A New Secondary Eyewall Formation Index; Transition to Operations and Quantification of Associated Hurricane Intensity and Structure Changes

A Joint Hurricane Testbed Project

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Project goals:

1. Transition a new model to operations that will provide probabilistic forecasts of secondary eyewall formation in hurricanes.

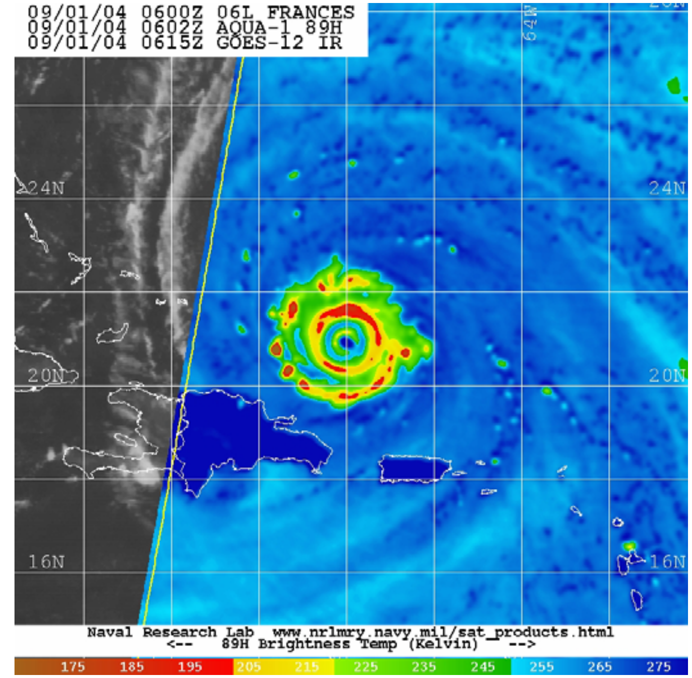
2. Utilize low-level aircraft reconnaissance data to construct a climatology of intensity and structure changes that can be used to quantify the changes associated with secondary eyewall formation.

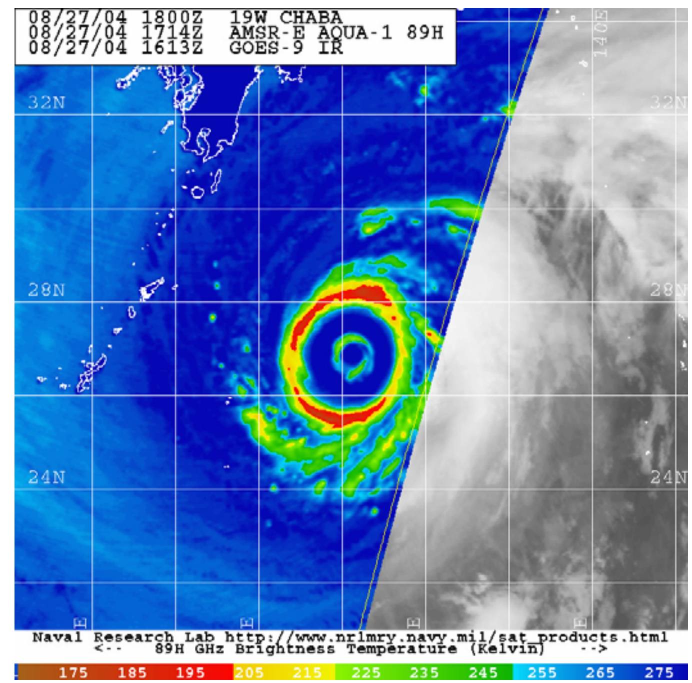
Secondary eyewall formation events

Precursors to large and rapid intensity and structure changes. Often interrupt intensification, sometimes briefly, sometimes permanently.

Wind field expands:
Critical wind radii, storm surge, and integrated kinetic energy all increase.

Present a unique forecast challenge, but no objective guidance available.





