Statistical Modeling Hurricanes Force Winds

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Written: Summer 2005, Edited Spring 2006

Abstract

In the present study, the primary aim concentrates on the modeling of hurricane force winds; that is, maximum sustained winds related to pressure, location and linear velocity. We were successful in modeling the wind speed within storm as a function of the contributing entities. In this study, we were able to re-evaluate the association between wind speed and pressure within storms and know this will lead to historical breakthroughs in how we see hurricanes and predict hurricanes. This paper is the first paper of a series, and its analysis of wind speed versus pressure indicates that further analysis of the Saffir-Simpson Scale is necessary, as well as determining if pressure is an indicator or a consequence of a hurricane force wind speed.

Keywords: Hurricane modeling and linea and nonlinear regression.

Introduction

There are statistical models in forecasting the track of hurricanes, but how well do we understand the mechanics underlying the birth and pathway of a tropical storm. At each level, we must rank the explanatory variables according to their contribution to the model and determine if it is possible to average categories. What is the difference in directional movement with respect to the season? Furthermore, what are the interactions? Is the best-fit model linear or non-linear? How well do the obtained models predictions compare with actual data?

Data containing wind speed, pressure and location of five category five storms

Data gleaned from UNISYS Tropical Prediction Center: for this paper only the five most recent storms classified as category 5 are considered. Provision included: charts on the track of the storm, tracking information, position in latitude and longitude, maximum sustained winds in knots, and central pressure in millibars.

Year	Storms	Max Sustained Wind	Pressure	Color
2005	Wilma	150	882	Purple
2005	Rita	150	----	Red
2005	Katrina	150	902	Orange
2004	Ivan	145	910	Green
2003	Isabel	140	920	Blue

Table 1: Table of maximum hurricane force winds and their associated pressures for five resent storms in the Atlantic region

These five storms will provide a glimpse into understanding the transitions between Category 0 (tropical storm) to Category 1, etc.

Modeling maximum sustained winds in hurricane conditions using

The phenomenon of hurricane force winds depends on the surrounding pressure as well as the latitude at which the circulations form. Hurricanes cannot form on the equator thanks to the Coriolis effect.

Primary variables available with hurricane records

w	Maximum sustained wind speed
P	Pressure at center
LAT	Longitude (in radians)
LON	Latitude (in radians)
x	Converted to Cartesian coordinates
y	Converted to Cartesian coordinates
Δx	The change in x
Δy	The change in y
$\delta = \sqrt{(\Delta x)^2 + (\Delta y)^2}$	The distance between movements
Δt	The change in time
$v = \lvert\vec{v}\rvert = \frac{\sqrt{(\Delta x)^2 + (\Delta y)^2}}{\Delta t}$	The magnitude of the approximate linear velocity
	Here the approximate linear velocity is $\vec{v} = \frac{\Delta x}{\Delta t} i + \frac{\Delta y}{\Delta t} j$.
$D = \int \Delta t$	Duration (up to that point)
d	Day of Year
Y	Year

Foremost, either wind speed or pressure could be considered as the response variable; however, the believe is the low pressures cause hurricanes to form, therefore in this paper we will treat the wind speed as the response variable and the pressure to be a contributing or explanatory variable.

Furthermore, the measurements of latitude and longitude are not uniformly scaled, they exist in a sphere; therefore latitudes for various longitudes are further apart near the equator and closer together near the poles. To try modeling hurricanes into terms of its position, these measurements first need to conversion to a Cartesian coordinates; where linear movements are a valid measure and therefore approximation linear velocities exist.

Conversion for latitude and longitude into Cartesian coordinates

If we let $a = 6378137m$, $b = \frac{1}{298.25722563}$, $c^2 = 2b - b^2$, $h \approx 100m$ (height above geoids) and $v = \frac{a}{(1 - b^2 \sin^2 b)}$, then $x = (v + h)\cos LAT \cos LON$ and $y = (v + h)\cos LAT \sin LON$.

Comparison of Latitude versus Longitude and the Cartesian coordinate using five storms

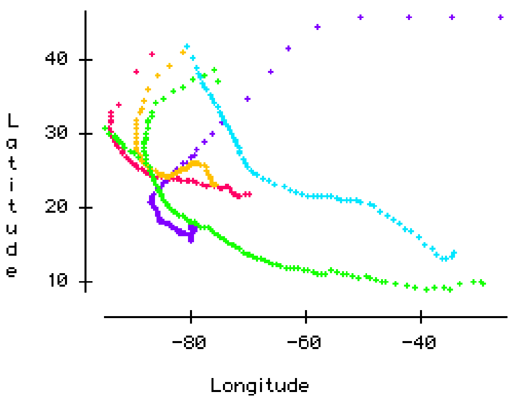


Figure 1: Scatter plot of latitude versus longitude

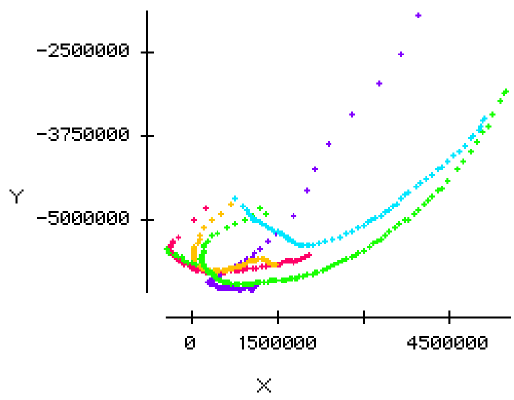


Figure 2: Scatter plot of converted latitude versus longitude into Cartesian coordinates x and y

It is interesting to note that four out of five of the storms move west the further north the storms moves, but the last storm moves mainly east as the storm moves. Furthermore, as illustrated in Figure 3, this single storm started were the other four storms ended and ended where two of the other storms began. As for the latitude, the all storms started closer to the equator as illustrate in Figure 4 and possible with a few wobbles, moves north.

What is the difference in directional movement with respect to the season?

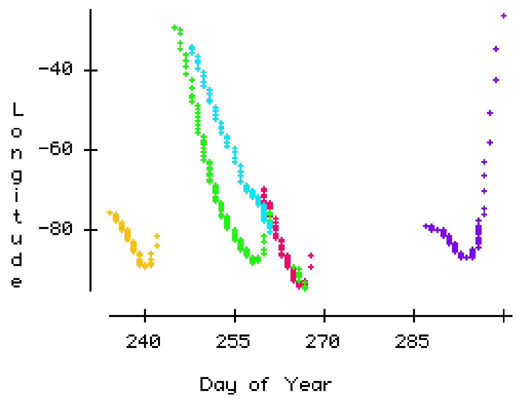


Figure 3: Line graph for longitude

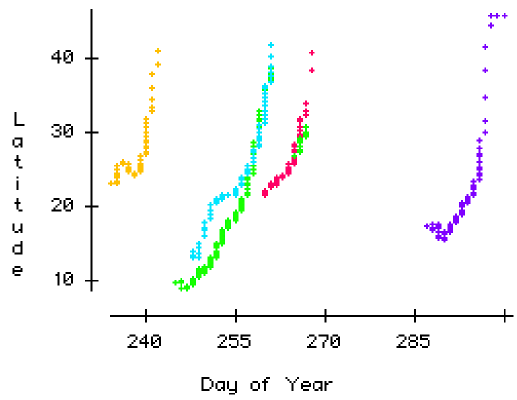


Figure 4: Line graph for latitude

Notice that Wilma occurred during winter when the earths rotation with respect to the sun is in the southern hemisphere, whereas the other four storms were in the summer months when the earths rotation with respect to the sun is in the northern hemisphere. See appendix A. This will be significant when modeling the directionality of future hurricanes.

