Extending the SHIPS Hurricane Intensity Forecasts with some Dynamical Variables.

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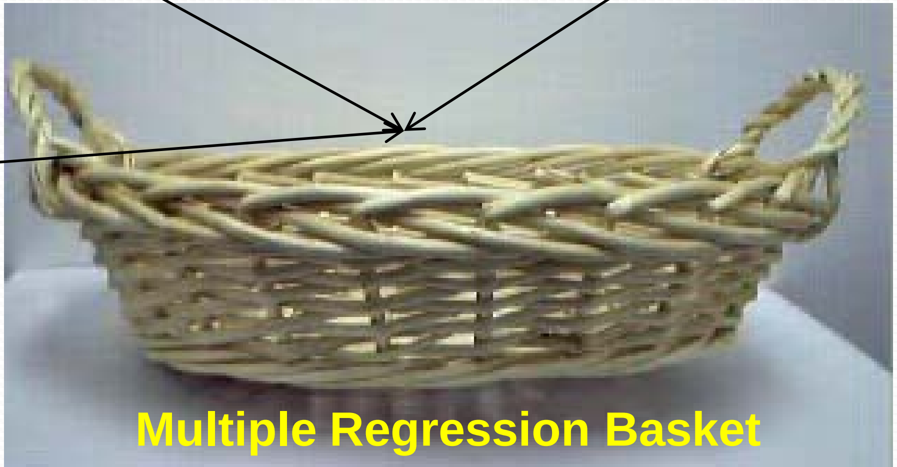
Talk Outline

- EXTENDING THE SHIPS + SPICE ALGORITHM
- SKILLS USING FSU DIAGNOSTIC PARAMETERS
- RESULTS
- CONCLUSIONS
- FUTURE WORK

FSU DIAGNOSTICS PARAMETERS

SHIPS FORECASTS

SPICE FORECASTS



SHIPS

- 21 total predictors used
- Atmospheric Predictors from GFS
- SST from Reynolds weekly fields
- Predictors from satellite data
  - Ocean Heat content from altimetry
  - GOES IR window channel brightness temperature

SHIPS Predictors

- Persistence
  - 12hr intensity change
  - Max winds at t = 0 (Vmax)
  - Vmax * 12 hr intensity change
- Upper Level Temperature
  - 200mb Temperature
  - 250mb Temperature (relative to threshold temperature of -44 C)
- Sea Surface Potential
  - Difference between forecasted Max Potential Intensity and t = 0 intensity
  - Sea Surface Potential squared
- GFS Vortex Tendency
  - Change in GFS 0-600km average symmetric tangential wind at 850mb

SHIPS Predictors cont…

- Zonal Storm motion(SPDX)
  - X component of motion from lat-lon position (finite differencing of forecast position from NHC)
- Steering Layer Pressure
  - Layer where wind best resembles storm motion
- Satellite Predictors
  - Standard Deviation of GOES Brightness Temperature (0-200km) * Vmax
  - Percent area where GOES $T_b < -20$ C (50-200km)
  - Ocean Heat Content
- Theta-E Excess
  - Theta-E difference (postive only) between a parcel lifted form the surface and its environment (200-800km average)

SHIPS Predictors cont…

- 850-200mb Shear
  - Magnitude of shear with vortex removed averaged from 0-500km (SHR)
  - Heading of above predictor
  - SHR * Latitude
  - SHR * Vmax
- 200mb Divergence
  - Averaged from 0-1000km
- 850mb Vorticity
  - Averaged from 0-1000km
- Mid Level Relative Humidity
  - Averaged from 700-500mb

SHIPS Forecast Methodology

- Multiple linear regression applied to normalized independent and dependant variables

$$\frac{(value - mean)}{stddev}$$

- Final forecast takes form of:

$$\left(A * \sum \frac{value(p) - mean(p)}{stdev(p)} \right) + B$$

where A is the standard deviation of the change in intensity, B is the mean change in intensity of all cases, and p represents the predictors.

THIS ENTIRE STUDY UTILIZES REGRESSIONS FOR INTENSITY TENDENCIES.

SPICE

SPICE (Statistical Prediction of Intensity from a Consensus Ensemble) has been developed as a combination of the official SHIPS and LGEM (logistic growth equation model) intensity guidance, as well as SHIPS and LGEM runs based of the large-scale environments in the GFDL and HWRF regional models. The six total forecasts are combined into two unweighted consensuses: one from the three SHIPS forecasts and one from the three LGEM forecasts. The two unweighted consensuses are then combined into one weighted consensus, with the weights determined empirically from the 2008-2010 official SHIPS and LGEM sample. These weights favored the SHIPS consensus in the early time periods, shifting to the LGEM consensus being weighted more heavily after about 36 hours. Retrospective tests of SPICE over the 2008-2010 Atlantic hurricane seasons indicated that SPICE outperformed both SHIPS and LGEM at all lead times, and the improvements were statistically significant at almost all times. SPICE was run real-time during the 2011 season as part of the Hurricane Forecast Improvement Project (HFIP), and results from the season will be presented here. Experiments with using COAMPS-TC, additional regional and global models, and a variable consensus will also be considered.

List of FSU Diagnostic Parameters

1. **Vertical Differential of Heating**

2. **Transformation of Shear to Curvature Vorticity**

3. **Energy Exchange from the Divergent to the Rotational Kinetic Energy in the Inner Core**

4. **Angular Momentum**

DATA SETS USED FOR FSU DIAGNOSTICS:

The data sets we used for the extended SHIPS were based on a reanalysis that was provided to us by the HWRF group. It carried the following steps:

1. Start with GFS analysis at T 382L64 , transform grid separation roughly 35 km

2. Remove vortex from GFS using GFDL method , Kurihara et al

3. Use HWRF's 12 hour forecast as a first guess to redefine a new initial vortex

4. Use above within GFS to re-assimilate that vortex along with the dropwindsonde data sets.

For this study we includes 154 forecast segments for every forecast at 12 hour interval between hours 12 to 108 hours.

The diagnostic variables: vertical differential of heating (for the complete PV equation), shear to curvature kinematics and the transformation of divergent kinetic energy into rotational kinetic energy are all evaluated from the final HWRF analysis at the 850hPa level. The advection of earths and relative angular momentum are averaged over a three dimensional box that covers the same horizontal area as above, in the vertical the box average extends from the surface to 100 hPa.

The domain of these computations is a 10 degree latitude by 10 degree longitude box, with the hurricane located close to the center of the box.

These computations are carried out every 12 hours and are designed to provide guidance for 12 hourly intensity forecasts.

Diabatic Potential Vorticity

Complete PV equation:

The natural framework for the diabatic potential vorticity uses the potential temperature as a vertical co-ordinate. The complete Ertel PV equation in isentropic co-ordinates (Bluestein, 1993) is expressed as:

$$\frac{d}{dt}\left(-\varsigma_{a\theta} g \frac{\partial\theta}{\partial p}\right) = \left(-\varsigma_{a\theta}\right)\frac{\partial}{\partial\theta}\frac{d\theta}{dt} + g\frac{\partial\theta}{\partial p}\left\{\nabla\frac{d\theta}{dt}\frac{\partial(V\ x\ k)}{\partial\theta}\right\} - \left\{\nabla.(F\ xk)\right\} g\frac{\partial\theta}{\partial p} \quad (1) \qquad (1)$$

where the isentropic absolute vorticity is given by :

$$\varsigma_{a\theta} = \left.\frac{\partial v}{\partial x}\right)_{\theta} - \left.\frac{\partial u}{\partial y}\right)_{\theta} + \frac{u}{a}\tan\phi \quad f$$

(2)

On an isentropic surface, the local rate of change of PV is the sum of (1) horizontal advection of PV; (2) vertical advection of PV; (3) vertical differential of heating; (4) horizontal differential of heating; (5) the friction term. If the last four terms are neglected, equation 4 reduces to the adiabatic equation for the conservation of potential vorticity. Retaining these terms allows us to account for the generation or destruction of potential vorticity arising from the horizontal or vertical heating differentials and friction.

Interpretation of diabatic PV contributions:

a. Vertical Advection

The vertical advection term in the isentropic frame is given as:

$$-\frac{d\theta}{dt}\frac{\partial}{\partial\theta}(PV)$$

Thus the contribution of the vertical advection term depends on the vertical distribution of PV. Figure (1a,b) illustrates the vertical distribution of and PV for Hurricane Ivan (at 12Z on 11 September 2004).

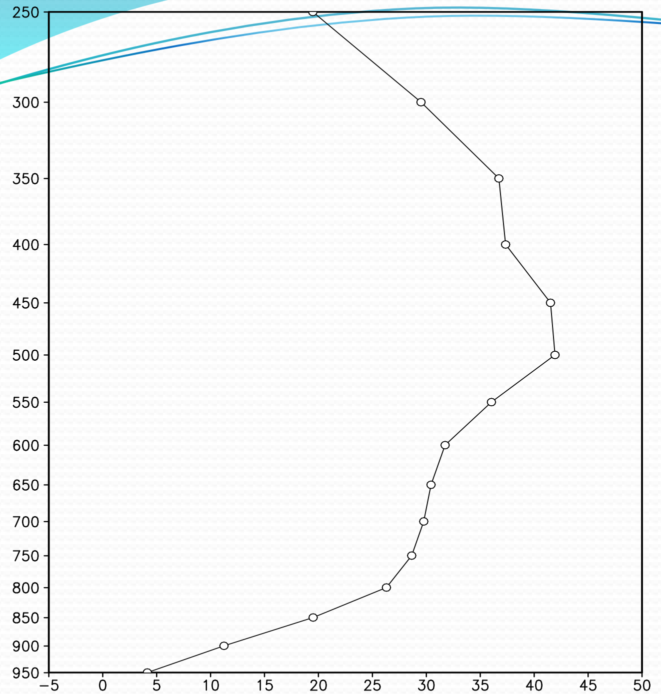


Figure 1a: Vertical distribution of $\frac{d\theta}{dt}$ (x 10^4) for hurricane IVAN, 11 September 2004, 12z. The unit is K/s.

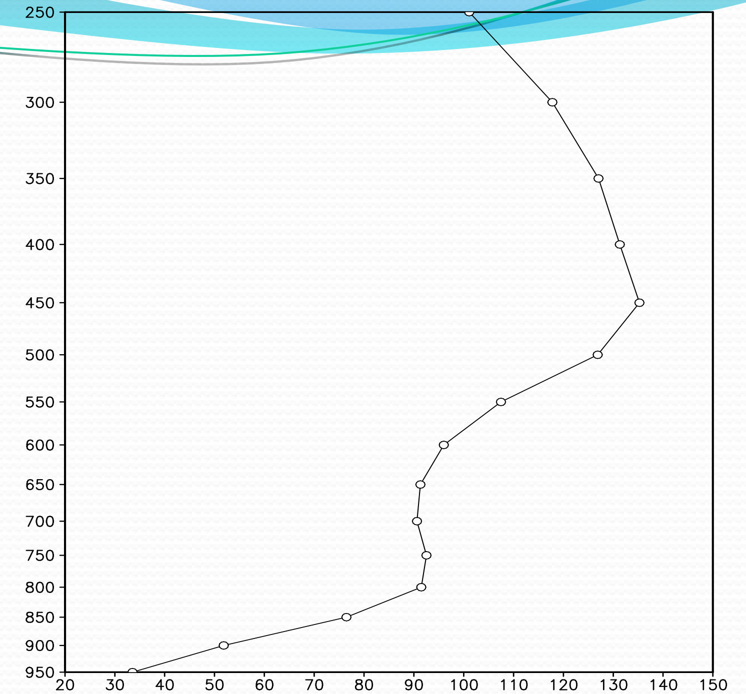
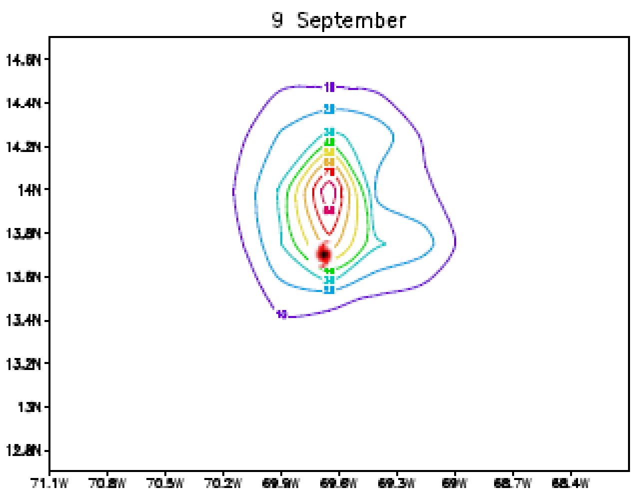


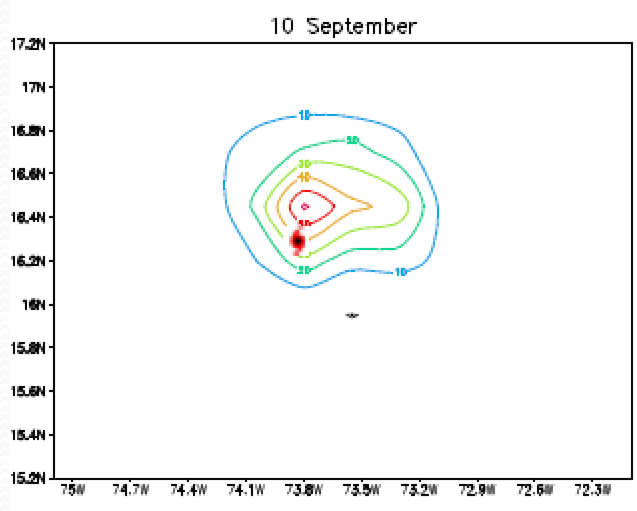
Figure 1b: Vertical distribution of PV (x 10^{-7}) for hurricane IVAN, 11 September 2004, 12z. The unit is $m^2s^{-1}kg^{-1}K$.

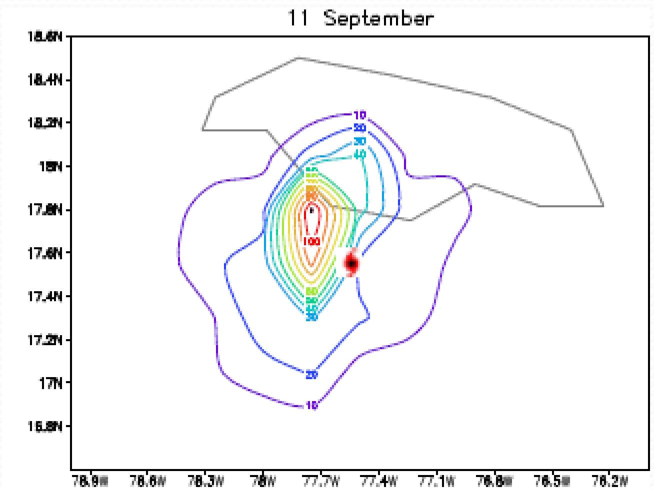
b. Vertical Differential of heating

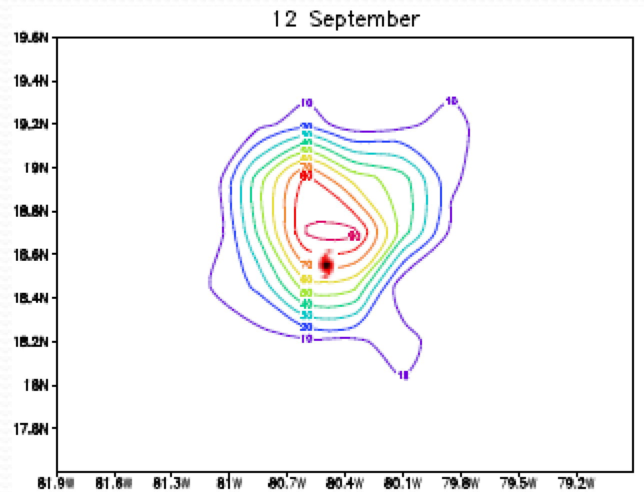
This is similar to the divergence term of the vorticity equation and is written as $+PV\frac{\partial}{\partial\theta}\frac{d\theta}{dt}$ (the isobaric component is $\varsigma_a\frac{\partial}{\partial p}\frac{dp}{dt}$ *i.e.* $\varsigma_a\frac{\partial\omega}{\partial p}$ *or* $-\xi_a\nabla..V$). Below the level of maximum heating $\frac{d\theta}{dt}$, the value of $\frac{\partial}{\partial\theta}\frac{d\theta}{dt}>0$ and the PV is positive. Thus a net generation of PV, (i.e., $PV\frac{\partial}{\partial\theta}\frac{d\theta}{dt}>0$) occurs. Large values of PV and $\frac{\partial}{\partial\theta}\frac{d\theta}{dt}$ were generally found in the lower troposphere below the 600 hPa level. Such an increase of PV in the inner core of the hurricane where the static stability is generally decreasing (and not increasing) leads to an increase of absolute vorticity (since PV is a product of absolute vorticity and stability). The increase of absolute vorticity contributes to an increase of curvature and the shear vorticity of the parcels, which in turn contributes to an increase of the storms intensity.