The "p-SEF" model

(**p**robability of **S**econdary **E**yewall **F**ormation model)

Probability of secondary eyewall formation, given a collection $\mathbf{F}$ of observed features (storm, environment, satellite):

$$P(C_{\text{sef}}|\mathbf{F}) = \frac{P(C_{\text{sef}})P(\mathbf{F}|C_{\text{sef}})}{P(\mathbf{F})}$$

Skill (10 years, cross-validated):

	Brier skill score
Climatology	0%
Current intensity only	12%
Current intensity plus SHIPS environmental	18%
Current intensity plus SHIPS environmental plus GOES	21%

Latest refinements increase the skill score to ~30%

SHIPS text output file

```
                  *   ATLANTIC SHIPS INTENSITY FORECAST       *
                  *      GOES DATA AVAILABLE                  *
                  *      OHC  DATA AVAILABLE                  *
                  *  AL03        AL992009  08/20/09  00 UTC   *

TIME (HR)          0     6    12    18    24    36    48    60    72    84    96   108   120
V (KT) NO LAND   115   115   118   121   122   122   122   113   109   103    92    77    65
V (KT) LAND      115   115   118   121   122   122   122   113   109   103    92    52    46
V (KT) LGE mod   115   114   112   111   109   107   106   100    90    82    65    42    41

SHEAR (KT)        11     3     5     3     6    12     5    12     8    11    29    77    74
SHEAR DIR        251   246   304   206   227   242   258   300   220   177   213   226   232
SST (C)         28.6  28.7  28.7  28.7  28.7  29.1  29.1  28.0  27.6  24.3  17.8  14.4  11.7
POT. INT. (KT)   148   149   149   149   149   155   156   139   134   105    80    76    74
ADJ. POT. INT.   143   144   143   140   139   144   142   123   118    95    76    73    72
200 MB T (C)   -51.3 -51.3 -51.0 -49.6 -50.1 -50.2 -48.5 -48.6 -47.5 -47.9 -47.4 -46.1 -43.8
TH_E DEV (C)      10    10     9     9    10     9     9     8     7     3     1     0     0
700-500 MB RH     61    59    60    62    59    61    59    64    65    64    56    41    44
GFS VTEX (KT)     30    29    31    33    32    34    36    35    35    38    37    37    43
850 MB ENV VOR    80    77    76    80    72    60    39    16    53    63   117   114   174
200 MB DIV       101    99    84   117    98    59    95    37   129    64    93    61    45
LAND (KM)        814   712   646   638   663   879  1047   763   623   355    30   -22   710
LAT (DEG N)     20.2  21.2  22.1  23.1  24.0  26.5  29.3  32.4  35.7  39.7  44.4  49.1  53.7
LONG(DEG W)     58.2  59.6  61.0  62.3  63.5  65.5  67.4  68.5  68.9  67.1  63.0  55.4  45.2
STM SPEED (KT)    16    16    16    15    15    16    16    16    18    25    32    37    39
HEAT CONTENT      59    47    43    48    41    43    27    16    23     0     0     0     0

  FORECAST TRACK FROM BEST      INITIAL HEADING/SPEED (DEG/KT):308/ 16      CX,CY: -12/ 10
  T-12 MAX WIND: 115            PRESSURE OF STEERING LEVEL (MB):  587  (MEAN=624)
  GOES IR BRIGHTNESS TEMP. STD DEV.  50-200 KM RAD:  12.2 (MEAN=14.5)
  % GOES IR PIXELS WITH T < -20 C    50-200 KM RAD:  99.0 (MEAN=65.0)

                      INDIVIDUAL CONTRIBUTIONS TO INTENSITY CHANGE
                       6   12   18   24   36   48   60   72   84   96  108  120