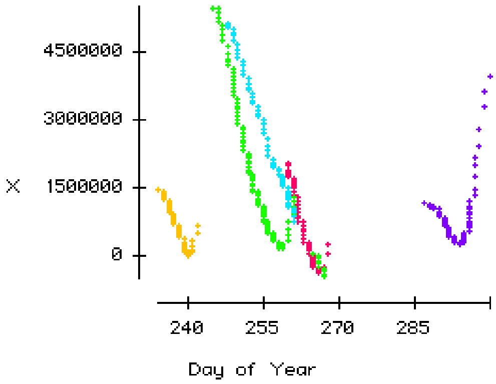


Figure 5: Line graph for converted latitude and longitude with respect to x

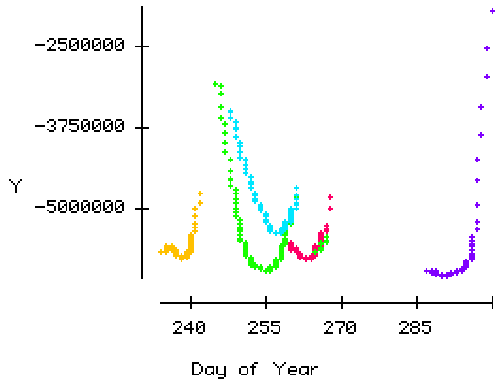


Figure 6: Line graph for converted latitude and longitude with respect to y

However, in the paper, we will be interested in which parameter to include in the model: latitude and longitude or the transformed x and y. Since x and y illustrate the real linear movement of the storm, these transformed information with be included in the following model.

Ranking of independent variables by maximum improvement in R^2

1. Pressure P	90.72%	
2. x	93.00%	
3. y	94.03%	
4. Duration D	94.34%	
5. Day of Year d	94.55%	
6. Velocity v	94.79%	
7. dx	94.88%	
8. dy	95.07%	
9. dt	95.17%	
10. Distance δ	95.19%	
11. Year Y	95.19%	(No improvement)

Table 2: Ranking of independent variables

Linear Regression

First, we will consider the regression using all categories within the five selected hurricanes and all parameters ranked in Table 1.

$$\hat{w} = \begin{cases} \hat{a}_0 + \hat{a}_1 P + \hat{a}_2 x + \hat{a}_3 y + \hat{a}_4 D + \hat{a}_5 d + \hat{a}_6 v \\ + \hat{a}_8 dx + \hat{a}_9 dy + \hat{a}_{10} dt + \hat{a}_{11} \delta + \hat{a}_{12} Y \end{cases} \tag{1}$$

Regressing this model using the data outlined above, we have the following printout including the associated p-values, see Figure 7.

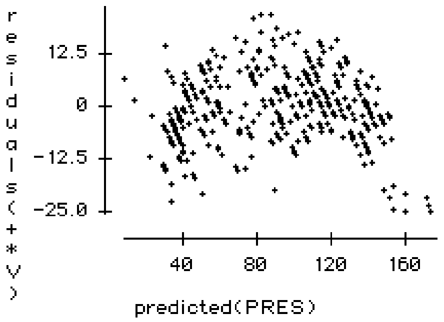
Initial Model: Full linear model

Dependent variable is: **WIND**
No Selector
402 total cases of which 5 are missing
R squared = 95.2% R squared (adjusted) = 95.1%
s = 8.727 with 397 - 12 = 385 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	580254	11	52750.4	693
Residual	29320.7	385	76.1576	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	-3079.32	3137	-0.982	0.3269
PRES	-1.12716	0.01549	-72.8	≤ 0.0001
X	9.40914e-6	1.064e-6	8.84	≤ 0.0001
Y	-13.1567e-6	1.485e-6	-8.86	≤ 0.0001
DURATION	0.672378	0.2182	3.08	0.0022
DAY	-0.0837455	0.02867	-2.92	0.0037
VELOCITY	6.58047e-6	4.237e-6	1.55	0.1213
dX	-77.3014e-6	14.1e-6	-5.48	≤ 0.0001
dY	68.0624e-6	18.7e-6	3.64	0.0003
dt	-7.77545	12.08	-0.644	0.5201
DISTANCE	0	28.36e-6	-0.196	0.8451
YEAR	2.08443	1.567	1.33	0.1843

Figure 7: Multiple regression of wind speed over pressure, time, location and other associated measures



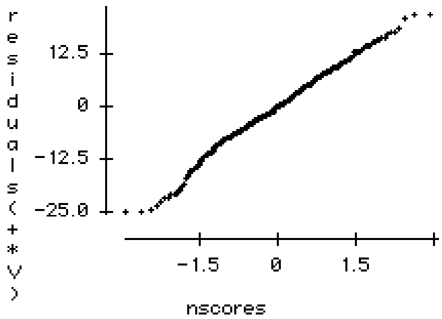


Figure 8: Residual plot for model outlined in Figure 7

Figure 9: Normal probability plot for the residuals of the model outlined in Figure 7

Note: $\delta = v\Delta t$, therefore this model actually contains the interaction of between velocities and the change in time and is insignificant. Other insignificant variables are the change in time and the year. Moreover, there is an obvious bowing of the data. Therefore, it illustrates the fact that there is at least one higher order term.

Model One: Full linear model with significant linear terms and quadratic term

$$\hat{w} = \begin{cases} \hat{a}_0 + \hat{a}_1 P + \hat{a}_2 x + \hat{a}_3 y + \hat{a}_4 D + \hat{a}_5 d + \hat{a}_6 v \\ + \hat{a}_8 dx + \hat{a}_9 dy \\ + \hat{a}_{10} P^2 \end{cases} \quad (2)$$

Dependent variable is: **WIND**
No Selector
402 total cases of which 5 are missing
R squared = 96.1%   R squared (adjusted) = 96.0%
s = 7.819 with 397 - 10 = 387 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	585915	9	65101.6	1.06e3
Residual	23660.5	387	61.1383	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	-2648.09	365.9	-7.24	≤ 0.0001
PRES	6.71895	0.7662	8.77	≤ 0.0001
X	8.12246e-6	581.5e-9	14	≤ 0.0001
Y	-13.5435e-6	1.251e-6	-10.8	≤ 0.0001
DURATION	0.207587	0.1056	1.97	0.0500
DAY	-0.081476	0.02433	-3.35	0.0009
VELOCITY	3.5205e-6	1.797e-6	1.96	0.0509
dX	-58.0522e-6	10.46e-6	-5.55	≤ 0.0001
dY	62.8245e-6	14.72e-6	4.27	≤ 0.0001
P^2	-0.00410053	400.3e-6	-10.2	≤ 0.0001

Figure 10: Multiple regression including significant linear terms and a single quadratic term for pressure

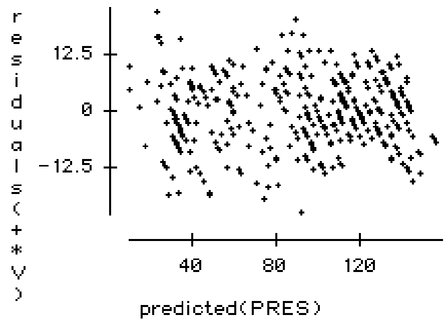


Figure 11: Residual plot for model outlined in Figure 10

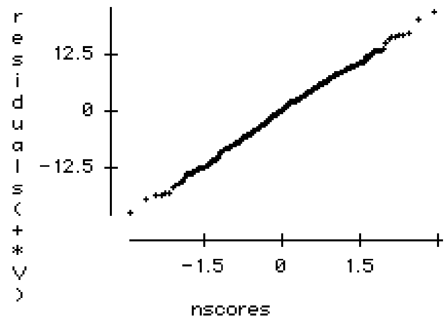


Figure 12: Normal probability plot for the residuals of the model outlined in Figure 10