Vertical Differential of Heating

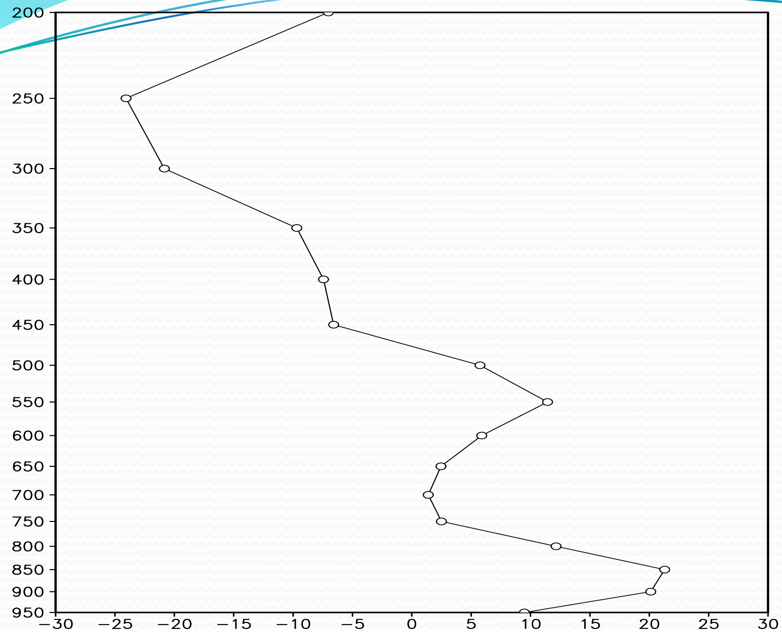








Contour plots of vertical differential of heating at 850 hPa (x 10^{-10} $Kg^{-1}m^{2}s^{-2}K$) for hurricane IVAN 9 September through 12 September 2004 at 00z. The storm center is also marked.



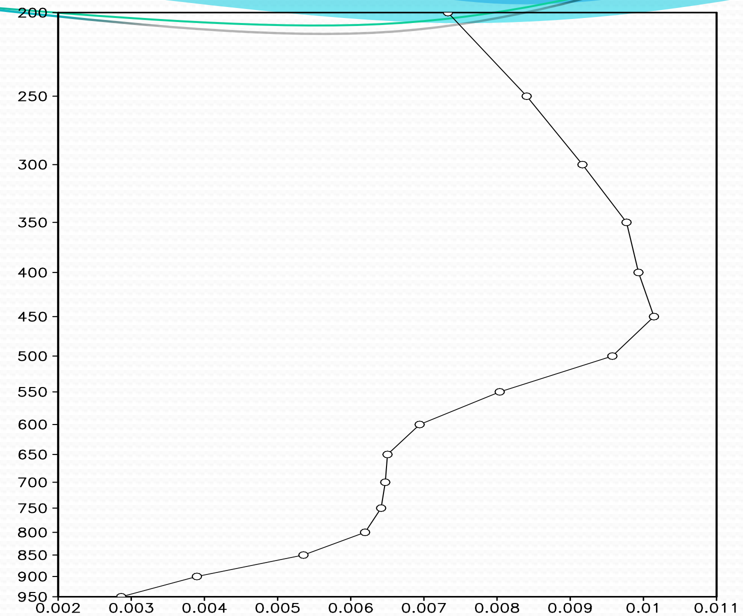


Figure 1c: Vertical distribution of $+PV \frac{\partial}{\partial\theta}\frac{d\theta}{dt}$ (x 10^{-7}) for hurricane IVAN, 11 September 2004, 12z. The unit is $m^2s^{-1}kg^{-1}K$

Figure 1d: Vertical distribution of $-g\frac{\partial\theta}{\partial p}$ for hurricane IVAN, 11 September 2004, 12z. The unit is $m^2kg^{-1}K$

c. Horizontal Differential of heating

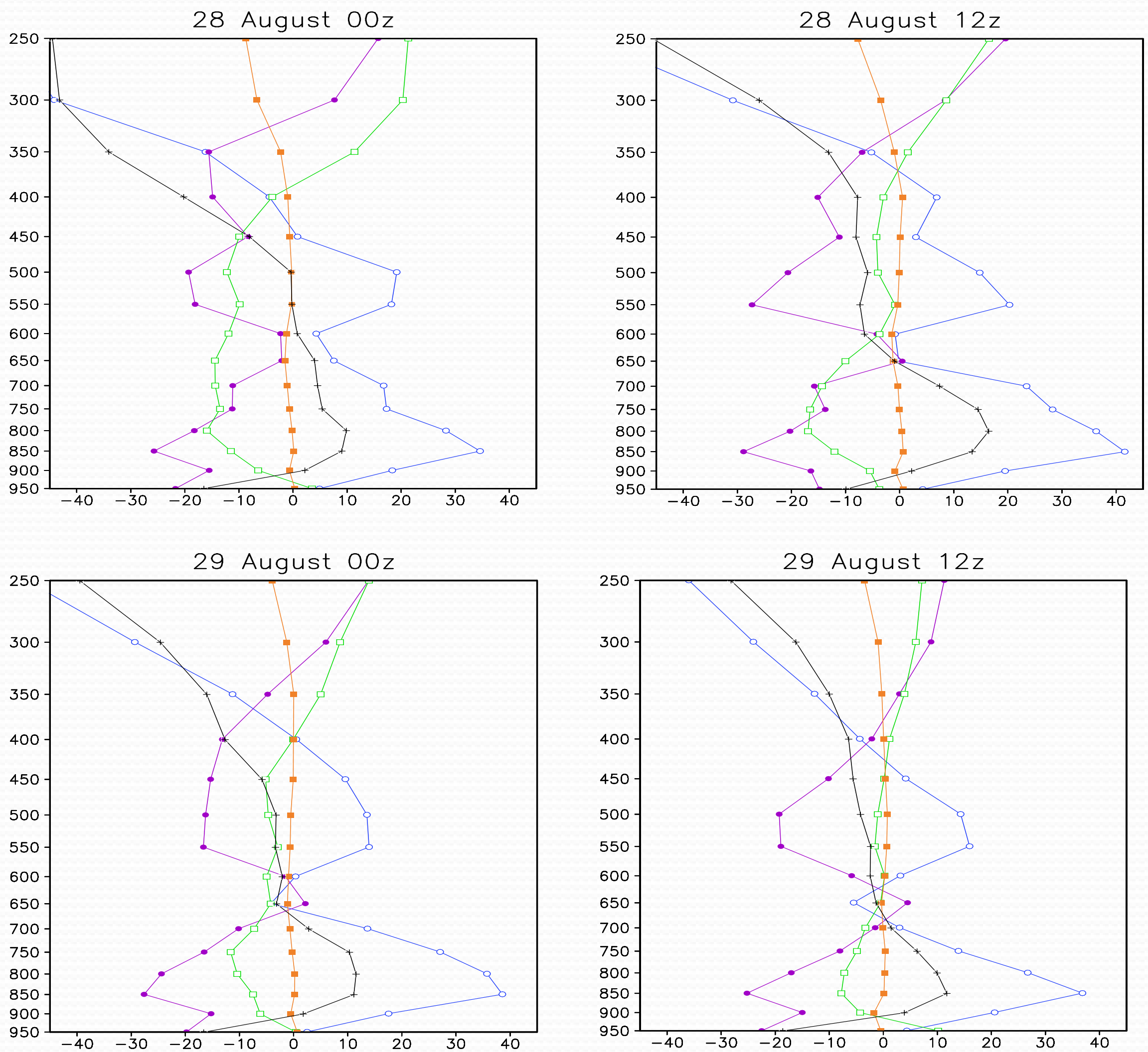
In the complete PV equation this diabatic term has the form $\left\{ \nabla \frac{d\theta}{dt} \cdot \frac{\partial (V \ x \ \hat{k})\theta}{} \right\} g \frac{d\theta}{dp}$.

This can be expressed in the scalar form $-g\frac{\partial\theta}{\partial p}\left(\frac{\partial u}{\partial\theta}\frac{\partial}{\partial y}\frac{d\theta}{dt}-\frac{\partial v}{\partial\theta}\frac{\partial}{\partial x}\frac{d\theta}{dt}\right)$. When we look at this, we note that this term is quite similar to the familiar twisting term of the vorticity equation in isobaric coordinates.

From the nature of it, we can expect some large values of this term across the eyewall and rainbands of a hurricane. The radial gradient of heating (especially convective heating) is large and changes sign across the eye wall. This term is expected to have opposite signs on the two sides of the eye wall. We can obtain an approximate order of magnitude of this term by examining it along the radial direction.

Along a radial line extending from the storm center outwards, we can approximate this term by the expression $-g\frac{\partial\theta}{\partial p}\left(\frac{\partial V_\theta}{\partial\theta}\frac{\partial}{\partial r}\frac{d\theta}{dt}\right)$, where V_θ is the tangential component of the wind. The change of $\frac{d\theta}{dt}$ along the radial direction over the approximately 10 km thickness of a typical eye wall can be substantial. As a result, the lateral heating term can also acquire a value of close to $10^{-10}\,kg^{-1}m^2s^{-2}K$. Some caution should be exercised in accepting this as a typical order of magnitude for the horizontal differential of heating since convective heating (and vertical motions) can be resolution dependent.

Vertical profiles of diabatic heating terms



Vertical distribution of the horizontal advection (green), vertical advection (purple), vertical differential of heating (Blue), horizontal differential of heating (orange) for the potential vorticity during the intensifying stage of Hurricane KATRINA The total diabatic heating is shown in black. Units are x 10^{-10} $Kg^{-1}m^{2}s^{-2}K$.

Transformation of Shear to Curvature Vorticity

Shear- and curvature-vorticity equations

Bell, G.D., and D. Keyser. 1993. Shear and Curvature vorticity and Potential-Vorticity Interchanges: Interpretation and Application to a Cutoff Cyclone Event. Mon. Wea. Rev. 121(76–102).

Viúdez, A., and R.L. Haney. 1996. On the Shear and Curvature Vorticity Equations. J. Atmos. Sci., 53(3384–3394).

$$\frac{d}{dt}\left(f+V\frac{\partial\alpha}{\partial s}\right)=-\frac{\partial V}{\partial s}\frac{d\alpha}{dt}-\frac{\partial}{\partial n}\left(\frac{\partial\phi}{\partial s}\right)$$

$$-\left(f+V\frac{\partial\alpha}{\partial s}\right)\nabla_p\cdot\mathbf{V}-V\frac{\partial\omega}{\partial s}\frac{\partial\alpha}{\partial p}, \quad (2.7a)$$

$$\frac{d}{dt}\left(-\frac{\partial V}{\partial n}\right)=\frac{\partial V}{\partial s}\frac{d\alpha}{dt}+\frac{\partial}{\partial n}\left(\frac{\partial\phi}{\partial s}\right)$$

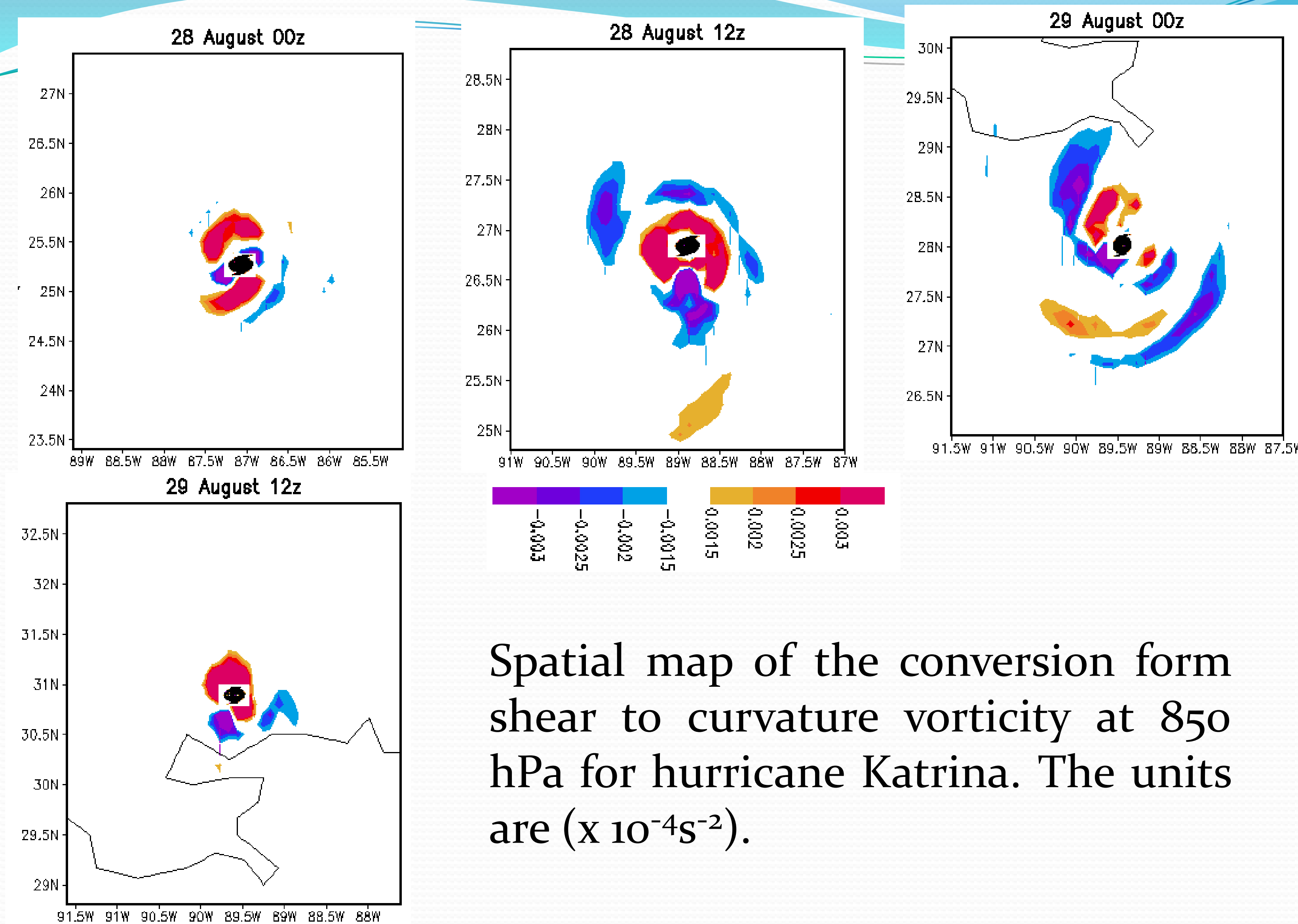
$$-\left(-\frac{\partial V}{\partial n}\right)\nabla_p\cdot\mathbf{V}+\frac{\partial\omega}{\partial n}\frac{\partial V}{\partial p}. \quad (2.7b)$$

The sum of (2.7a) and (2.7b) recovers the natural-coordinate form of the tendency equation for absolute vorticity:

$$\frac{d}{dt}\left(f + V\frac{\partial \alpha}{\partial s} - \frac{\partial V}{\partial n}\right) = -\left(f + V\frac{\partial \alpha}{\partial s} - \frac{\partial V}{\partial n}\right)\nabla_p \cdot \mathbf{V} - V\frac{\partial \omega}{\partial s}\frac{\partial \alpha}{\partial p} + \frac{\partial \omega}{\partial n}\frac{\partial V}{\partial p}. \quad (2.7c)$$

Cartesian Coordinate Expressions for the Terms in the Tendency Equations for Shear and Curvature Vorticity