                      ----------------------------------------------------------
  SAMPLE MEAN CHANGE   1.   2.   3.   4.   6.   8.   9.  11.  11.  12.  13.  13.
  SST POTENTIAL       -0.   1.   1.  -0.  -4. -11. -21. -31. -41. -49. -54. -60.
  VERTICAL SHEAR MAG  -1.  -1.  -0.   0.  -0.   4.   6.   9.  11.  11.   6.   0.
  VERTICAL SHEAR DIR  -0.  -1.  -1.  -1.  -2.  -1.  -1.   0.   2.   3.   5.   7.
  PERSISTENCE         -0.  -1.  -1.  -1.  -1.  -1.  -1.  -1.  -1.  -0.  -0.  -0.
  200/250 MB TEMP.    -1.  -1.  -2.  -3.  -5.  -8. -10. -12. -15. -18. -21. -25.
  THETA_E EXCESS      -0.  -0.  -0.  -0.  -1.  -1.  -2.  -3.  -5.  -8. -11. -14.
  700-500 MB RH       -0.  -0.  -0.  -0.  -1.  -1.  -1.  -1.  -1.  -2.  -2.  -2.
  GFS VORTEX TENDENCY -0.   0.   1.   1.   2.   4.   3.   3.   5.   4.   4.   8.
  850 MB ENV VORTICITY 0.   1.   1.   1.   2.   2.   2.   2.   2.   3.   4.   5.
  200 MB DIVERGENCE    0.   1.   2.   3.   5.   7.   7.  10.  10.  11.  10.  10.
  ZONAL STORM MOTION   0.   0.   1.   1.   2.   2.   3.   3.   3.   4.   4.   4.
  STEERING LEVEL PRES  0.   0.   0.   0.   0.   0.   0.   0.   1.   0.   0.   0.
  DAYS FROM CLIM. PEAK 0.   0.   0.   0.   0.   0.   0.  -0.  -0.  -0.  -0.  -0.
  GOES PREDICTORS      1.   1.   1.   2.   3.   4.   4.   5.   6.   5.   4.   4.
  OCEAN HEAT CONTENT  -0.  -0.  -0.  -0.  -0.  -0.  -1.  -1.  -1.  -1.  -0.  -0.
                      ----------------------------------------------------------
  TOTAL CHANGE         0.   3.   6.   7.   7.   7.  -2.  -6. -12. -23. -38. -50.

   ** 2009 ATLANTIC RI INDEX AL992009 AL03       08/20/09  00 UTC **
           ( 30 KT OR MORE MAX WIND INCREASE IN NEXT 24 HR)

 12 HR PERSISTENCE (KT):   0.0 Range:-45.0 to  30.0 Scaled/Wgted Val:  0.6/  1.3
 850-200 MB SHEAR (KT) :   5.6 Range: 26.2 to   3.2 Scaled/Wgted Val:  0.9/  1.2
 D200 (10**7s-1)       :  99.8 Range:-21.0 to 140.0 Scaled/Wgted Val:  0.8/  1.1
 POT = MPI-VMAX (KT)   :  27.0 Range: 33.5 to 126.5 Scaled/Wgted Val:  0.0/  0.0
 850-700 MB REL HUM (%):  71.0 Range: 56.0 to  85.0 Scaled/Wgted Val:  0.5/  0.3
 % area w/pixels <-30 C:  99.0 Range: 16.0 to 100.0 Scaled/Wgted Val:  1.0/  0.3
 STD DEV OF IR BR TEMP :  12.2 Range: 30.6 to   3.2 Scaled/Wgted Val:  0.7/  1.1
 Heat content (KJ/cm2) :  47.6 Range:  0.0 to 130.0 Scaled/Wgted Val:  0.4/  0.0

 Prob of RI for 25 kt RI threshold=    31% is   2.5 times the sample mean(12.3%)
 Prob of RI for 30 kt RI threshold=     3% is   0.3 times the sample mean( 8.0%)
 Prob of RI for 35 kt RI threshold=     1% is   0.3 times the sample mean( 4.8%)

   ##          ANNULAR HURRICANE INDEX (AHI) AL992009 AL03       08/20/09  00 UTC         ##
   ## STORM NOT ANNULAR, SCREENING STEP FAILED, NPASS=6 NFAIL=1                           ##
   ## AHI=  0   (AHI OF 100 IS BEST FIT TO ANN. STRUC., 1 IS MARGINAL, 0 IS NOT ANNULAR) ##
   ##      ANNULAR INDEX RAN NORMALLY

** PROBABILITY OF SECONDARY EYEWALL FORMATION (p-SEF) AL992009 AL03       08/20/2009  00 UTC **
TIME (HR)          0     6    12    18    24         EXPERIMENTAL PRODUCT (p-SEF model)
p-SEF (%)         42    49    47    39    33
```