This yields $R^2 = 96.1\%$ and $R^2_{adj} = 96.0\%$, over the previous $R^2 = 95.2\%$ and $R^2_{adj} = 95.1\%$.

$$\text{Model One (I): } w = \begin{cases} -2648.09 + 6.71895P + (8.12246\times10^{-6})x - (13.5435\times10^{-6})y \\ +0.207587D - 0.081476d + (3.5205\times10^{-6})v \\ -(58.0522\times10^{-6})\Delta x + (62.8245\times10^{-6})\Delta y \\ -0.00410053P^2 \end{cases} \quad (3)$$

Comparison of Model I predictions and the recorded Wind Speed

Dependent variable is: MODEL 1
No Selector
402 total cases of which 5 are missing
R squared = 96.1%   R squared (adjusted) = 96.1%
s = 7.587 with 397 - 2 = 395 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	563161	1	563161	9.78e3
Residual	22739.3	395	57.5679	

Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	3.52311	0.961	3.67	0.0003
WIND	0.961176	0.009718	98.9	≤ 0.0001

Figure 13: Simple linear regression to compare predicted values using Model I to that of the actual wind speed

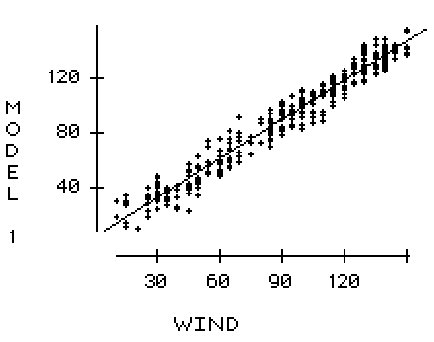


Figure 14: Scatter plot of predicted values using Model I versus the actual wind speed

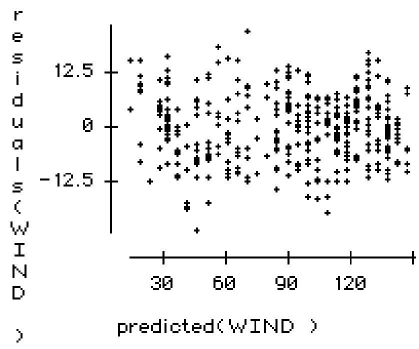


Figure 15: Residual plot for Model I

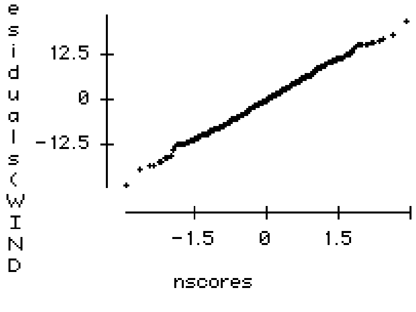


Figure 16: Normal probability plot for the residuals of Model I

Therefore, 96.1% of the variation in the wind speed is explained by the five main explanatory variables outlined as primary variables in the study; namely, pressure, latitude and longitude converted, day of year and duration. For the simple transformations used to obtain the remaining contributing entities see the outlined section labeled conversion for latitude and longitude into Cartesian coordinates.

Additional Interaction between three most significant factors

$$\text{Interactive Model: } \hat{w} = \begin{cases} \hat{a}_0 + \hat{a}_1 P + \hat{a}_2 x + \hat{a}_3 y + \hat{a}_4 D + \hat{a}_5 d + \hat{a}_6 v \\ + \hat{a}_8 dx + \hat{a}_9 dy + \hat{a}_{10} P^2 \\ + \hat{a}_{11} Px + \hat{a}_{12} Py + \hat{a}_{13} xy \end{cases} \tag{4}$$

Dependent variable is: **WIND**
No Selector
402 total cases of which 5 are missing
R squared = 97.1% R squared (adjusted) = 97.0%
s = 6.834 with 397 - 13 = 384 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	591643	12	49303.6	1.06e3
Residual	17932.1	384	46.6981	

Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	-608.126	502.4	-1.21	0.2269
PRES	3.76158	0.8942	4.21	≤ 0.0001
X	37.052e-6	17.47e-6	2.12	0.0346
Y	225.327e-6	36.98e-6	6.09	≤ 0.0001
DURATION	0.688718	0.1142	6.03	≤ 0.0001
DAY	-0.17764	0.02318	-7.66	≤ 0.0001
VELOCITY	11.9308e-6	1.747e-6	6.83	≤ 0.0001
dX	-59.9979e-6	9.34e-6	-6.42	≤ 0.0001
dY	94.6117e-6	13.43e-6	7.04	≤ 0.0001
P^2	-0.00334659	404.3e-6	-8.28	≤ 0.0001
PxX	0	16.74e-9	0.712	0.4769
PxY	-271.773e-9	38.99e-9	-6.97	≤ 0.0001
XxY	7.55891e-12	733.3e-15	10.3	≤ 0.0001

Figure 17: Multiple regression including significant linear terms, a single quadratic term for pressure and interaction

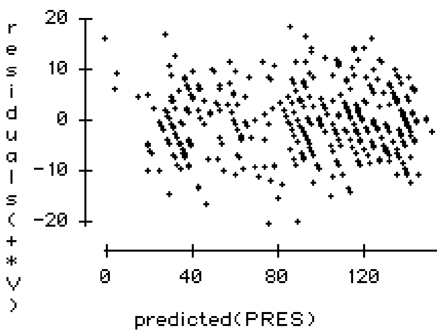


Figure 18: Residual plot for the model outlined in Figure 17

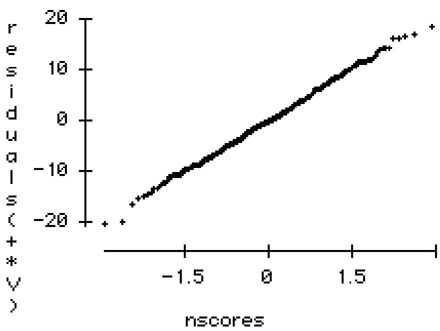


Figure 19: Normal probability plot for the model outlined in Figure 17

Of the included interactions, there is only one insignificant interaction; that is, the pressure P is not interactive with the coordinate x.

Model Two (II): Full linear model with quadratic term and significant interaction

$$\text{Model II: } \hat{w} = \begin{cases} -727.895 + 3.91341P + 49.1989\times10^{-6}x + 210.721\times10^{-6}y \\ +0.650216D - 0.178422d + 11.9516\times10^{-6}v \\ -60.005\times10^{-6}dx + 94.4684\times10^{-6}dy \\ -0.00337569P^2 \\ -256.827\times10^{-9}Py + 7.71408\times10^{-12}xy \end{cases} \quad (4)$$

Dependent variable is: **WIND**
No Selector
402 total cases of which 5 are missing
R squared = 97.1% R squared (adjusted) = 97.0%
s = 6.829 with 397 - 12 = 385 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	591619	11	53783.6	1.15e3
Residual	17955.8	385	46.6383	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	-727.895	473.1	-1.54	0.1247
PRES	3.91341	0.8679	4.51	≤ 0.0001
X	49.1989e-6	3.766e-6	13.1	≤ 0.0001
Y	210.721e-6	30.74e-6	6.85	≤ 0.0001
DURATION	0.650216	0.1006	6.47	≤ 0.0001
DAY	-0.178422	0.02314	-7.71	≤ 0.0001
VELOCITY	11.9516e-6	1.745e-6	6.85	≤ 0.0001
dX	-60.0054e-6	9.334e-6	-6.43	≤ 0.0001
dY	94.4684e-6	13.42e-6	7.04	≤ 0.0001
P^2	-0.00337569	402e-6	-8.4	≤ 0.0001
PxY	-256.827e-9	32.84e-9	-7.82	≤ 0.0001
XxY	7.71408e-12	699.8e-15	11	≤ 0.0001