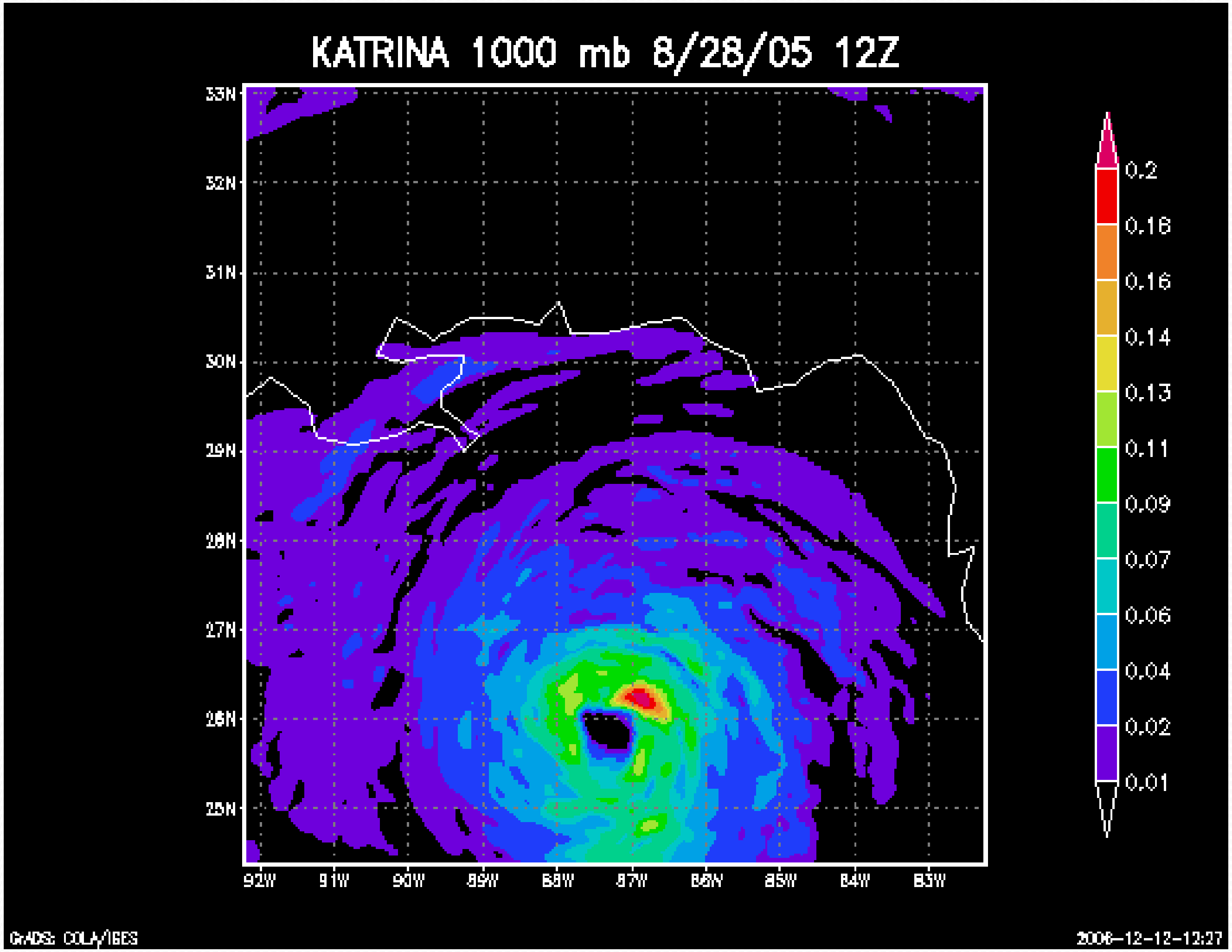
Although the natural-coordinate system (refer to Fig. 1) is well suited to isolating and interpreting the interchange process between shear and curvature vorticity, numerical evaluation of differential quantities in this coordinate system is a particularly cumbersome task. In order to avoid the need to calculate the various terms in the tendency equations for shear and curvature vorticity in natural coordinates, we transform these terms into Cartesian coordinates. The Cartesian coordinate counterparts of the terms in the tendency equations then may be discretized using standard centered finite differences.



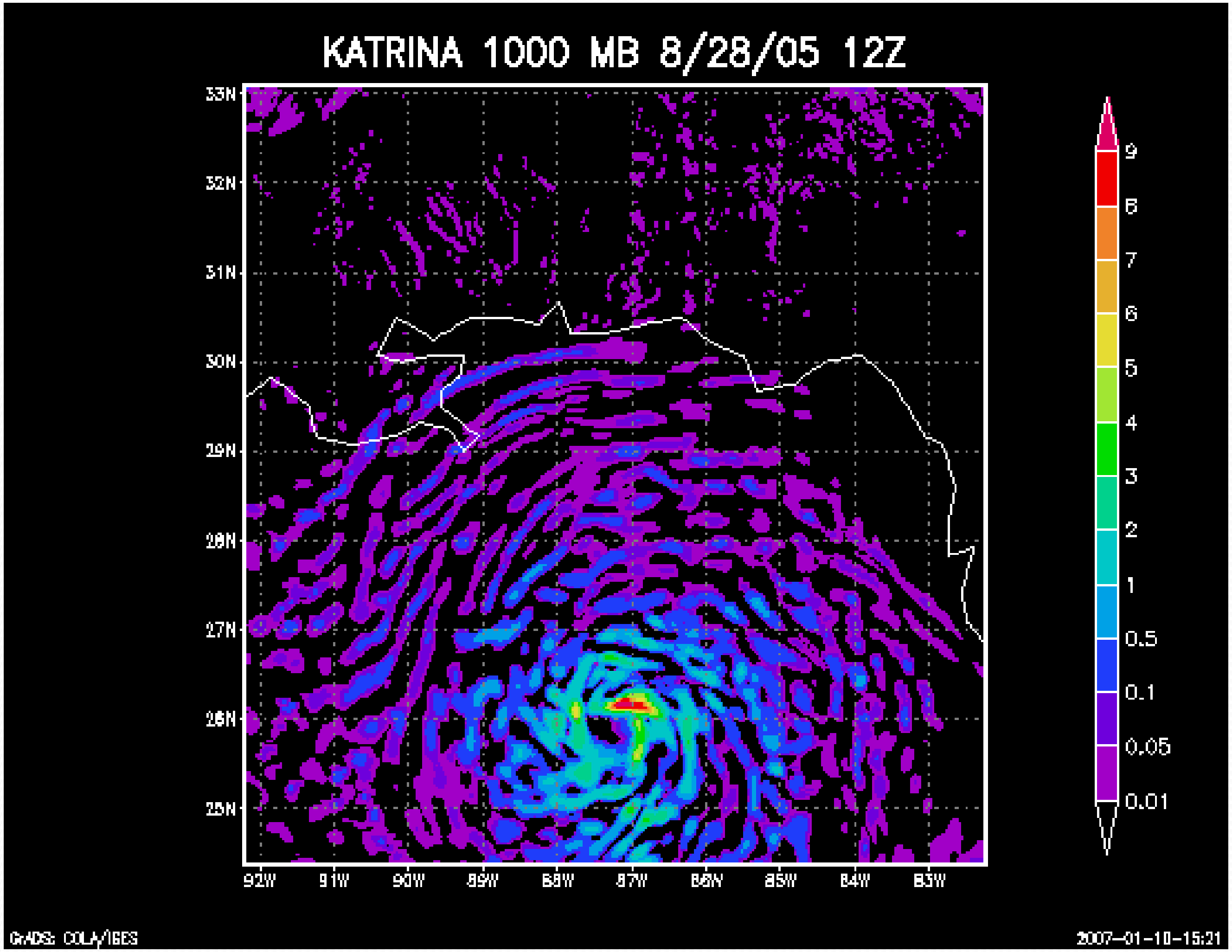
Spatial map of the conversion form shear to curvature vorticity at 850 hPa for hurricane Katrina. The units are ($x\ 10^{-4} s^{-2}$).

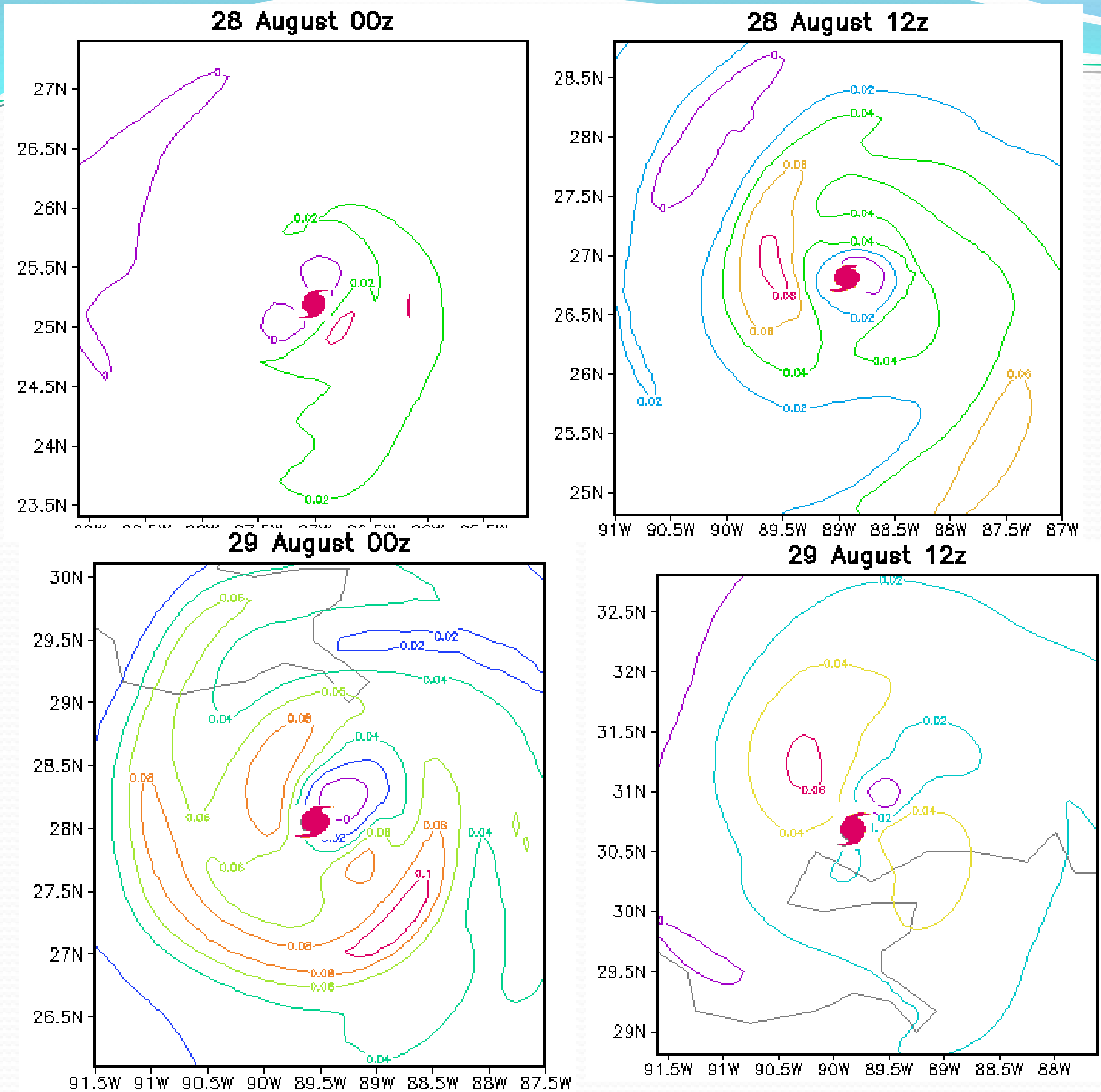
Energy Exchange from the Divergent to the Rotational Kinetic Energy in the Inner Core