proposed new output lines

Proposed p-SEF model output examples

```
** PROBABILITY OF SECONDARY EYEWALL FORMATION (p-SEF) AL992009 AL03       08/20/2009   00 UTC **
TIME (HR)              0     6     12    18    24        EXPERIMENTAL PRODUCT (p-SEF model)
p-SEF (%)             42    49     47    39    33
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** PROBABILITY OF SECONDARY EYEWALL FORMATION (p-SEF) AL992009 AL03       08/20/2009   00 UTC **
TIME (HR)              0     6     12    18    24        EXPERIMENTAL PRODUCT (p-SEF model)
p-SEF (%)             42  NOSH   LAND  <HUR    33
```

```
** PROBABILITY OF SECONDARY EYEWALL FORMATION (p-SEF) AL992009 AL03       08/20/2009   00 UTC **
TIME (HR)              0     6     12    18    24        EXPERIMENTAL PRODUCT (p-SEF model)
p-SEF (%)             59    65     64    55    49        CAUTION...NO IR...MODEL SKILL DEGRADED
```

Goal 2: Toward a climatology of intensity and structure changes associated with SEF

There are case studies and informal paradigms exist.

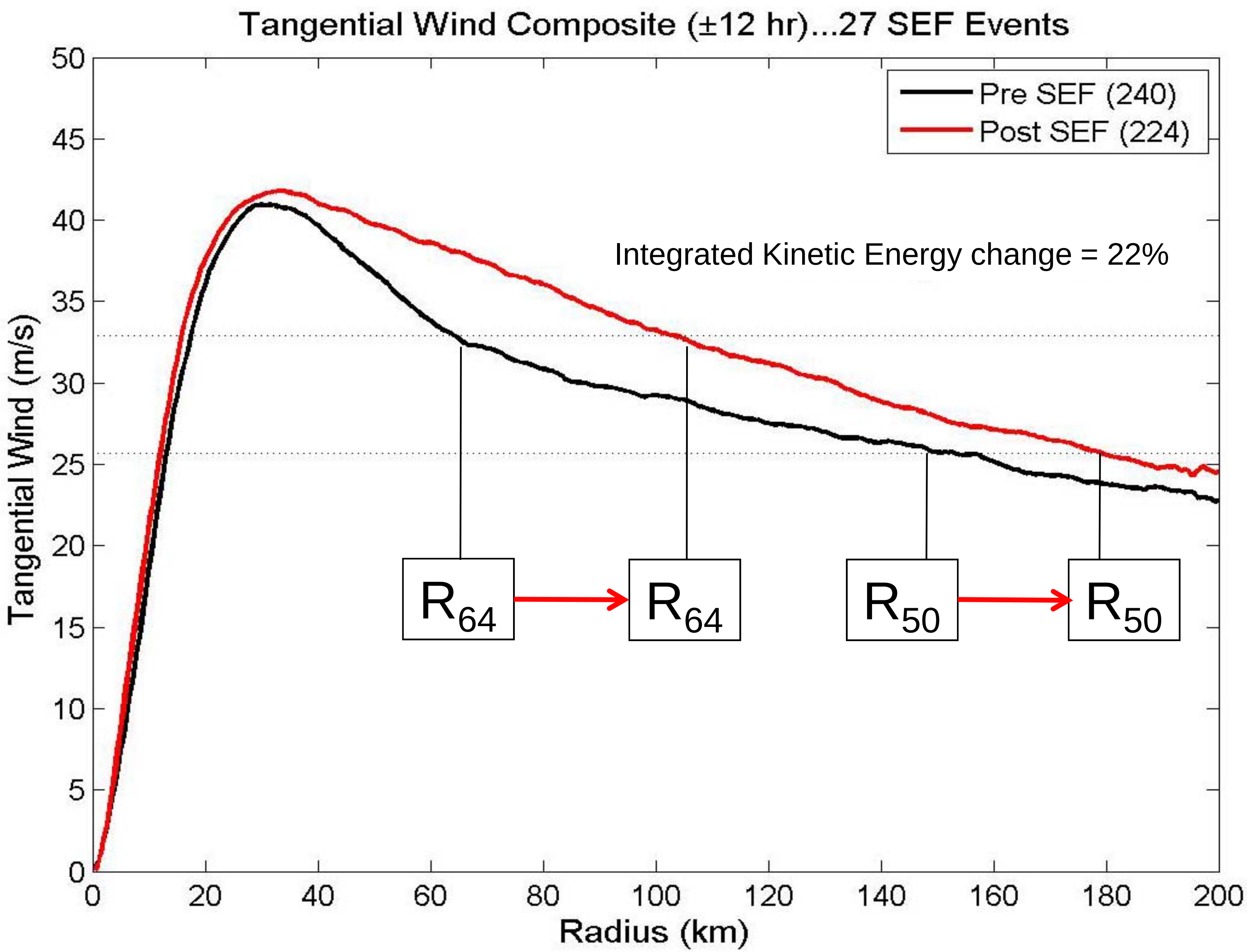
There is a subjective expectation that intensification rate will decrease or weakening will occur, then intensification will begin again (transient effect). Concurrently, the wind field will broaden and the storm will grow outward in scale (permanent effect).