Figure 20: Multiple regression including significant linear terms, a single quadratic term for pressure and significant interaction

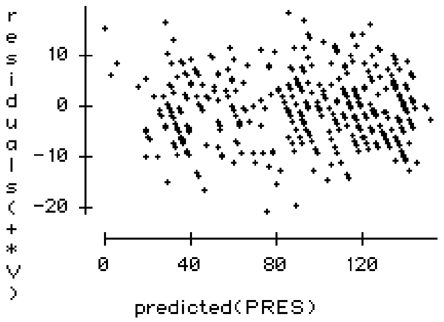


Figure 21: Residual plot for model (2)

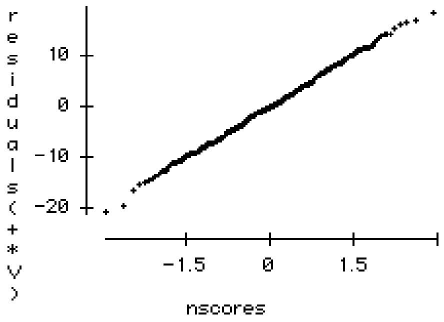


Figure 22: Normal probability plot for model (2)

This yields $R^2 = 97.1\%$ and $R^2_{adj} = 97.0\%$, with or without interaction between the pressure and the converted x value. Invoking the law of parsimony, we will not include this interaction in our model.

Comparison of Model II predictions and the recorded Wind Speed

Dependent variable is: **MODEL 2**
No Selector
402 total cases of which 5 are missing
R squared = 97.1% R squared (adjusted) = 97.0%
s = 6.642 with 397 - 2 = 395 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	574183	1	574183	13e3
Residual	17425.3	395	44.1147	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	2.67528	0.8412	3.18	0.0016
WIND	0.970536	0.008507	114	≤ 0.0001

Figure 23: Simple linear regression to compare predicted values using Model II to that of the actual recorded wind speed

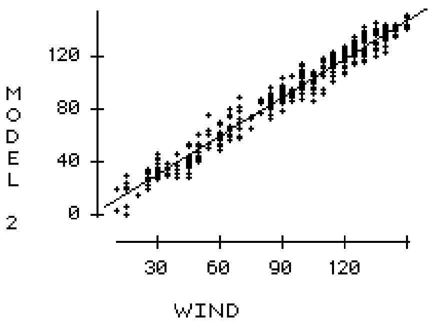


Figure 24: Scatter plot of predicted values using Model II versus the actual wind speed

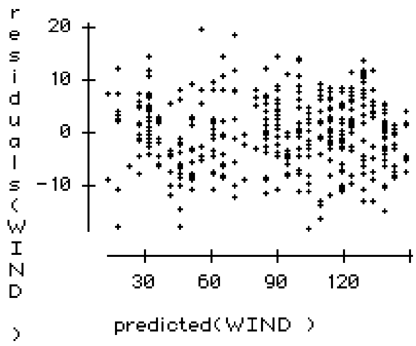


Figure 25: Residual plot for Model II

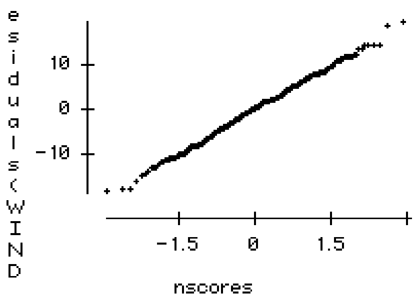


Figure 26: Normal probability plot for the residuals of Model II

Predictions using both models for each hurricane compared with record wind speed

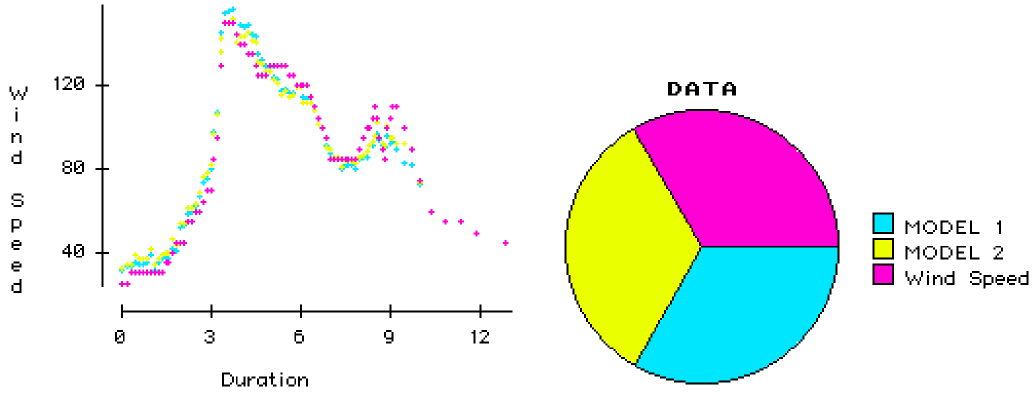


Figure 27: Line graph comparison for hurricane Wilma

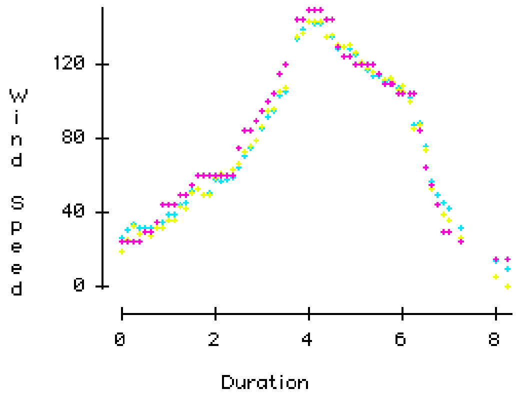


Figure 28: Line graph comparison for hurricane Rita

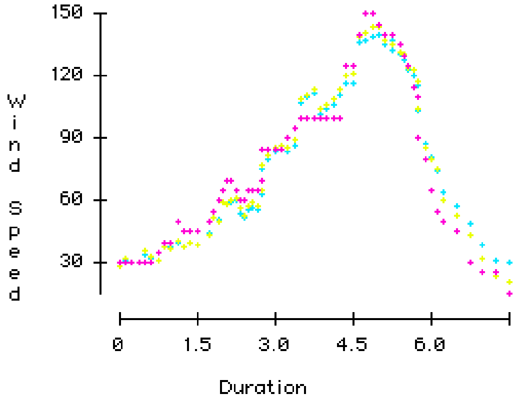


Figure 29: Line graph comparison for hurricane Katrina

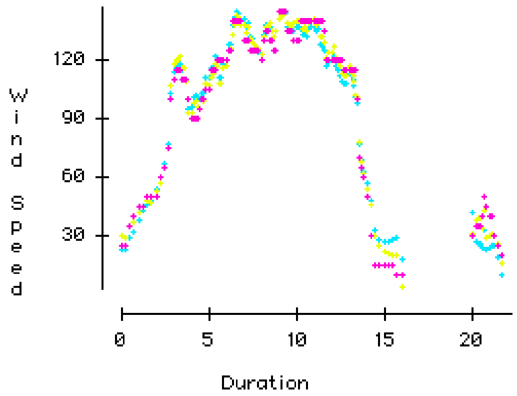


Figure 30: Line graph comparison for hurricane Ivan

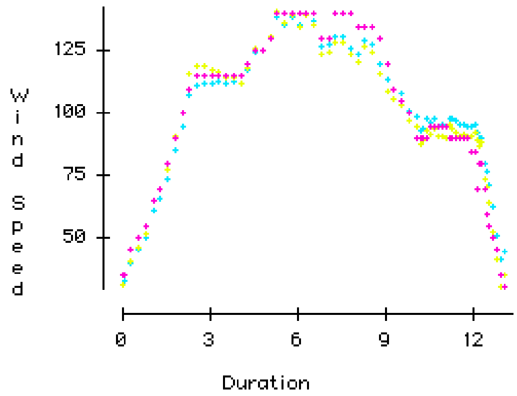


Figure 31: Line graph comparison for hurricane Isabel

Model 2_0: Model II (2) for category zero storms (tropical storms and depressions)