$$f(\nabla\psi \bullet \nabla\chi)$$



$$\nabla^2\psi(\nabla\psi \bullet \nabla\chi)$$

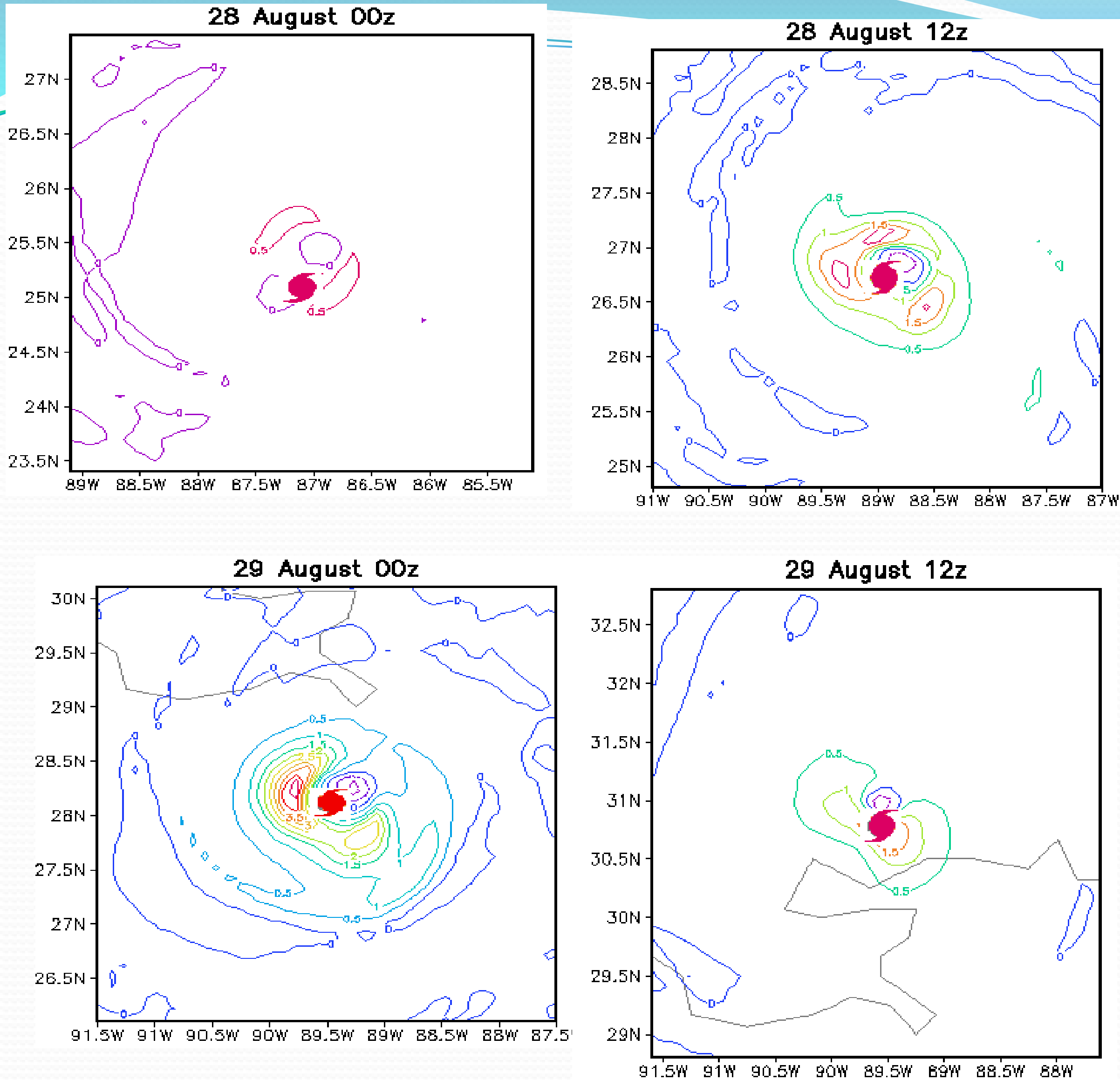




$$f\nabla\psi\nabla\chi$$

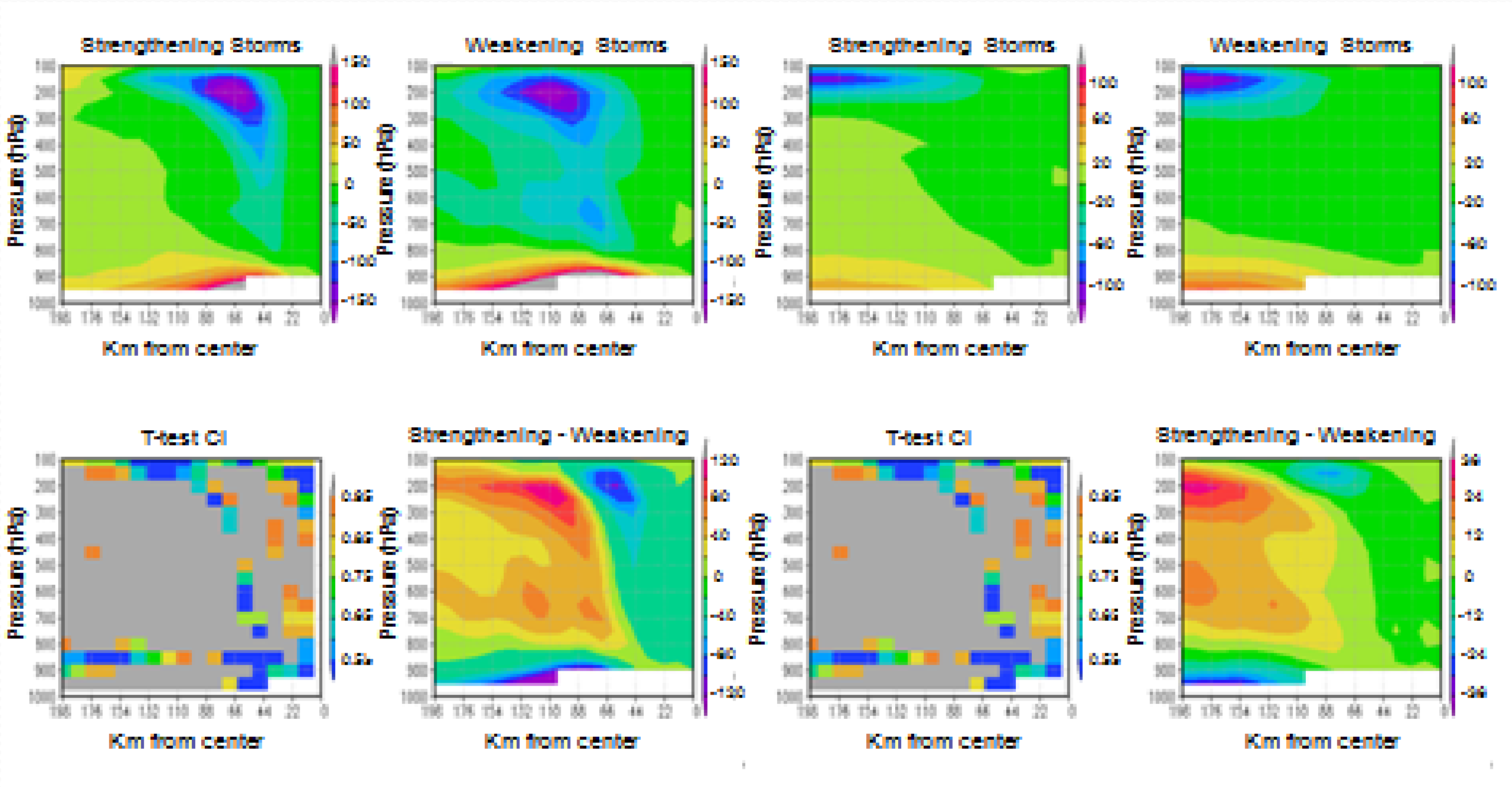
Spatial distribution of the term (at 850hPa) for hurricane Katrina. The position of the storm center is marked. The contours are drawn with an interval of 0.02. Units m^2s^{-3}.

$$\nabla^2\psi\nabla\psi.\nabla\chi$$



Spatial distribution of the term (at 850 hPa) for hurricane Katrina. The position of the storm center is marked. The contours are drawn with an interval of 0.5. Units m^2s^{-3}.

Angular Momentum



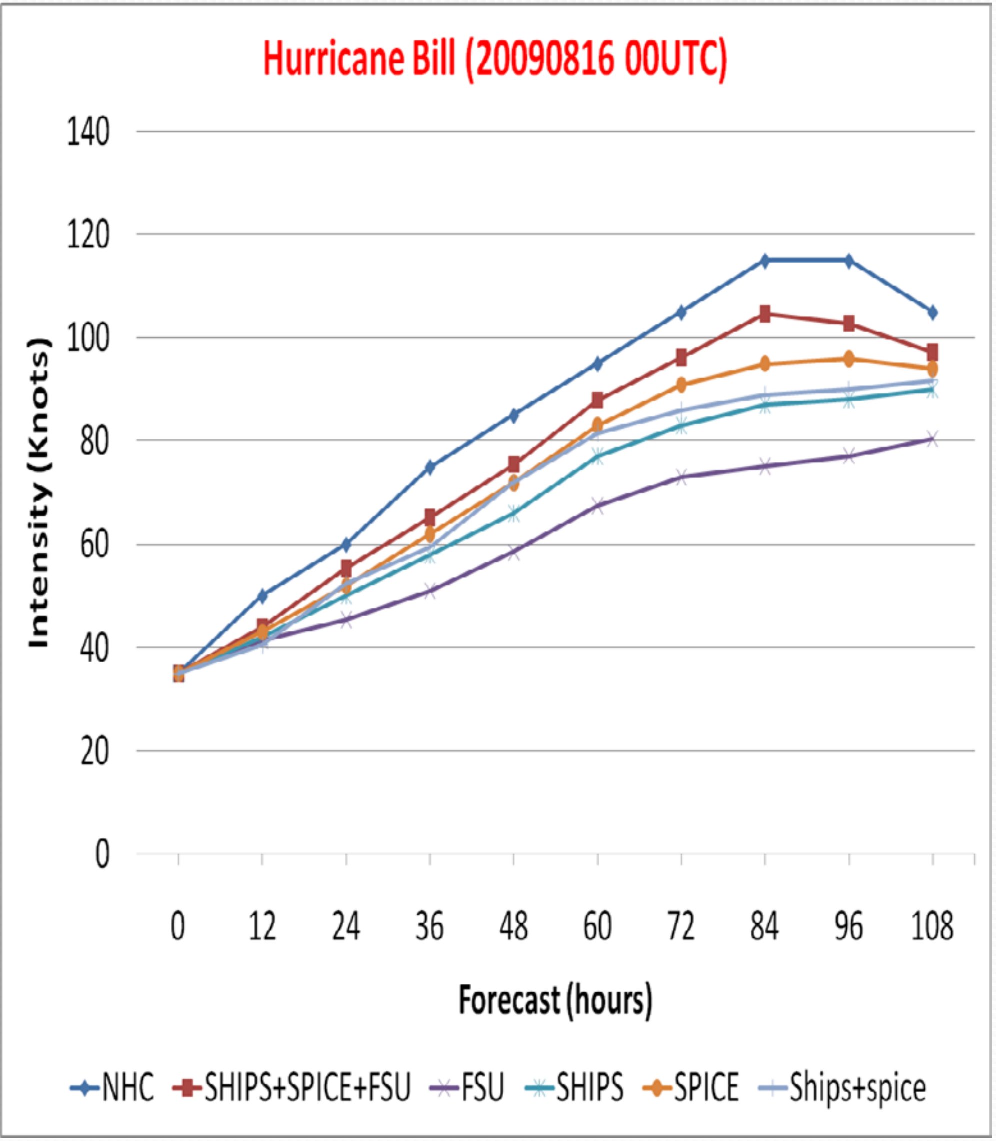
Cross-section composites of horizontal advection in storms category 2 and higher for (a) Earth's angular momentum and (b) Relative angular momentum

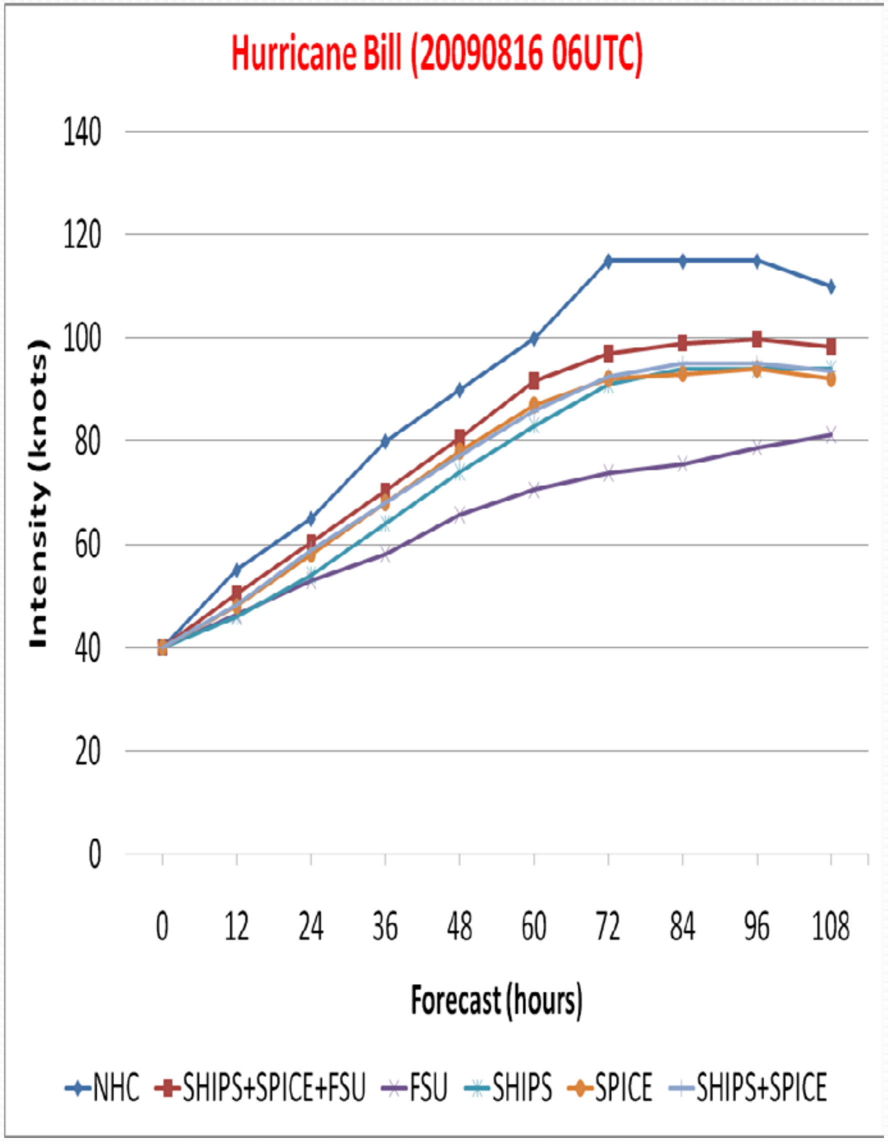
Data sets of the present study

1. FSU Diagnostic parameters are computed from HWRF Forecast for many hurricane cases during the 2008 and 2009 seasons.
2. HWRF model simulations carry two nested domains 27km and 9km. We have used Inner nest domain (9km resolution) data for computation of FSU Diagnostics parameters.

3. Data sets used for Regressions (154 hurricanes) include most of the **2008 and 2009 Hurricane cases, this does not include cases that were deliberately left out for forecast applications (15 hurricanes) presented here.**

RESULTS


Hurricane Bill (20090816 00UTC)
Intensity (Knots)
140
120
100
80
60
40
20
0
0
12
24
36
48
60
72
84
96
108
Forecast (hours)
NHC
SHIPS+SPICE+FSU
FSU
SHIPS
SPICE
Ships+spice


