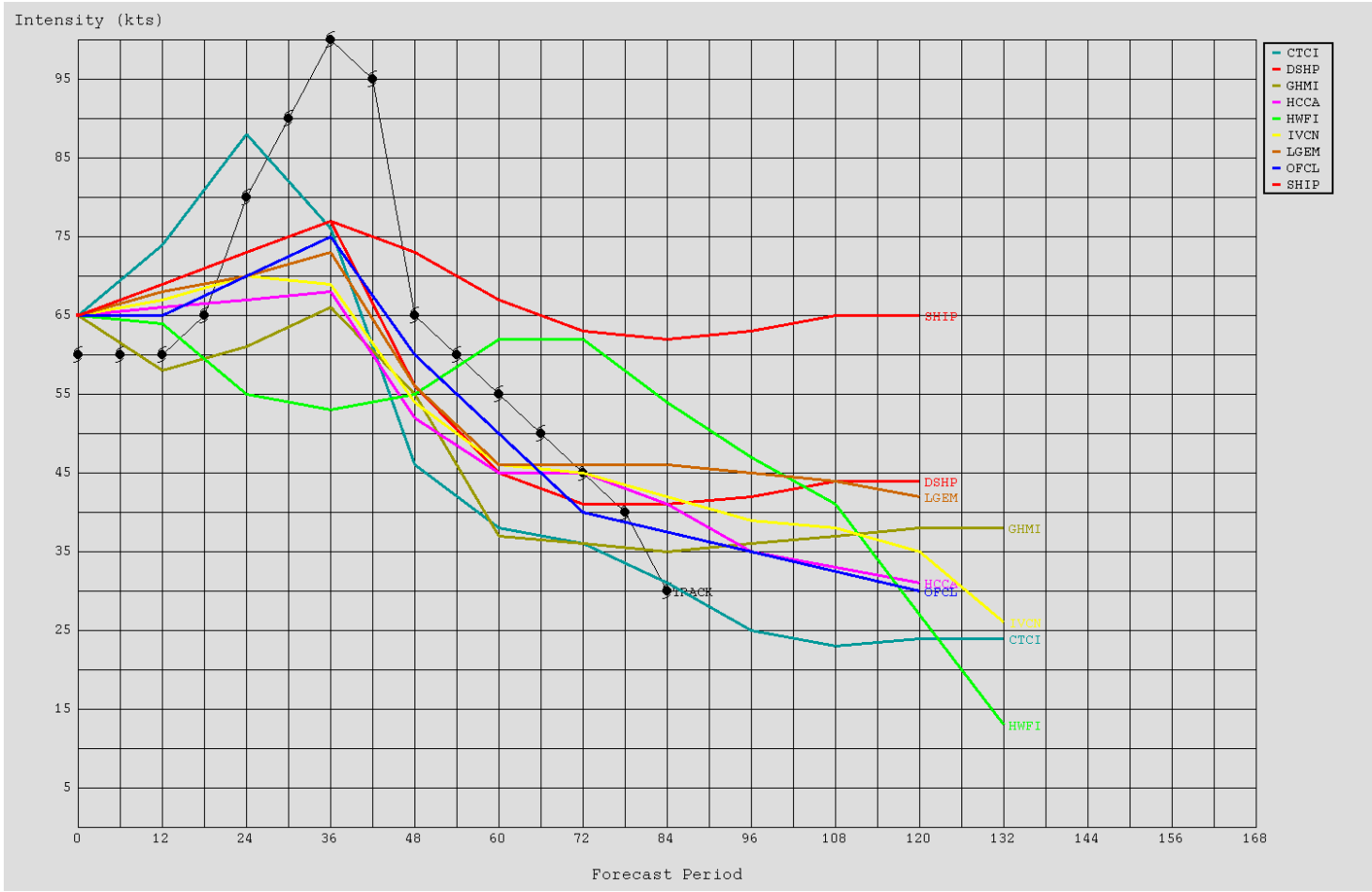
**  ATLANTIC RI INDEX  **
(SHIPS-RII PREDICTOR TABLE for 30 KT OR MORE MAXIMUM WIND INCREASE IN NEXT 24-h)

| Predictor | Value | RI Predictor Range | Scaled Value(0-1) | % Contribution |
|---|---|---|---|---|
| 12 HR PERSISTENCE (KT): | 5.0 | -49.5 to 33.0 | 0.66 | 6.3 |
| 850-200 MB SHEAR (KT) : | 12.5 | 28.8 to 2.9 | 0.63 | 2.7 |
| HEAT CONTENT (KJ/cm2) : | 38.4 | 0.0 to 155.1 | 0.25 | 0.8 |
| STD DEV OF IR BR TEMP : | 10.1 | 37.5 to 2.9 | 0.79 | 3.3 |
| 2nd PC OF IR BR TEMP : | 0.1 | 2.8 to -3.1 | 0.45 | 1.9 |
| MAXIMUM WIND (kt) : | 65.0 | 22.5 to 121.0 | 0.89 | 1.3 |
| D200 (10**7s-1) : | 85.6 | -23.1 to 181.5 | 0.53 | 0.9 |
| POT = MPI-VMAX (KT) : | 79.6 | 28.4 to 139.1 | 0.46 | 1.1 |
| % AREA WITH TPW <45 mm: | 0.0 | 100.0 to 0.0 | 1.00 | 1.0 |
| BL DRY-AIR FLUX (w/m2): | 156.8 | 960.3 to -67.1 | 0.78 | 0.0 |

SHIPS Prob RI for 20kt/ 12hr RI threshold= 11% is 2.0 times sample mean ( 5.5%)
SHIPS Prob RI for 25kt/ 24hr RI threshold= 33% is 2.8 times sample mean (11.6%)
SHIPS Prob RI for 30kt/ 24hr RI threshold= 19% is 2.7 times sample mean ( 7.2%)
SHIPS Prob RI for 35kt/ 24hr RI threshold= 15% is 3.7 times sample mean ( 4.2%)
SHIPS Prob RI for 40kt/ 24hr RI threshold= 11% is 3.8 times sample mean ( 2.8%)
SHIPS Prob RI for 45kt/ 36hr RI threshold= 21% is 4.3 times sample mean ( 4.9%)
SHIPS Prob RI for 55kt/ 48hr RI threshold= 20% is 3.8 times sample mean ( 5.1%)

# What is your 36 hr Intensity Forecast?

# Answer: 36 hr Max Wind = 100 kt




Bonus Question: What TC was this?