Dependent variable is: **WIND**
No Selector
121 total cases of which 5 are missing
R squared = 81.8% R squared (adjusted) = 79.8%
s = 6.187 with 116 - 12 = 104 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	17837	11	1621.54	42.4
Residual	3980.89	104	38.2778	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	-16566.1	4945	-3.35	0.0011
PRES	34.9694	9.969	3.51	0.0007
X	43.9658e-6	5.318e-6	8.27	≤ 0.0001
Y	73.3969e-6	151.2e-6	0.485	0.6285
DURATION	0.824294	0.1718	4.8	≤ 0.0001
DAY	-0.314	0.04283	-7.33	≤ 0.0001
VELOCITY	7.25361e-6	3.106e-6	2.34	0.0214
dX	-72.3117e-6	11.56e-6	-6.26	≤ 0.0001
dY	107.035e-6	17.62e-6	6.08	≤ 0.0001
P^2	-0.0185406	0.005055	-3.67	0.0004
PxY	0	152.8e-9	-0.761	0.4483
XxY	6.49822e-12	1.103e-12	5.89	≤ 0.0001

Figure 32: Multiple regression including significant linear terms, a single quadratic term for pressure and significant interaction for category zero only

Here the see with such low wind speeds, our model is less reliable; that is, the model when estimated using only data defined as a tropical storm or depression explains only 81.8% of the variation in the wind speed.

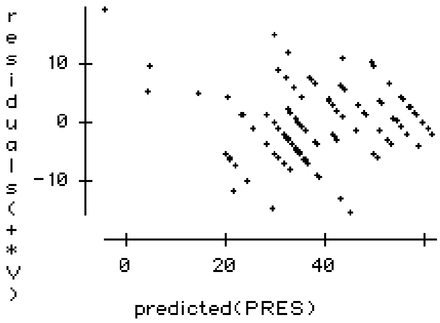


Figure 33: Residual plot for model (2_0)

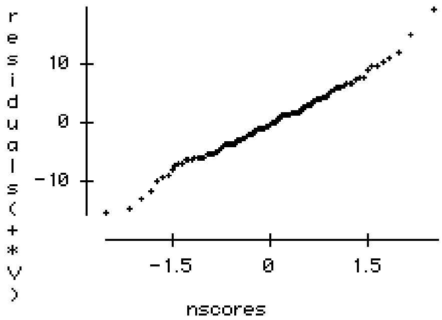


Figure 34: Normal probability plot for the residuals of model (2_0)

Model 2_0:

$$w = \begin{cases} -16566.1 + 34.9694P + (43.9658\times10^{-6})x + (73.3969\times10^{-6})y \\ +\,0.824294D - 0.314d + (7.25361\times10^{-6})v \\ -\,(72.3117\times10^{-6})\Delta x + (107.035\times10^{-6})\Delta y \\ -\,0.0185406P^2 - (0)Py + (6.49822\times10^{-12})xy \end{cases}$$

The wind speed depends less on the latitude and longitude, and more on the change in latitude and longitude. Recall: $x = f(LAT, LON)$ and $y = g(LAT, LON)$

Predictions for hurricane Ivan Category 0:

Wind Speed	Model 2_0	Model 2
25	31.9	29.0
25	30.8	28.8
35	35.6	35.9
40	35.5	37.7
45	42.0	42.8
45	46.3	45.5
50	48.2	48.4
50	48.6	47.9
50	53.5	53.8
60	58.1	57.9
60	55.4	62.9
50	51.3	54.4
30	45.4	46.5
15	29.8	29.6
15	24.7	24.8
15	22.2	21.3
15	21.0	20.8
15	20.2	19.6
10	21.9	19.8
10	4.3	3.5
30	36.1	31.6
35	38.5	38.6
35	38.5	39.6
35	38.1	39.1
40	33.9	34.2
50	43.8	43.1
45	29.9	28.3
40	30.8	29.4
40	32.2	31.2
30	30.8	29.3
25	25.7	25.6
20	14.8	15.8

Table 3: Wind speed, predictions for model 2_0 and model 2

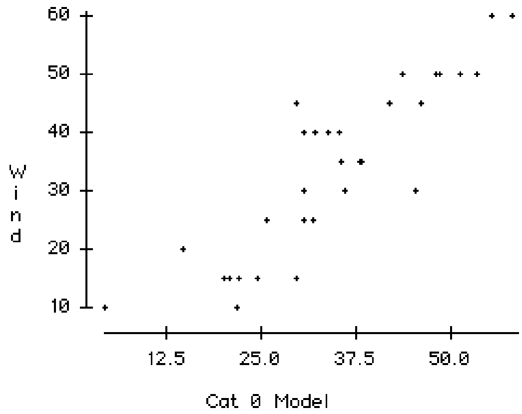


Figure 35: Scatter plot for model 2_0 and recorded wind speed

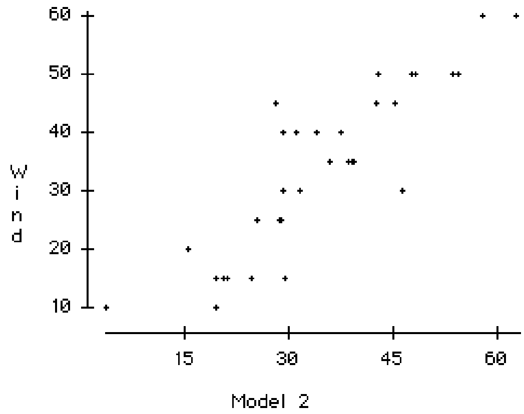


Figure 36: Scatter plot for model 2 and recorded wind speed

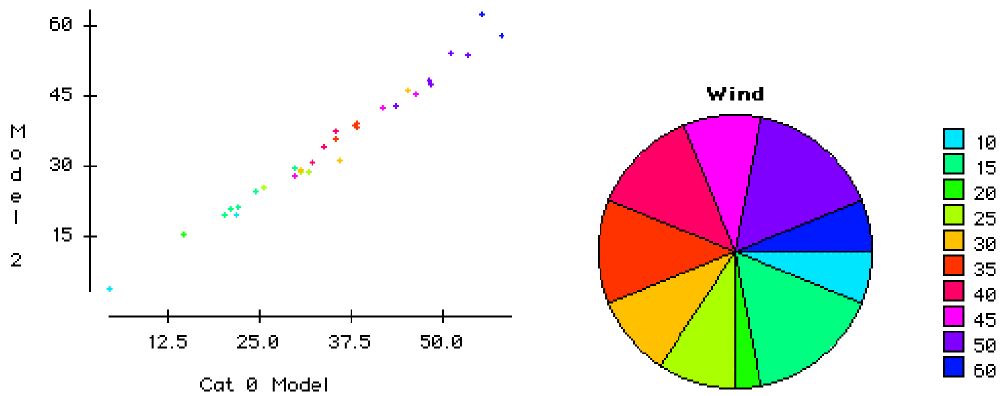


Figure 37: Scatter plot of predictions using model 2 versus model 2_0

We see these models are more concurrent for the lower wind speeds. As the wind speeds increase, there is more disparity between the two models, but are highly correlated with $R^2 = 98.1\%$ and $R^2_{adj} = 98.0\%$. Notice however, the recorded data is only measured in multiples of five.