Hurricane Bill (20090816 06UTC)
Intensity (knots)
140
120
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80
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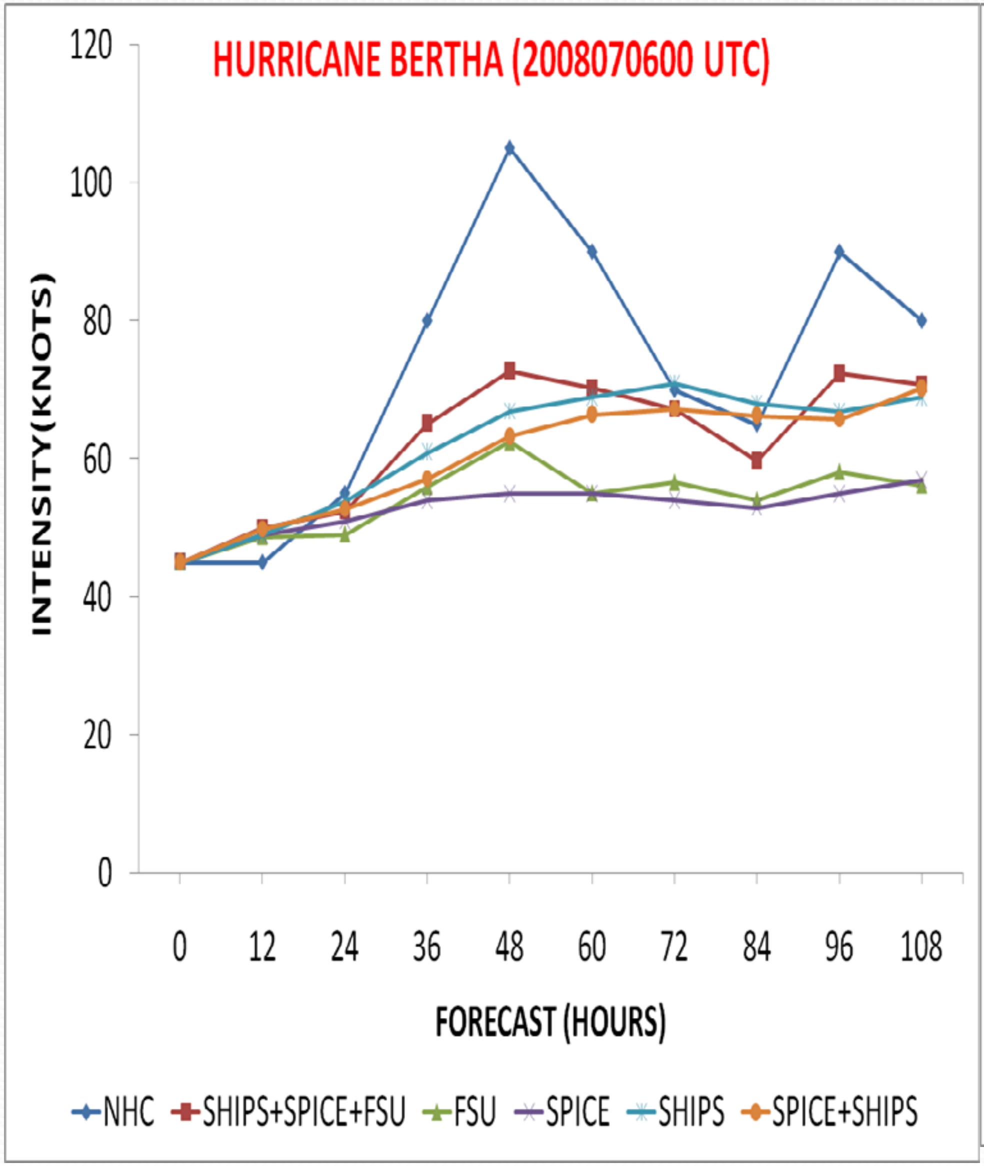
108
Forecast (hours)
NHC
SHIPS+SPICE+FSU
FSU
SHIPS
SPICE
SHIPS+SPICE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INTENSITY(KNOTS)
0
20
40
60
80
100
120
0
12
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36
48
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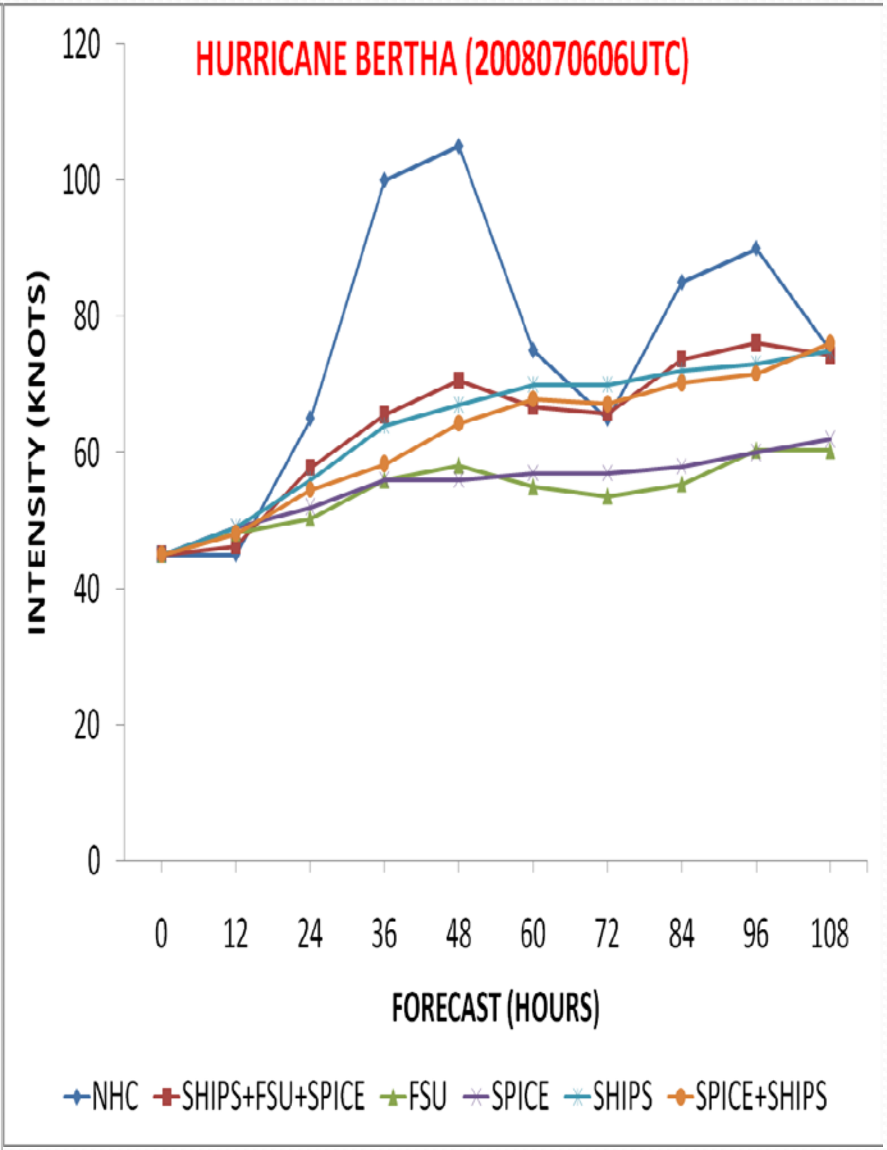
72
84
96
108
FORECAST (HOURS)
NHC
SHIPS+SPICE+FSU
FSU
SPICE
SHIPS
SPICE+SHIPS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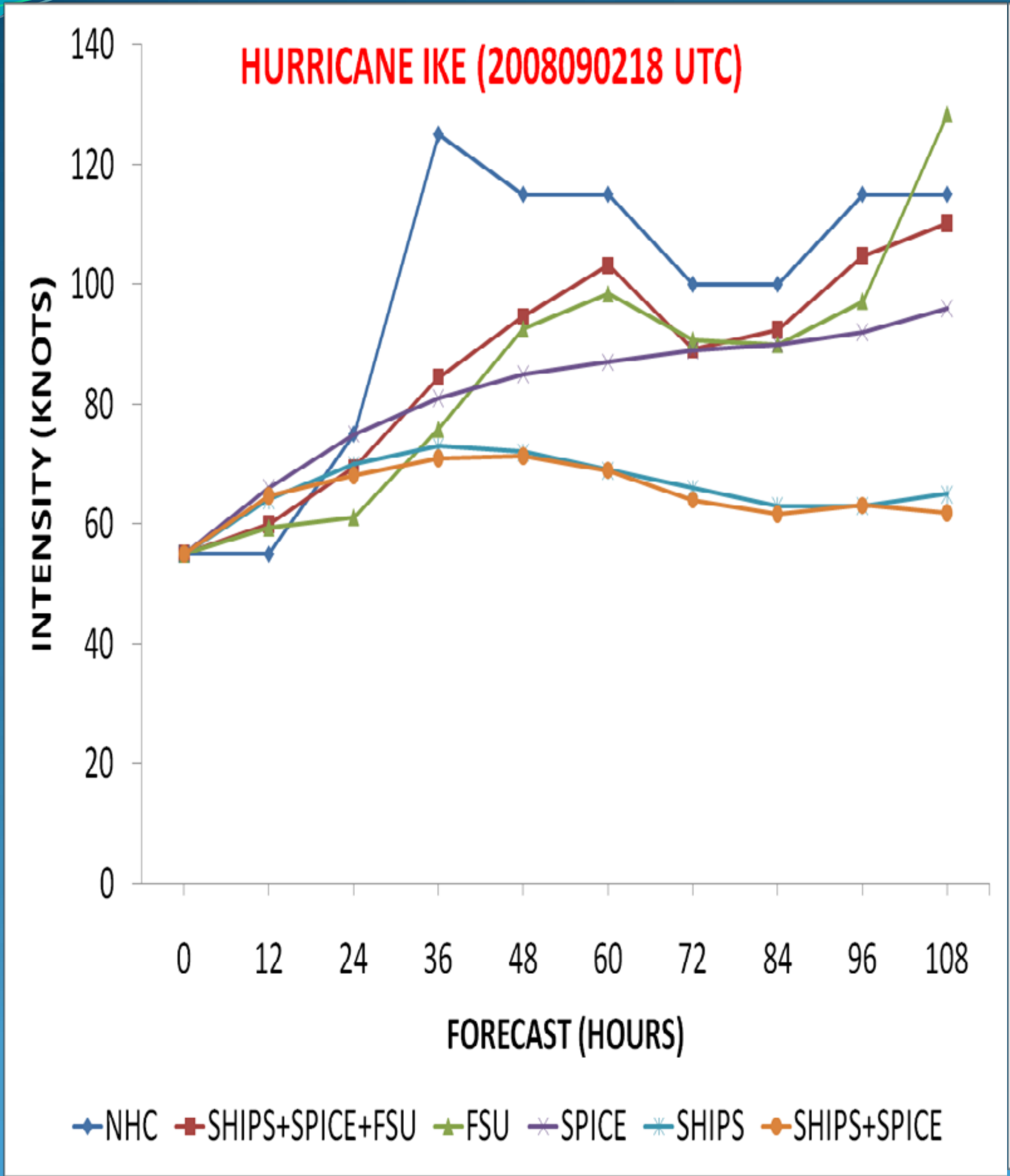
108
FORECAST (HOURS)
NHC
SHIPS+FSU+SPICE
FSU
SPICE
SHIPS
SPICE+SHIPS


HURRICANE IKE (2008090218 UTC)
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120
100
80
60
40
20
0
INTENSITY (KNOTS)
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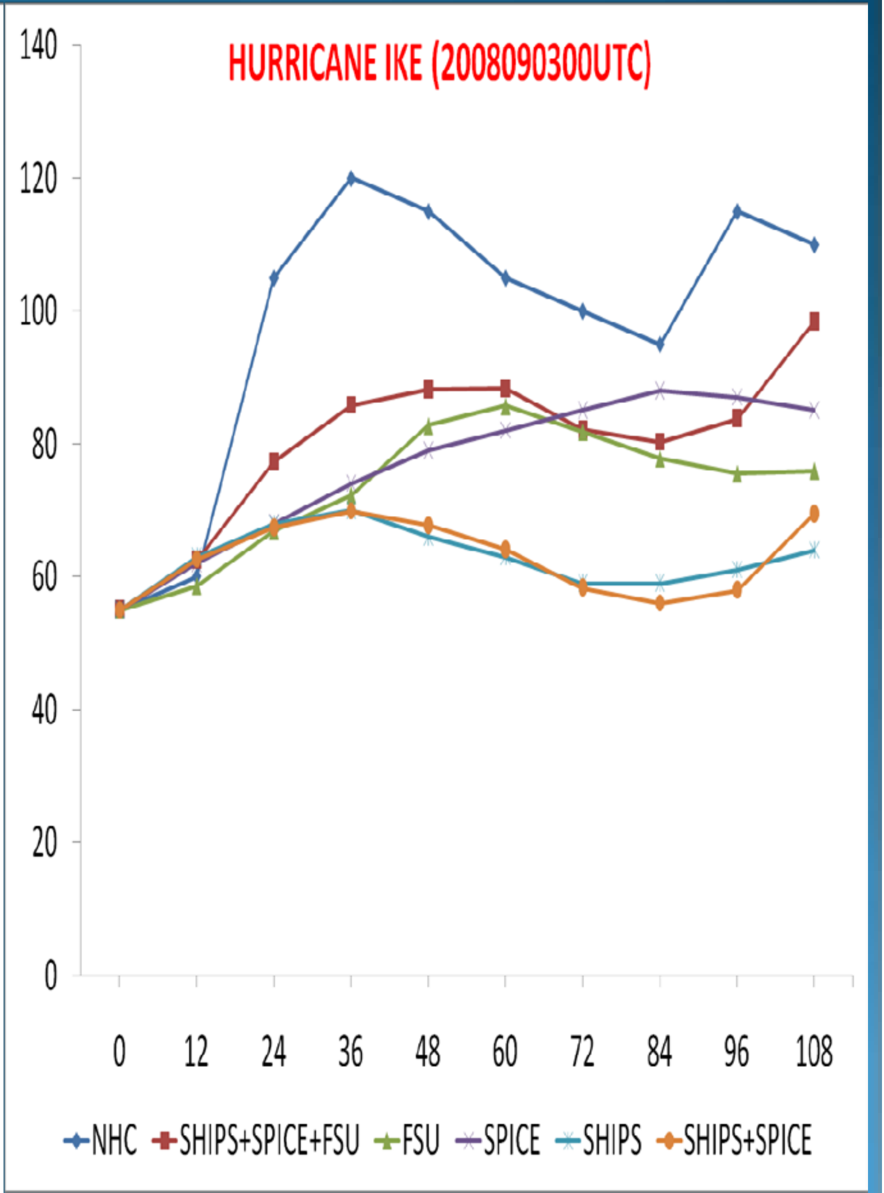
FORECAST (HOURS)
NHC
SHIPS+SPICE+FSU
FSU
SPICE
SHIPS
SHIPS+SPICE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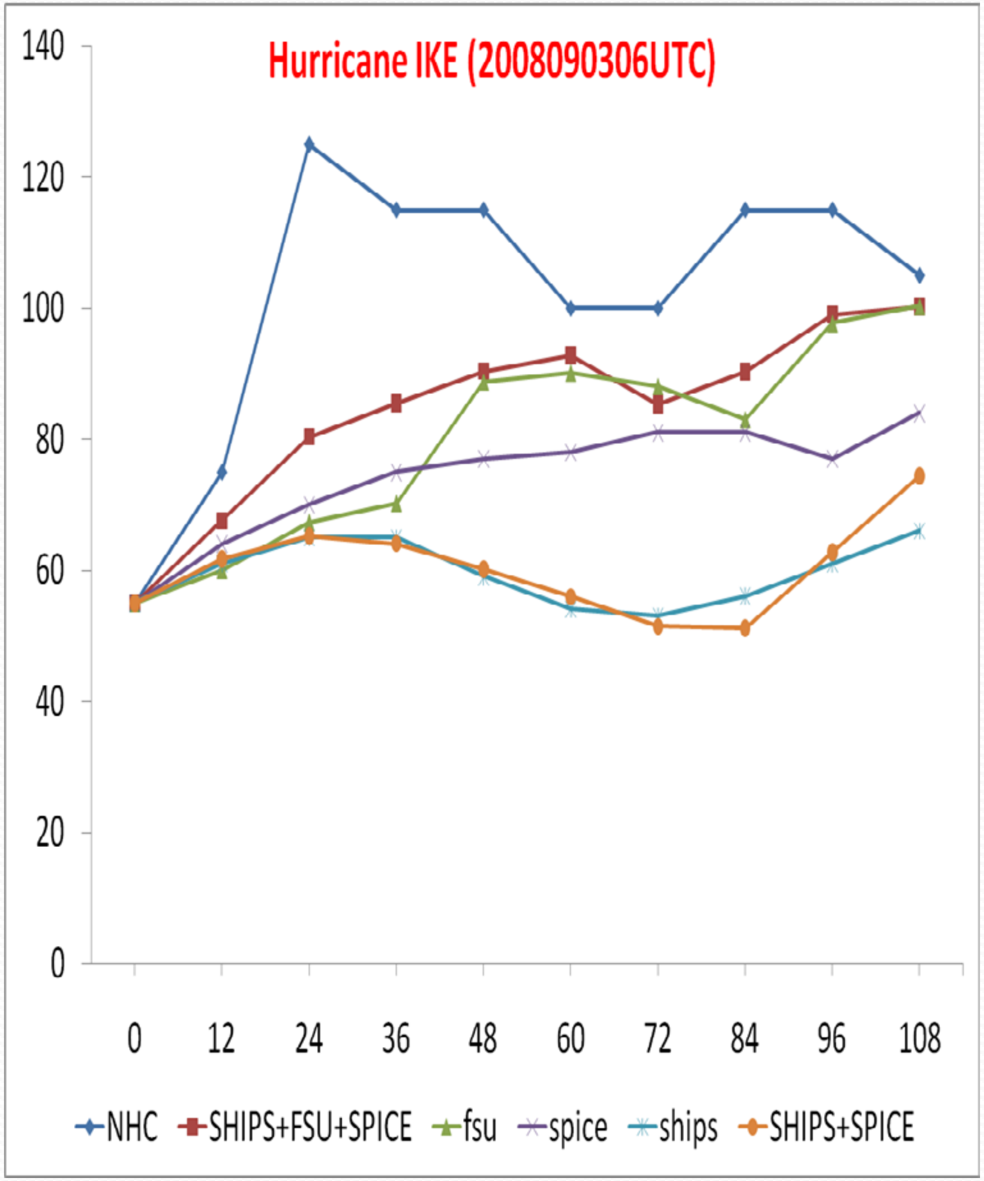
NHC
SHIPS+SPICE+FSU
FSU
SPICE
SHIPS
SHIPS+SPICE



Hurricane IKE (2008090306UTC)
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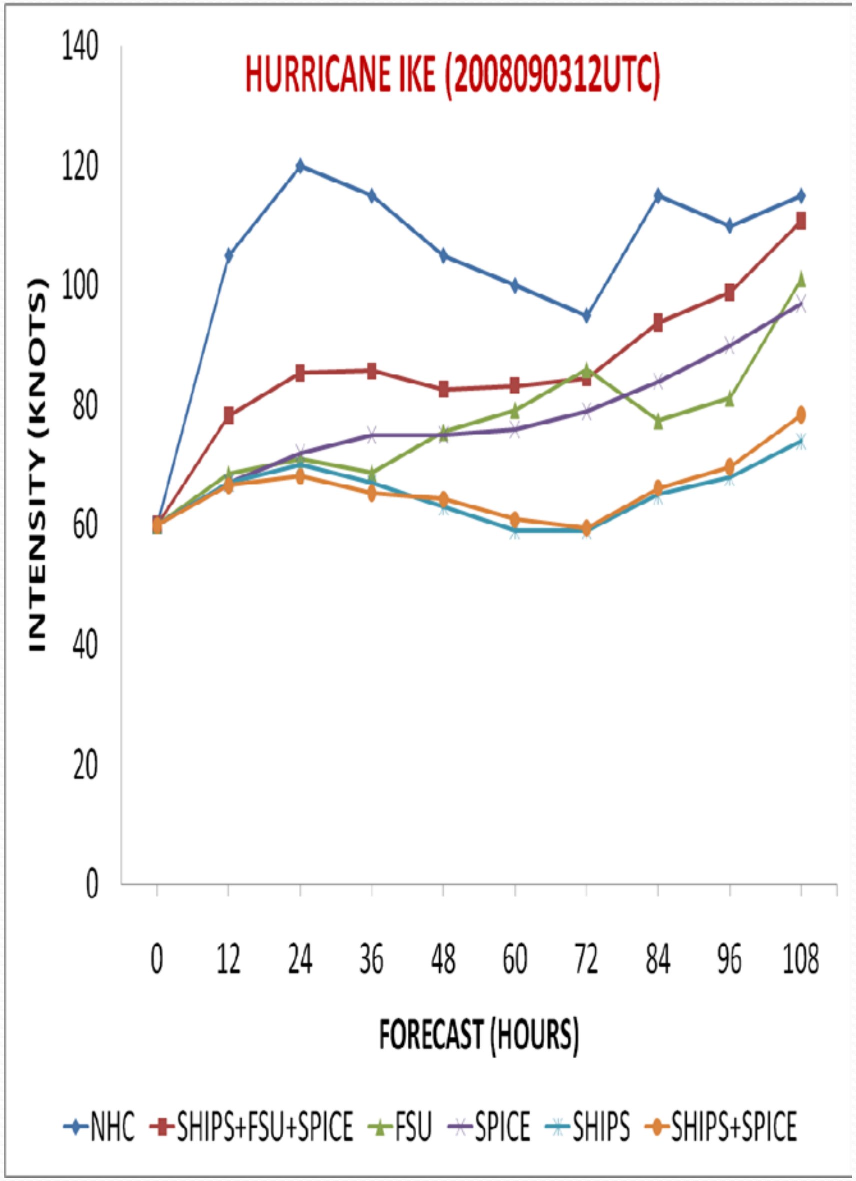
0 12 24 36 48 60 72 84 96 108
NHC SHIPS+FSU+SPICE fsu spice ships SHIPS+SPICE