We want to better quantify these effects. Best track intensity data are too smoothed to capture the transient effects, so flight-level data are used.

Reconnaissance data

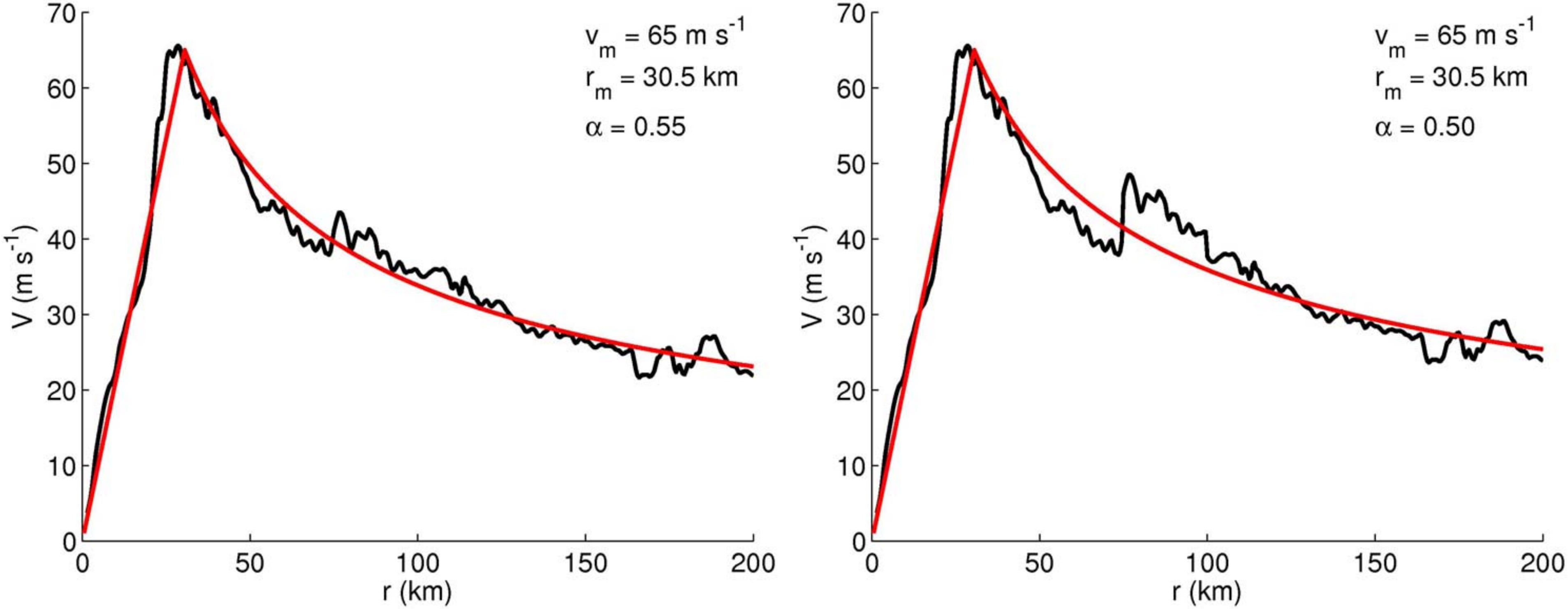
- 14 storms (2002-2006), 27 SEF events
- Over 2000 radial legs produced, ~500 used in composite analysis
- USAF (~80%) all 10s data
- NOAA data (~20%) both 10s and 1Hz data
- 10s data interpolated to 1 Hz
- Radial Legs out to 200 km from storm center
- HRD track files used for storm centering
  - Fixes every 2 minutes