Model 2_1: Model (2) for category one storms

Dependent variable is: **WIND**
No Selector
R squared = 64.7% R squared (adjusted) = 38.8%
s = 4.201 with 27 - 12 = 15 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	485.275	11	44.1159	2.5
Residual	264.725	15	17.6484	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	-19622.3	17.72e3	-1.11	0.2855
PRES	42.6571	35.07	1.22	0.2427
X	20.1088e-6	24.68e-6	0.815	0.4280
Y	292.832e-6	467.4e-6	0.627	0.5404
DURATION	-0.0226496	0.5501	-0.0412	0.9677
DAY	-0.290091	0.1548	-1.87	0.0805
VELOCITY	0	11.63e-6	0.107	0.9159
dX	-158.771e-6	122.3e-6	-1.3	0.2139
dY	156.542e-6	92.53e-6	1.69	0.1113
P^2	-0.0230542	0.01736	-1.33	0.2041
PxY	0	484.3e-9	-0.652	0.5243
XxY	0	4.733e-12	0.627	0.5401

Figure 38: Multiple regression including significant linear terms, a single quadratic term for pressure and significant interaction for category one only

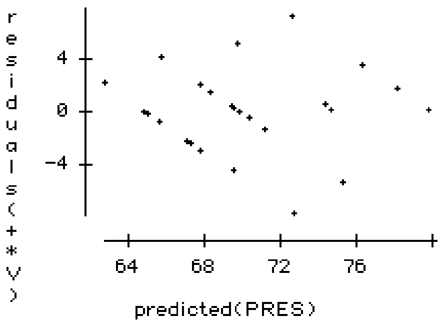


Figure 39: Residuals for model 2_1

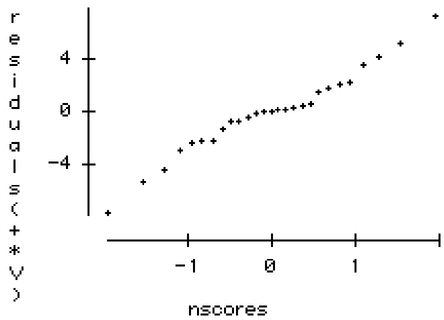


Figure 40: Normal probability plot for model 2_1

Predictions for hurricane Ivan Category 1

Wind	Model 2_1	Model 2
65	65.1	65.5
75	74.8	75.3
70	69.9	78.5
65	62.7	68.0

Table 4: Wind speed, predictions for model 2_1 and model 2

Model 2_2: Model (2) for category two storms

Dependent variable is: **WIND**
No Selector
R squared = 33.2%   R squared (adjusted) = 14.8%
s = 3.543 with 52 - 12 = 40 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	249.426	11	22.6751	1.81
Residual	502.016	40	12.5504	

Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	111.59	8147	0.0137	0.9891
PRES	-5.30602	16.66	-0.319	0.7518
X	-10.7958e-6	24.69e-6	-0.437	0.6643
Y	-922.941e-6	648.4e-6	-1.42	0.1624
DURATION	0.666278	0.6873	0.969	0.3382
DAY	-0.0945513	0.08259	-1.14	0.2591
VELOCITY	0	4.536e-6	0.148	0.8832
dX	12.5431e-6	25.57e-6	0.491	0.6264
dY	-19.0285e-6	40.53e-6	-0.469	0.6413
P^2	0.00550897	0.00896	0.615	0.5421
PxY	958.897e-9	681.8e-9	1.41	0.1673
XxY	0	4.259e-12	-0.526	0.6016

Figure 41: Multiple regression including significant linear terms, a single quadratic term for pressure and significant interaction for category two only

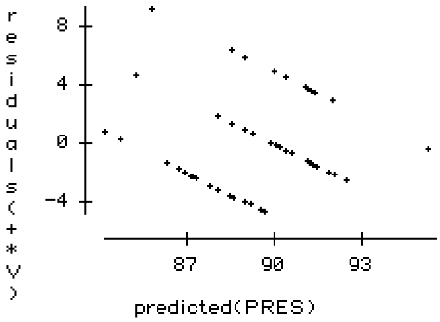


Figure 42: Residuals for model 2_2

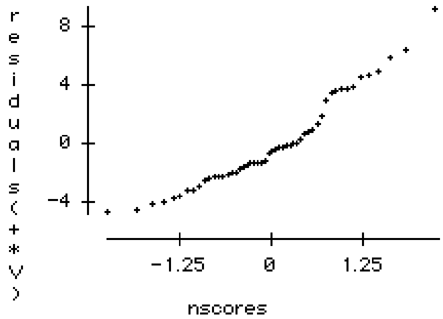


Figure 43: Normal probability plot for model 2_2

Predictions for hurricane Ivan Category 2:

Wind	Model 2_2	Model 2
90	92.5	93.4
90	91.5	98.3
90	91.4	99.1
90	91.3	96.6
95	92.0	95.2

Table 5: Wind speed, predictions for model 2_2 and model 2

Model 2_3: Model (2) for category three storms

Dependent variable is: **WIND**
No Selector
48 total cases of which 1 is missing
R squared = 67.1% R squared (adjusted) = 56.7%
s = 2.796 with 47 - 12 = 35 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	557.164	11	50.6513	6.48
Residual	273.687	35	7.81962	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	-2491.58	5300	-0.47	0.6412
PRES	7.52938	10.4	0.724	0.4738
X	-20.898e-6	10.64e-6	-1.96	0.0574
Y	281.317e-6	203.9e-6	1.38	0.1765
DURATION	-0.758989	0.3681	-2.06	0.0467
DAY	0.182453	0.04165	4.38	0.0001
VELOCITY	0	2.464e-6	-0.559	0.5797
dX	-15.621e-6	23.26e-6	-0.672	0.5062
dY	0	28.16e-6	0.348	0.7299
P^2	-0.00499804	0.005097	-0.981	0.3335
PxY	0	217e-9	-1.29	0.2071
XxY	-4.16168e-12	1.89e-12	-2.2	0.0343

Figure 44: Multiple regression including significant linear terms, a single quadratic term for pressure and significant interaction for category three only

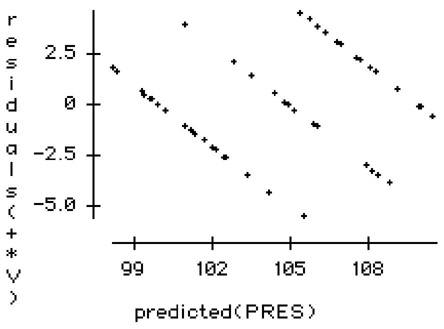


Figure 45: Residuals for model 2_3

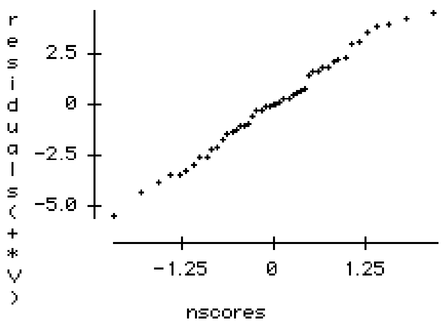


Figure 46: Normal probability plot for model 2_3

Predictions for hurricane Ivan Category 3:

Wind	Model 2_3	Model 2
100	102.5	107.9
110	110.5	118.8
110	110.0	116.6
110	110.0	116.6
110	107.6	109.1
100	98.1	93.0
100	102.2	100.1
100	102.1	99.2
105	105.0	108.4
105	105.2	107.4
100	99.3	101.7