HURRICANE IKE (2008090312UTC)
INTENSITY (KNOTS)
140
120
100
80
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40
20
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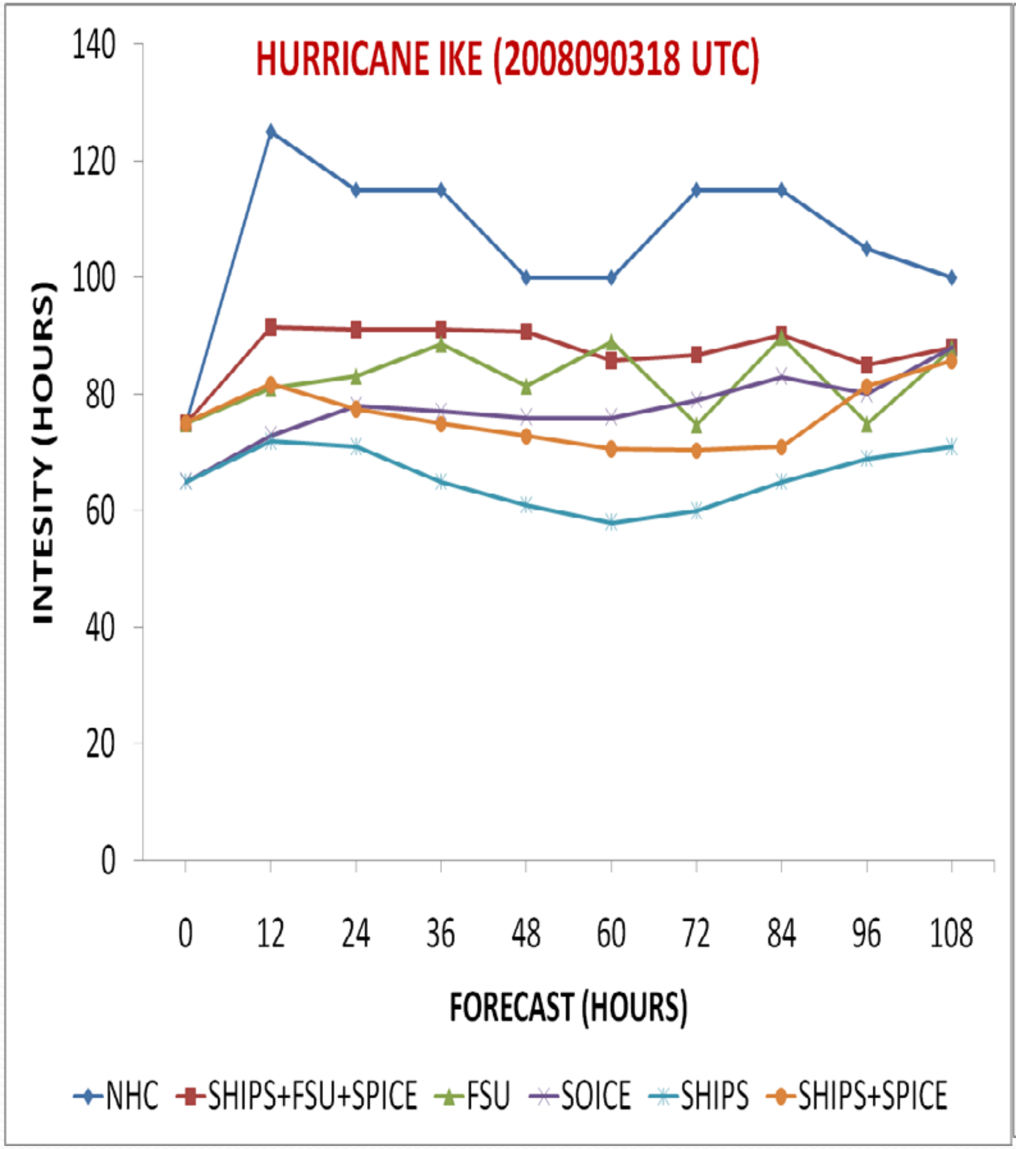
0 12 24 36 48 60 72 84 96 108
FORECAST (HOURS)
NHC SHIPS+FSU+SPICE FSU SPICE SHIPS SHIPS+SPICE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INTESITY (HOURS)
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120
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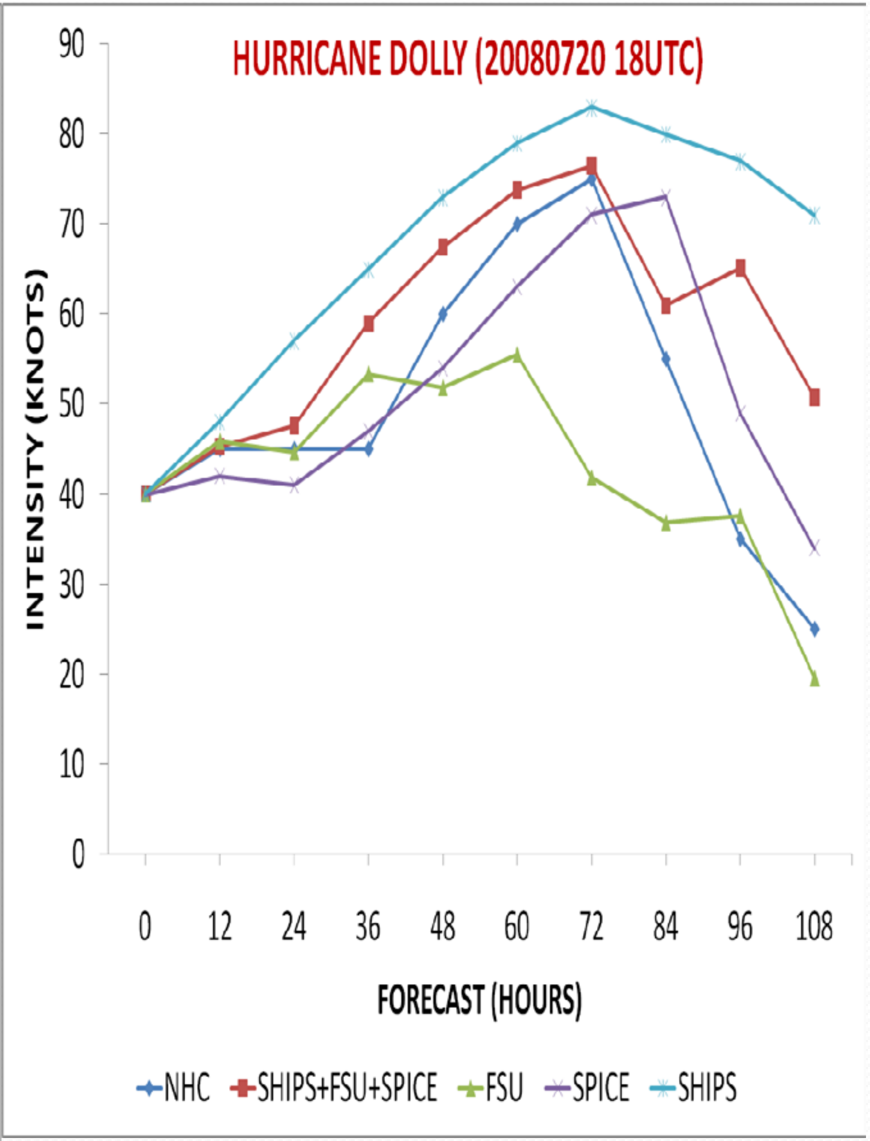
108
FORECAST (HOURS)
NHC
SHIPS+FSU+SPICE
FSU
SOICE
SHIPS
SHIPS+SPICE


HURRICANE DOLLY (20080720 18UTC)
INTENSITY (KNOTS)
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80
70
60
50
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30
20
10
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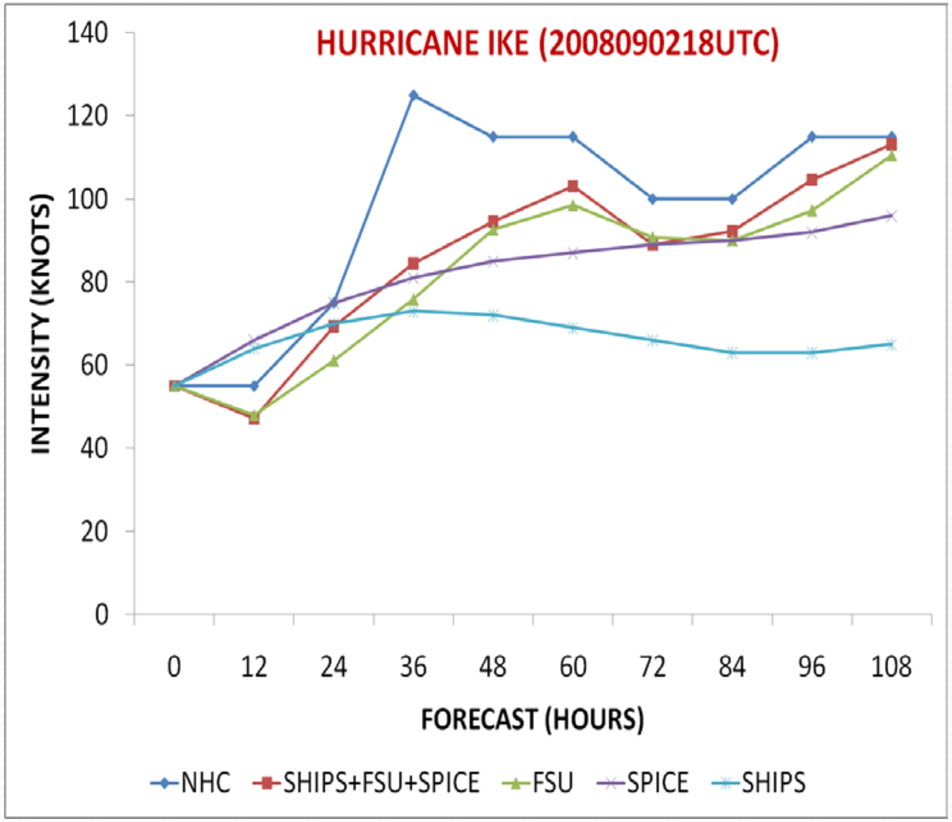
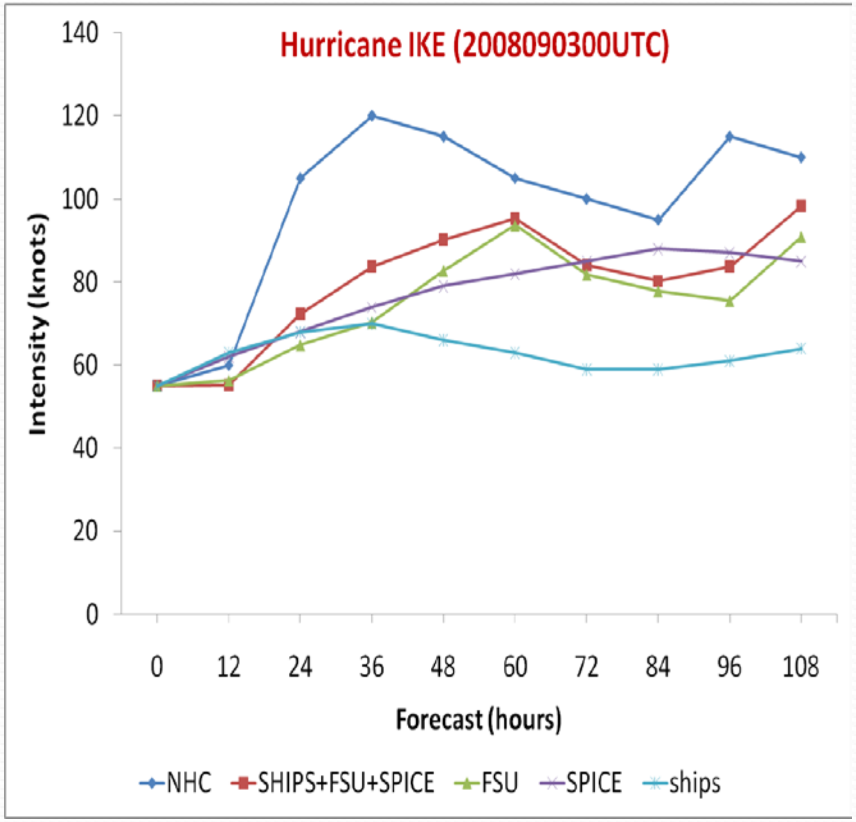
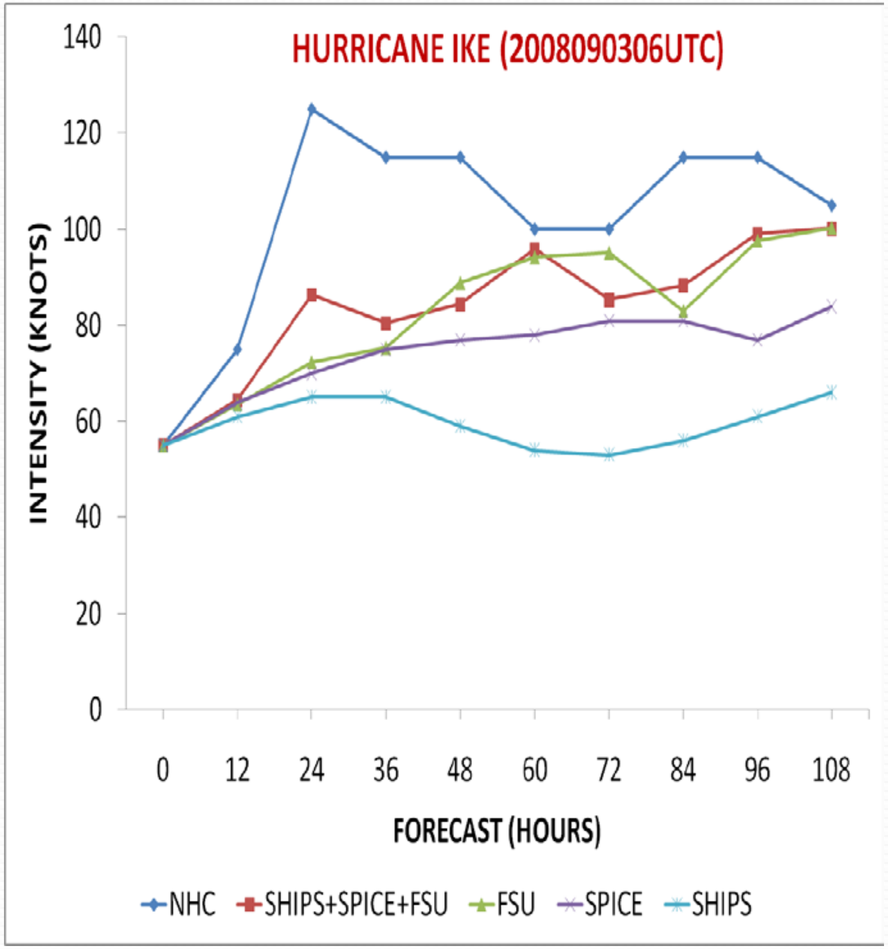
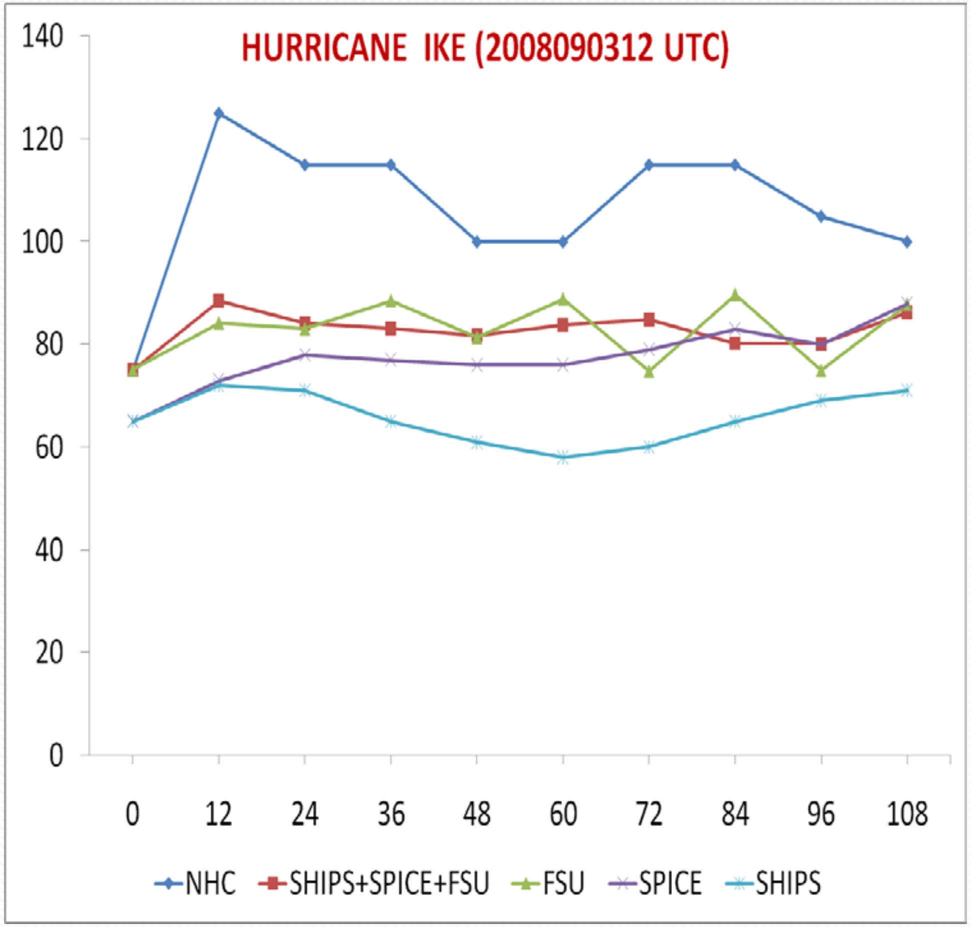
0
12
24
36
48
60
72
84
96
108
FORECAST (HOURS)
NHC
SHIPS+FSU+SPICE
FSU
SPICE
SHIPS