24-hour structure change centered on SEF

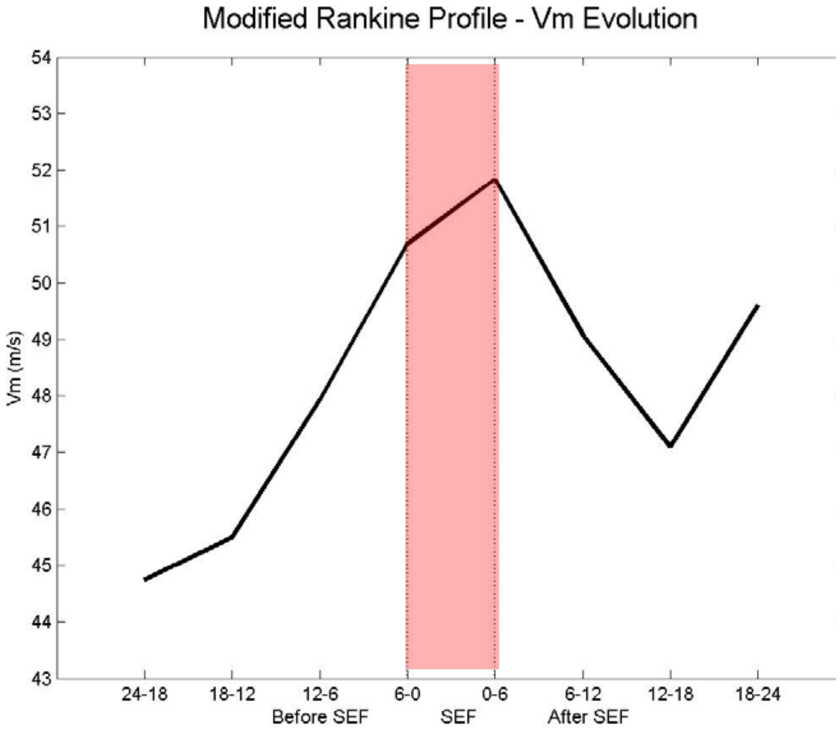


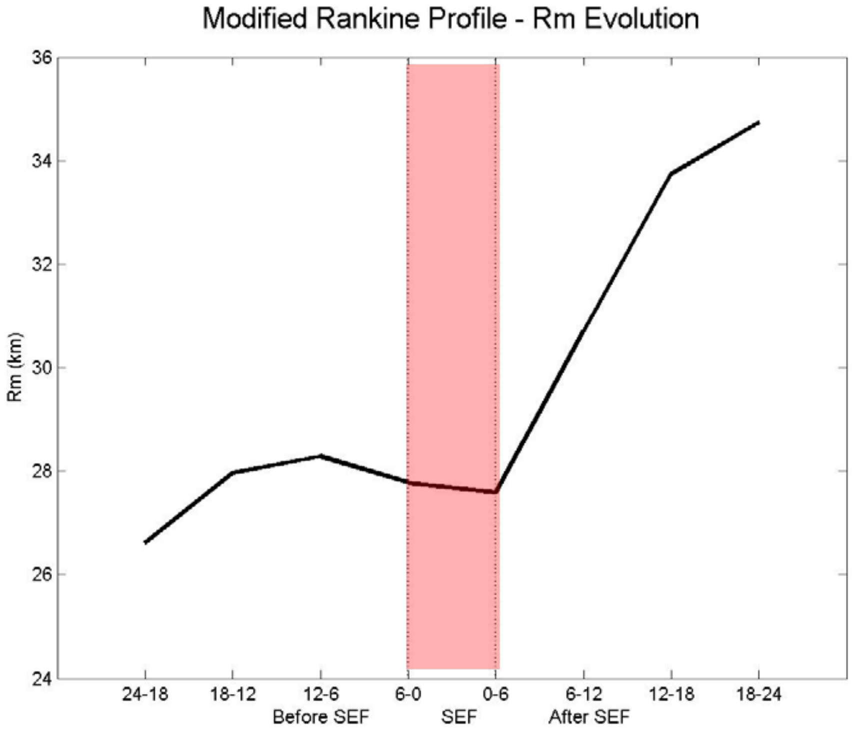
Parametric profile fits

modified Rankine vortex: $$v(r) = v_m \left(\frac{r_m}{r} \right)^{\alpha}$$



Intensity and RMW evolution during SEF





Summary

The p-SEF model has been installed in the latest version of SHIPS, and the output will be available as an experimental product during the 2010 NATL hurricane season.

During the second year of this project, we'll continue analyzing the recon data with the goal of establishing a climatology of intensity and structure changes related to SEF.

Ideally, this information will be useful for forecasting by offering some objective guidance about when SEF will occur and what it actually means for the forecast.