Table 5: Wind speed, predictions for model 2_3 and model 2

Model 2_4: Model (2) for category four storms

Dependent variable is: **WIND**
No Selector
R squared = 75.3%   R squared (adjusted) = 72.4%
s = 3.521 with 106 - 12 = 94 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	3549.68	11	322.698	26
Residual	1165.41	94	12.398	

Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	2599.18	3005	0.865	0.3893
PRES	-2.75125	5.617	-0.49	0.6254
X	11.209e-6	10.1e-6	1.11	0.2698
Y	352.684e-6	177.8e-6	1.98	0.0502
DURATION	0.13329	0.1791	0.744	0.4585
DAY	-0.0434259	0.0395	-1.1	0.2744
VELOCITY	-14.0169e-6	3.992e-6	-3.51	0.0007
dX	-137.429e-6	23.99e-6	-5.73	≤ 0.0001
dY	56.9414e-6	51.36e-6	1.11	0.2704
P^2	45.1686e-6	0.002607	0.0173	0.9862
PxY	-388.73e-9	193.6e-9	-2.01	0.0475
XxY	0	1.764e-12	0.746	0.4574

Figure 47: Multiple regression including significant linear terms, a single quadratic term for pressure and significant interaction for category four only

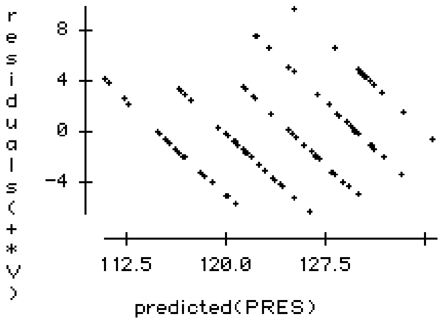


Figure 48: Residuals for model 2_4

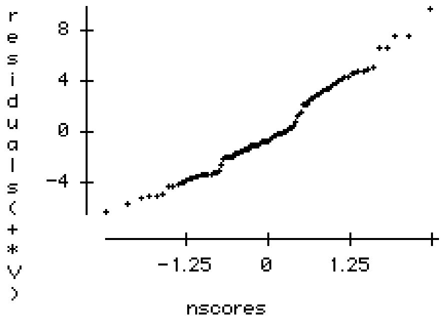


Figure 49: Normal probability plot for model 2_4

Predictions for hurricane Ivan Category 4:

Wind	Model 2_4	Model 2	Wind	Model 2_4	Model 2
115	112.8	120.8	130	129.8	135.8
115	112.7	121.0	125	128.9	132.8
115	111.1	122.1	125	130.0	135.6
115	118.2	111.5	135	131.0	139.7
115	118.5	113.0	135	130.5	138.9
115	120.8	118.8	135	130.3	137.4
120	120.9	117.5	130	129.6	139.5
120	117.0	108.2	130	131.0	140.7
120	117.5	108.7	130	131.3	140.1
120	120.7	116.9	135	125.2	129.1
120	121.6	117.6	120	122.5	121.3
125	124.8	125.5	120	123.6	124.6
125	125.4	126.2	120	123.0	124.8
130	132.0	138.7	120	124.3	127.7
130	131.0	134.3	120	122.0	121.3
130	131.2	137.4	120	120.7	119.7
125	128.3	131.3	120	119.6	117.8
125	128.2	130.0	120	116.7	113.4
125	127.1	128.6	115	116.3	112.7
125	126.5	126.5	115	116.9	112.1
125	125.0	126.6	115	118.4	117.0
120	125.2	124.0	115	115.7	116.6
130	129.2	132.2	115	118.4	113.9
135	131.2	137.9	115	114.9	112.8
135	130.3	137.0	115	112.3	109.4
130	130.0	139.7	115	110.7	102.1

Table 6: Wind speed, predictions for model 2_4 and model 2

Model 2_5: Model (2) for category five storms

Dependent variable is: **WIND**
No Selector
R squared = 64.6%   R squared (adjusted) = 54.0%
s = 2.598 with 49 - 12 = 37 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	455.334	11	41.394	6.13
Residual	249.768	37	6.75049	

Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	5137.17	5195	0.989	0.3291
PRES	-8.46967	9.611	-0.881	0.3839
X	18.0895e-6	21.7e-6	0.834	0.4098
Y	345.174e-6	339.6e-6	1.02	0.3160
DURATION	-0.0911814	0.3668	-0.249	0.8050
DAY	-0.0905694	0.08101	-1.12	0.2707
VELOCITY	0	9.017e-6	0.0812	0.9357
dX	-80.443e-6	53.05e-6	-1.52	0.1379
dY	-90.4121e-6	88.89e-6	-1.02	0.3157
P^2	0.00324754	0.004387	0.74	0.4638
PxY	0	370.5e-9	-1.05	0.3018
XxY	0	3.875e-12	0.903	0.3724

Figure 50: Multiple regression including significant linear terms, a single quadratic term for pressure and significant interaction for category five only

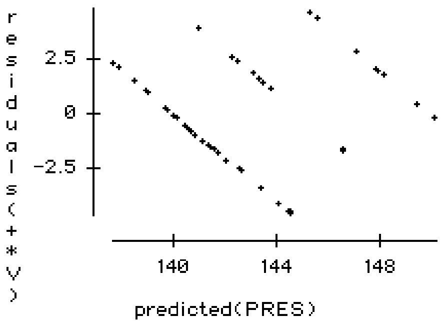


Figure 51: Residuals for model 2_5

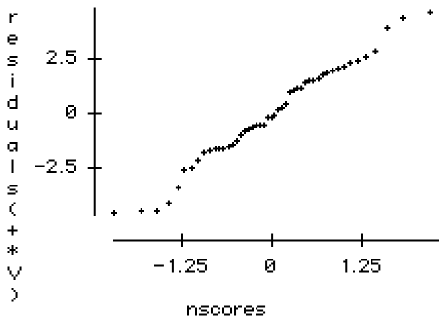


Figure 52: Normal probability plot for model 2_5

Predictions for hurricane Ivan Category 5:

Wind	Model 2_5	Model 2
140	137.6	133.7
140	139.7	138.6
140	142.7	143.1
140	142.6	142.4
140	140.9	138.7
145	141.1	141.3
145	143.1	143.3
145	142.3	143.6
145	143.5	145.1
140	142.1	140.0
140	140.5	136.2
140	141.2	138.0
140	139.7	135.2
140	141.5	139.6
140	141.4	140.7
140	140.5	141.1
140	140.2	138.6
140	140.7	140.3
140	137.8	132.5
140	140.0	132.4

Table 7: Wind speed, predictions for model 2_5 and model 2

Comparison of model 2 predictions and the sub-models 2_i predictions in union

First, consider the general model II (2) versus the wind speed; 97.1% of the variation in the wind speed is explained by the least square regression of model (2) (as shown in Figure 53) whereas 98.9% of the variation in the wind speed is explained by the conditional model (2_i) (shown in Figure57).