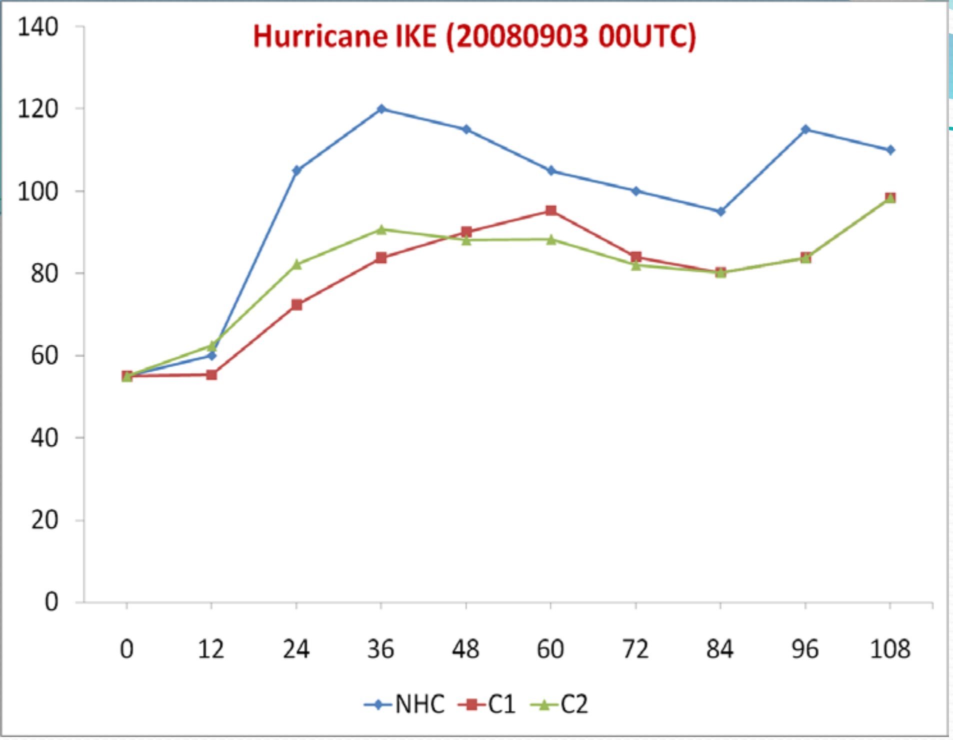
RESULTS FROM ADDITION OF A SCALING ALGORITHM

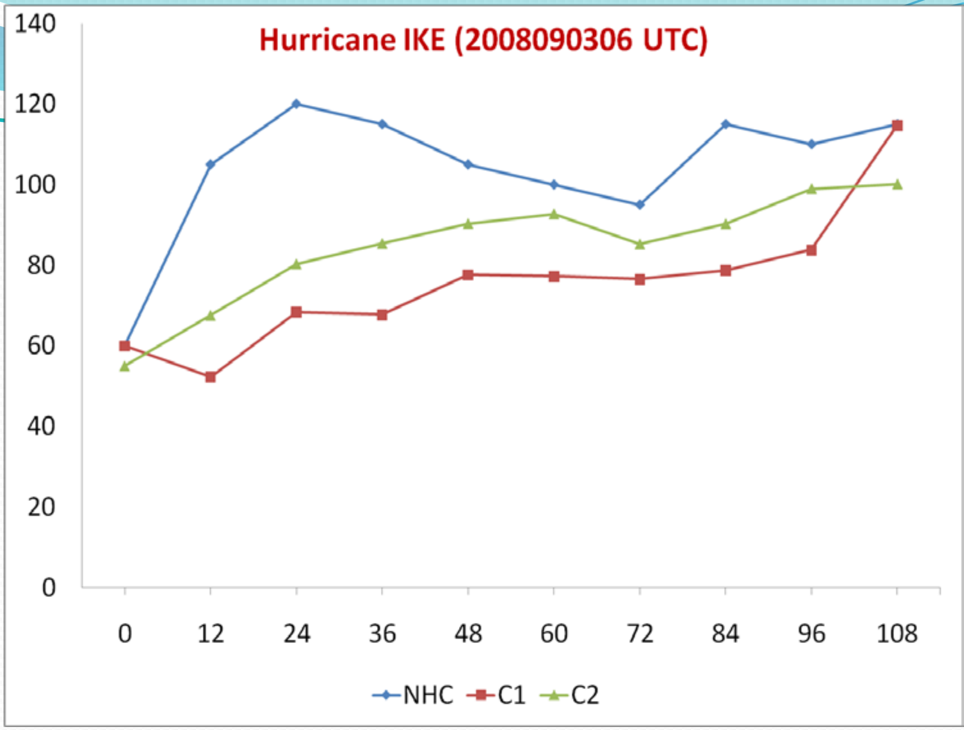


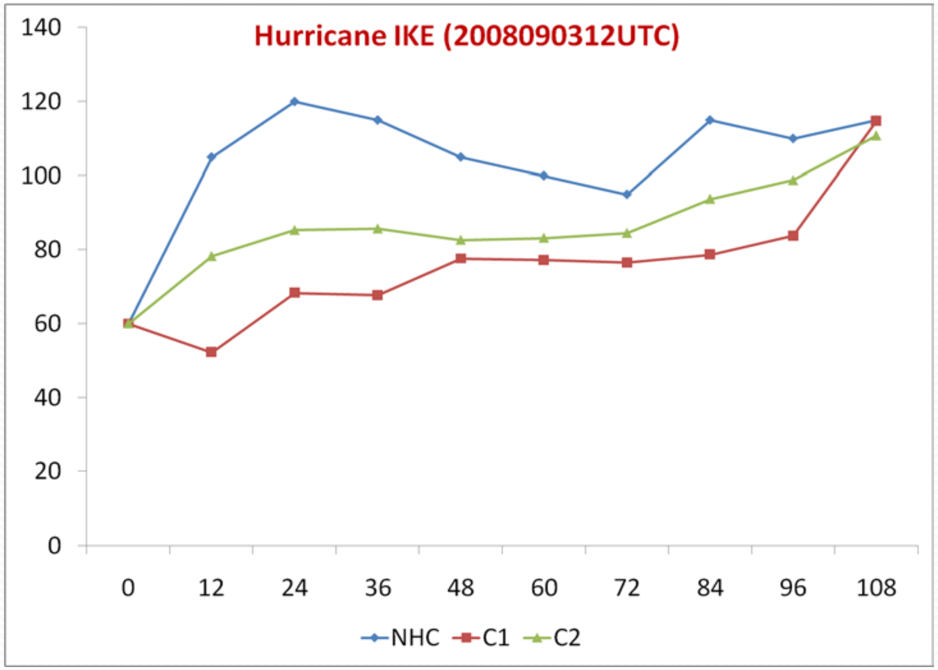


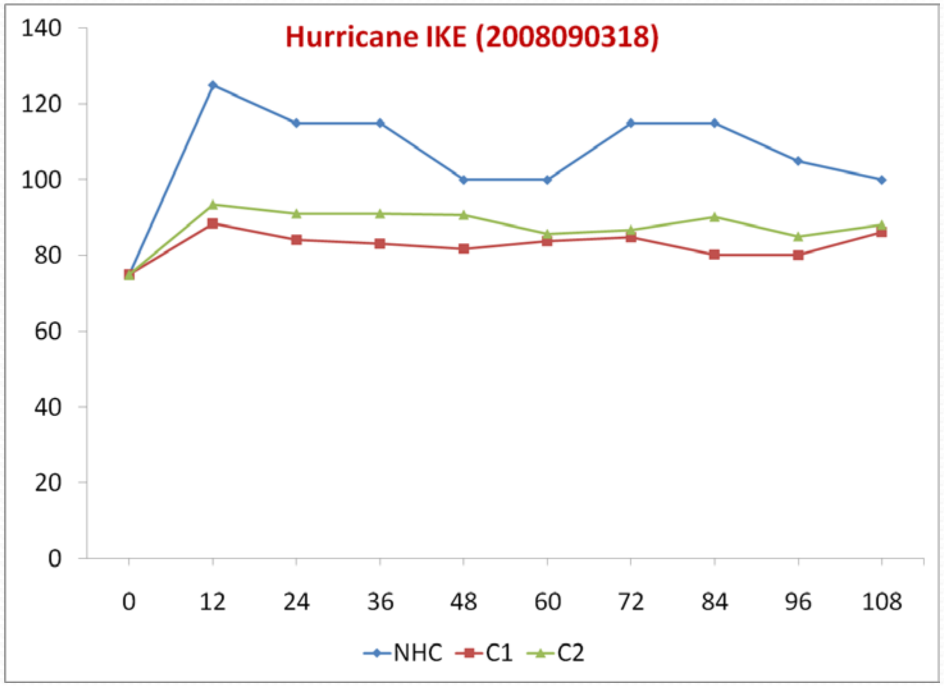

HURRICANE IKE (2008090306UTC)
INTENSITY (KNOTS)
FORECAST (HOURS)
0
20
40
60
80
100
120
140
0
12
24
36
48
60
72
84
96
108
NHC
SHIPS+SPICE+FSU
FSU
SPICE
SHIPS

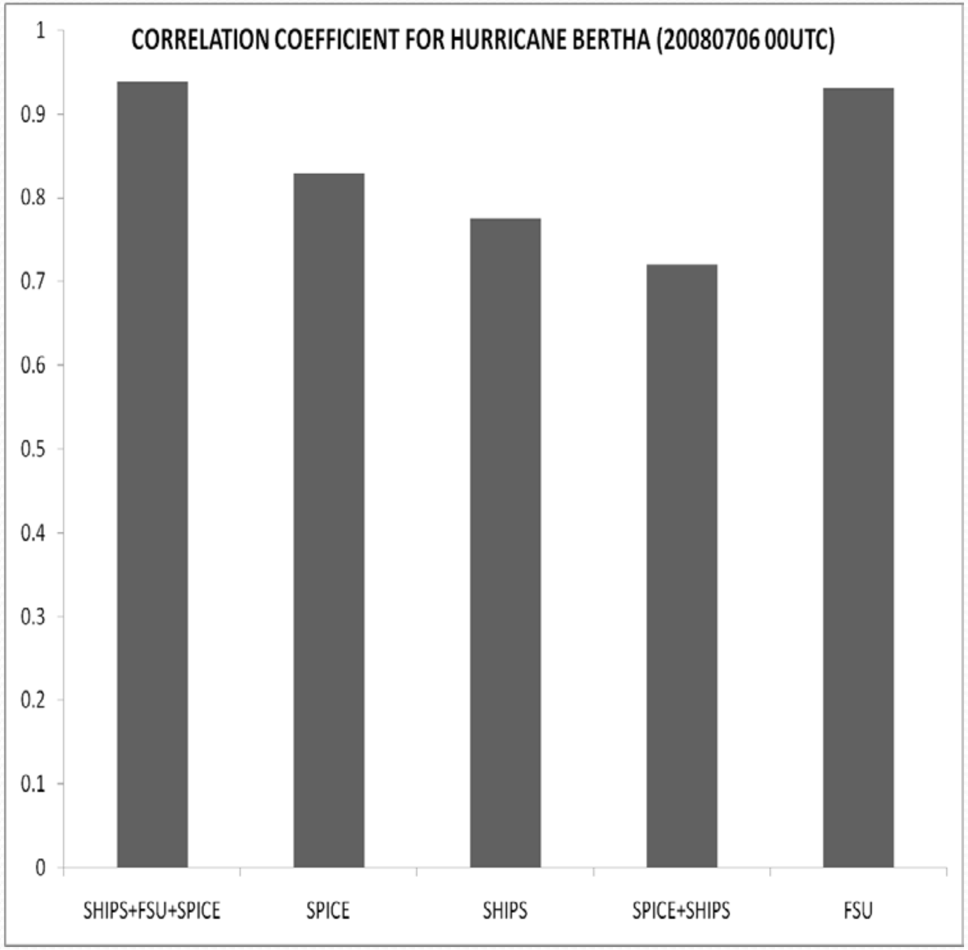

HURRICANE IKE (2008090312 UTC)
0
20
40
60
80
100
120
140
0
12
24
36
48
60
72
84
96
108
NHC
SHIPS+SPICE+FSU
FSU
SPICE
SHIPS

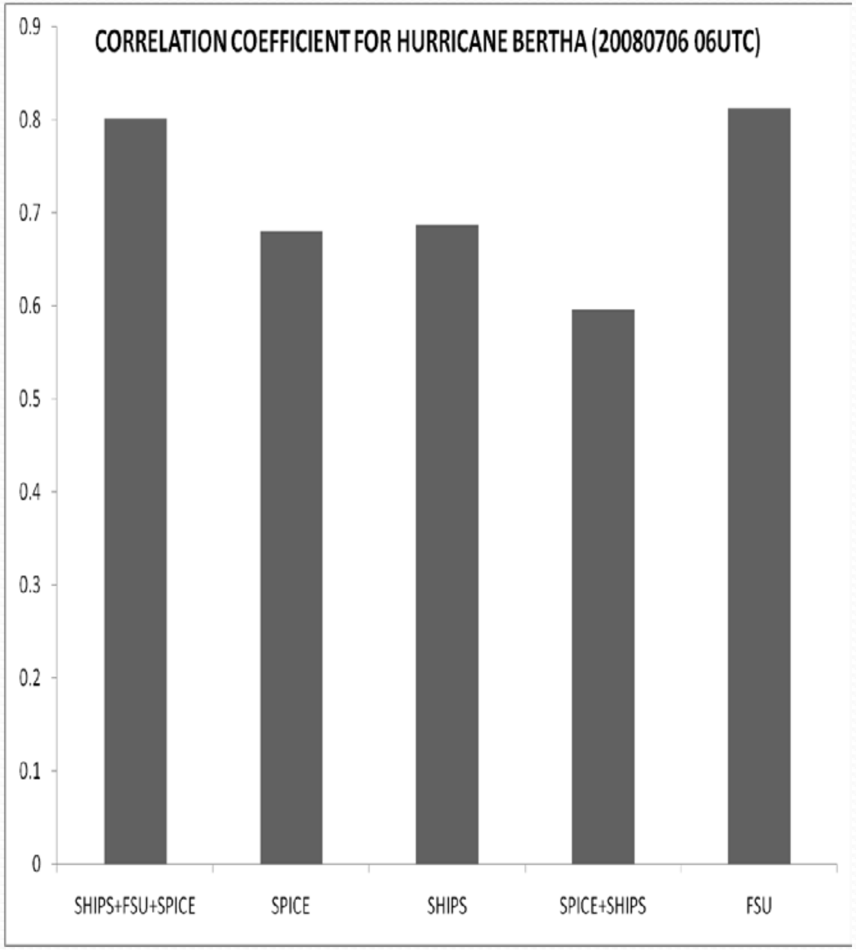

Hurricane IKE (20080903 00UTC)
140
120
100
80
60
40
20
0
0 12 24 36 48 60 72 84 96 108
NHC C1 C2

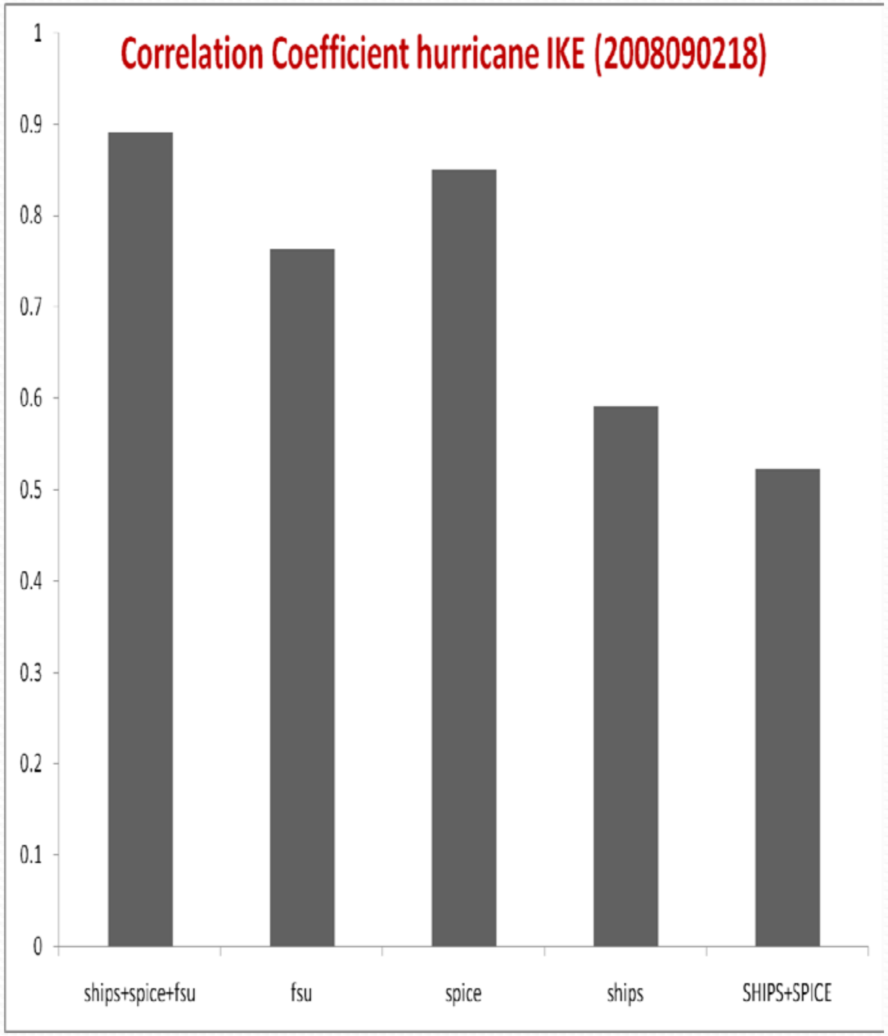

Hurricane IKE (2008090306 UTC)
140
120
100
80
60
40
20
0
0 12 24 36 48 60 72 84 96 108
NHC C1 C2


Hurricane IKE (2008090312UTC)
140
120
100
80
60
40
20
0
0 12 24 36 48 60 72 84 96 108
NHC C1 C2

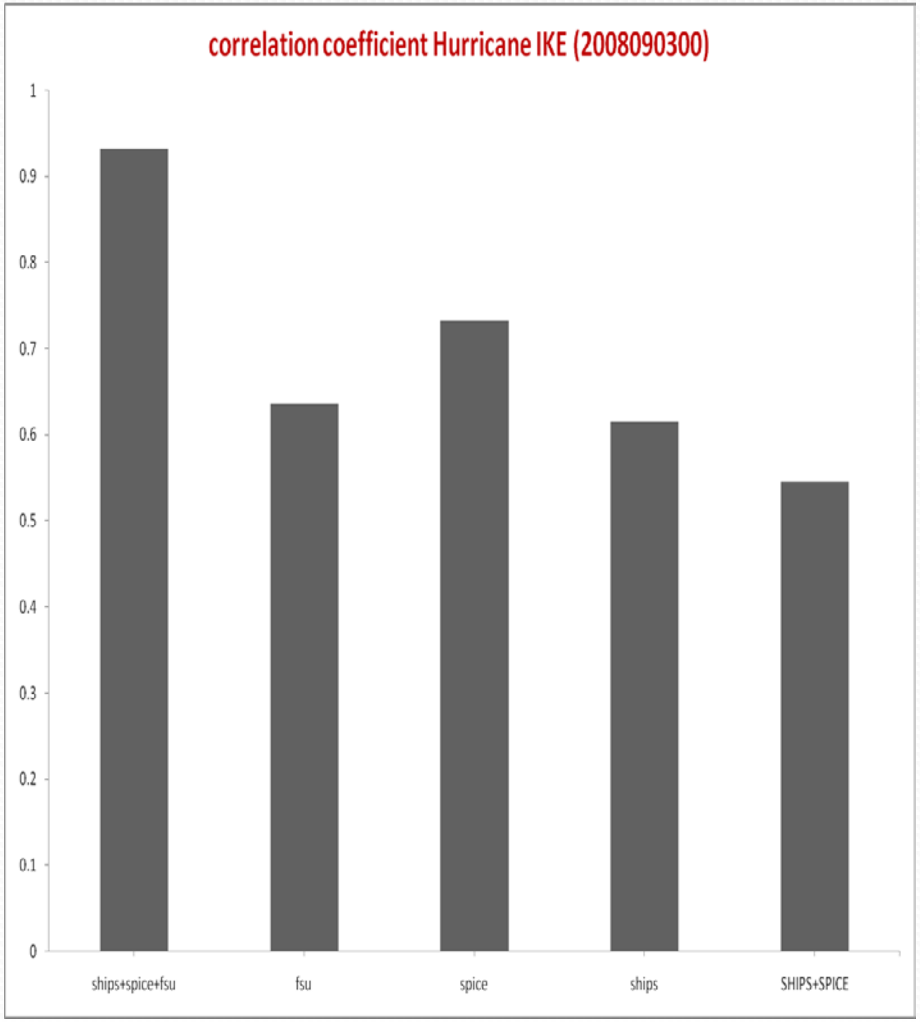

Hurricane IKE (2008090318)
140
120
100
80
60
40
20
0
0 12 24 36 48 60 72 84 96 108
NHC C1 C2


CORRELATION COEFFICIENT FOR HURRICANE BERTHA (20080706 00UTC)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
SHIPS+FSU+SPICE
SPICE
SHIPS
SPICE+SHIPS
FSU

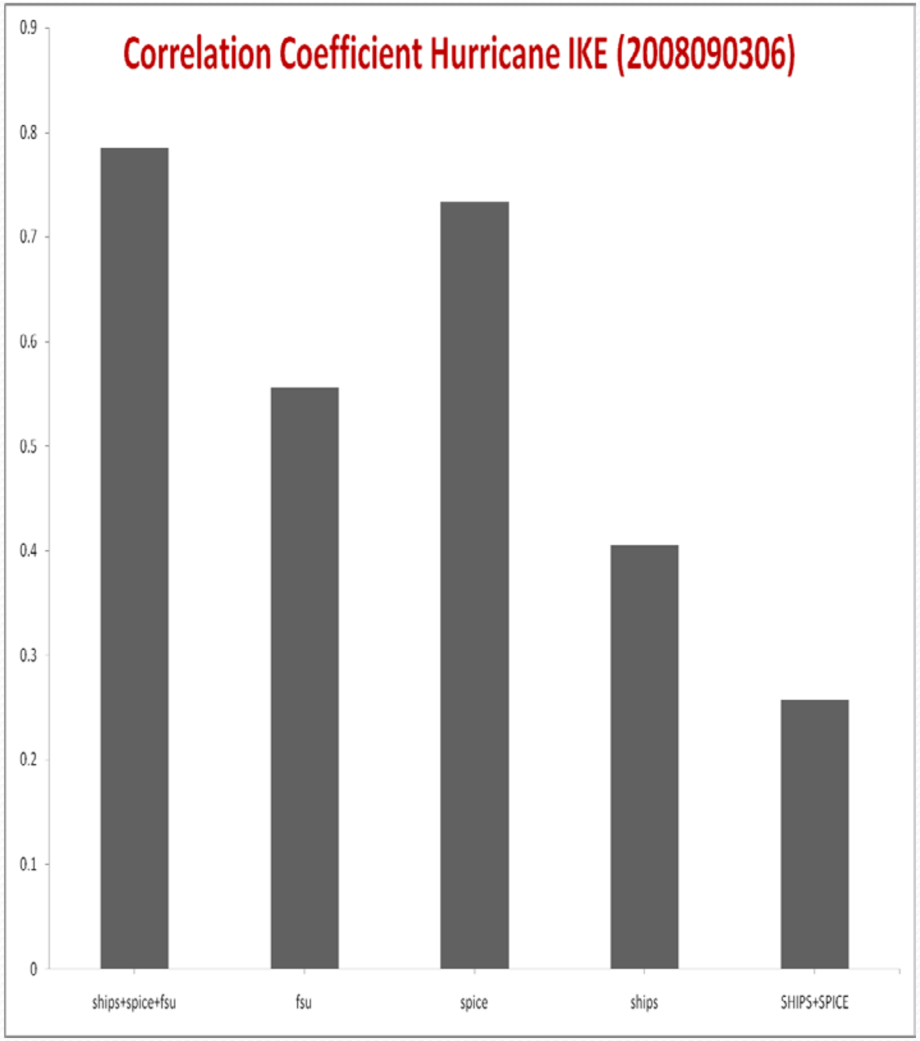

CORRELATION COEFFICIENT FOR HURRICANE BERTHA (20080706 06UTC)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
SHIPS+FSU+SPICE
SPICE
SHIPS
SPICE+SHIPS
FSU

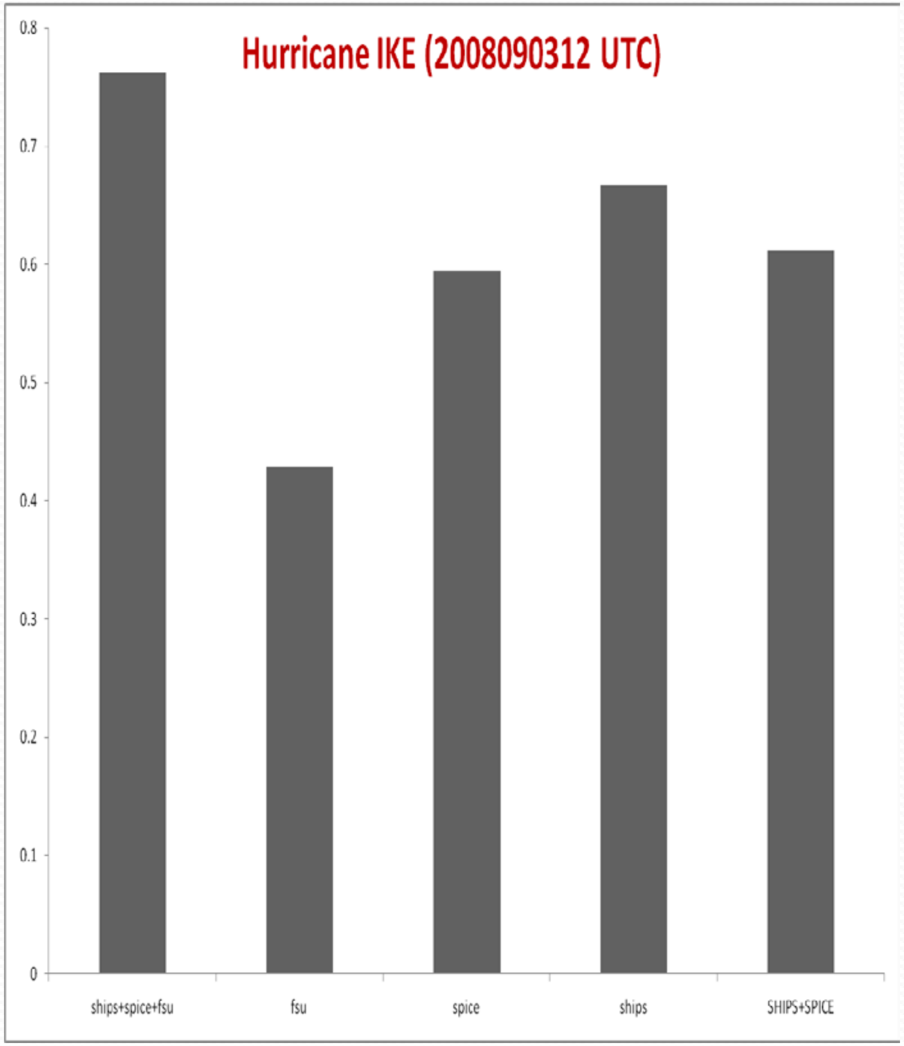


Correlation Coefficient hurricane IKE (2008090218)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
ships+spice+fsu
fsu
spice
ships
SHIPS+SPICE



correlation coefficient Hurricane IKE (2008090300)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
ships+spice+fsu
fsu
spice
ships
SHIPS+SPICE


Correlation Coefficient Hurricane IKE (2008090306)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
ships+spice+fsu
fsu
spice
ships
SHIPS+SPICE


Hurricane IKE (2008090312 UTC)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
ships+spice+fsu
fsu
spice
ships
SHIPS+SPICE

CONCLUSIONS

- **FSU EXTENDED SHIPS/SPICE ALGORITHM FOR HURRICANE INTENSITY FORECAST IMPROVEMENTS IS ALMOST READY FOR OPERATIONS.**

- **THE FSU DIAGNOSTIC VARIABLES BASED ON DIABATIC PV, ANGULAR MOMENTUM TRANSPORTS INTO HURRICANE CORE , ENERGY PROVIDED BY DIVERGENT WINDS AND THE SHEAR TO CURVATURE KINEMATICS PROVIDE GREAT STRENGTHS TO THE CURRENT SHIPS AND THE SPICE FORECAST PARAMETERS.**

- **RESULTS SHOW THAT A COMBINATION OF THE SHIPS, SPICE AND FSU PARAMETRS PROVIDES, CONSISTENTLY, THE BEST HURRICANE INTENSITY FORECASTS.**

- **FOR DAY 3 FORECAST THE COMBINED ALOGORITH IMPROVE INTENSITY FORECAST BY 7% COMPARE TO SPICE AND FOR 108 HOUR FORECAST THE IMPROVEMENTS ARE AROUND 5%.**


THANK YOU
NOT TIME TO ABANDON SHIPS YET