Model (2) versus reported wind speed

Dependent variable is: **WIND**
No Selector
402 total cases of which 5 are missing
R squared = 97.1%   R squared (adjusted) = 97.0%
s = 6.742 with 397 - 2 = 395 degrees of freedom

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**
Regression	591621	1	591621	13e3
Residual	17954.5	395	45.4544	

Variable	**Coefficient**	**s.e. of Coeff**	**t-ratio**	**prob**
Constant	-0.0010708	0.8648	-0.00124	0.9990
Model 2	1.00001	0.008765	114	≤ 0.0001

Figure 53: Simple linear regression to compare predicted values using model 2 to that of the actual wind speed

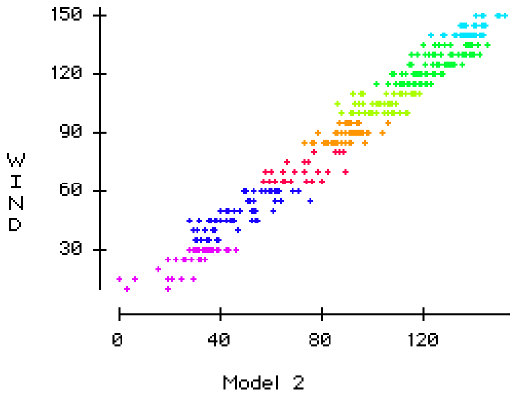


Figure 54: Scatter plot of predicted values using model 2 and the recorded wind speed

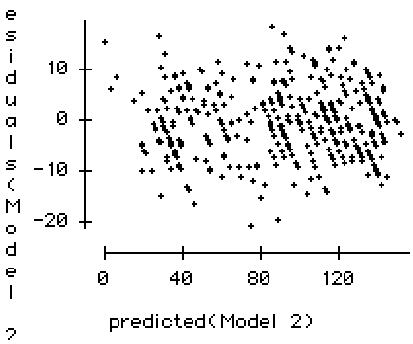


Figure 55: Residuals for model 2

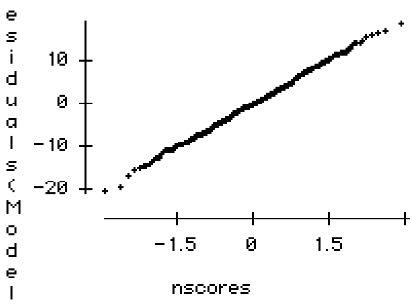


Figure 56: Normal probability plot for model 2

Model (2_{union}) versus reported wind speed

Dependent variable is: **WIND**
No Selector
402 total cases of which 5 are missing
R squared = 98.9% R squared (adjusted) = 98.9%
s = 4.035 with 397 - 2 = 395 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	603144	1	603144	37e3
Residual	6430.73	395	16.2803	

Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	-27.5328e-6	0.5133	-53.6e-6	1.0000
Model 2_	1	0.005195	192	≤ 0.0001

Figure 57: Simple linear regression to compare predicted values using model 2_i in union to that of the actual wind speed

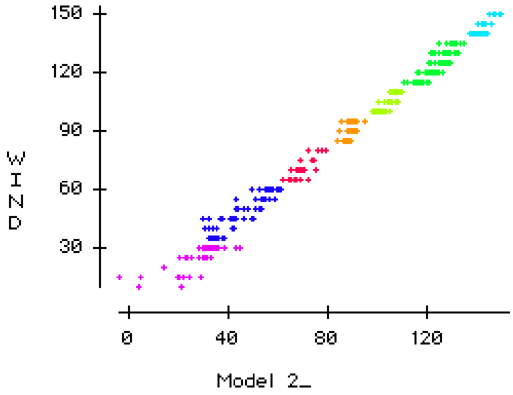


Figure 58: Scatter plot of predicted values using model 2_i in union and the recorded wind speed

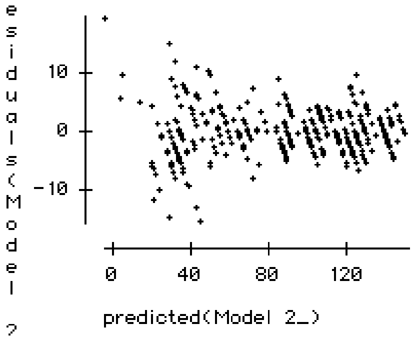


Figure 59: Residuals for model 2_i in union

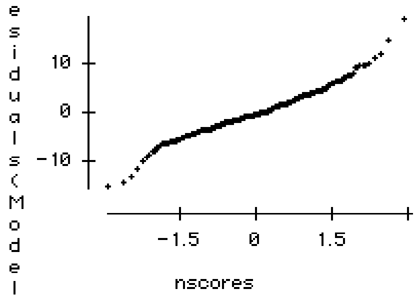


Figure 60: Normal probability plot for model 2_i in union

Notice there is significantly less error in the scatter plot for the model formed using the individually formulated using models 2_i in union. However there is almost the same error for tropical storms. Therefore our models are more reliable for predicting the wind speeds of hurricane category storms and less reliable for category zero storms; that is, this model is less reliable in predicting tropical storms and depressions. By considering one model over all categories over a model generated by six individual models for each category we loss 1.8% of the explanation.

Model 2_{0w}: Model (2) for category winds measured less than or equal to w

In analyzing the various categories, the question becomes when should we adjust the coefficients in our model to better predict the wind speeds in an ever-changing environment.

Consider the sequential model 2_{ij} where i is the category of storm and j is the maximum wind speed included in the model starting with tropical depressions.

Minimum Wind Speed	Maximum Wind Speed	Category	R^2	R^2_{adj}
0	***30***	***TD***	***74.5%***	***38.3%***
0	35	TD,TS	61.6%	54.4%
0	40	TD,TS	57.6%	50.6%
0	45	TD,TS	52.0%	45.9%
0	50	TD,TS	60.4%	56.1%
35	45	TS	57.3%	41.3%
35	50	TS	60.5%	52.0%
35	55	1	71.5%	65.7%
35	60	1	78.7%	77.5%
35	65	1	81.1%	78.6%
35	***70***	***TS,1***	***84.3%***	***82.5%***
35	75	1	80.1%	77.9%
35	80	1	81.7%	79.8%
65	80	1	55.5%	31.9%
65	85	1,2	58.2%	47.8%
65	90	1,2	65.2%	60.4%
65	95	1,2	66.8%	62.4%
65	100	1,3	73.5%	70.8%
65	105	1,3	74.8%	72.6%
65	110	1,3	78.6%	77.0%
65	115	1,4	83.2%	82.1%
65	120	1,4	85.2%	84.4%
65	125	1,4	86.7%	86.1%
65	130	1,4	88.5%	88.0%
65	135	1,4	88.9%	88.5%
65	140	1,5	90.6%	90.3%
65	145	1,5	91.0%	90.7%
65	*150*	*1,5*	*91.5%*	*91.3%*
70	**155**	**1,5**	**90.4%**	**90.1%**
75	155	1,5	89.8%	89.4%
0	63	0	81.8%	79.8%
64	82	1	64.7%	38.8%
83	95	2	33.2%	14.8%
96	112	3	67.1%	56.7%
113	135	4	75.0%	72.4%
136	-----	5	64.6%	54.0%

Table 9: Regression for various intervals of wind speeds

Results and Interpretations (Discussion)

Statistically, with just a few prior pieces of information, we can estimate with high degree of accuracy the associated wind speed; that is, our model explains 97.1% of the variation in the in the wind speed. Some of the secondary result, estimating the coefficients for the various categories may need to be re-evaluated since it has be shown that the Saffir-Simpson scale does not categories hurricane force winds appropriately according to significant changes in the pressure. Reclassification of the categories might yield a better fitting model when regressed categorically. Furthermore, coupling physics with statistics should produce a much more reliable model; however, categories aside, the non-linear statistical model develop can still be used to more accurately estimate the intensity of a storm.

Conclusion

With the present day technology and the historical data now readily available, hurricane prediction will become more accurate in the near future. This model predicts the intensity of the storm, now we need to address the issues of direction and duration and how this relates to the intensity. The spaghetti string models, averaged and used to make the cone shaped predictions and forecast as new information is gathered, can be adjust to be more accurate or simply replaced my stochastic systems developed by statisticians working with meteorologist.

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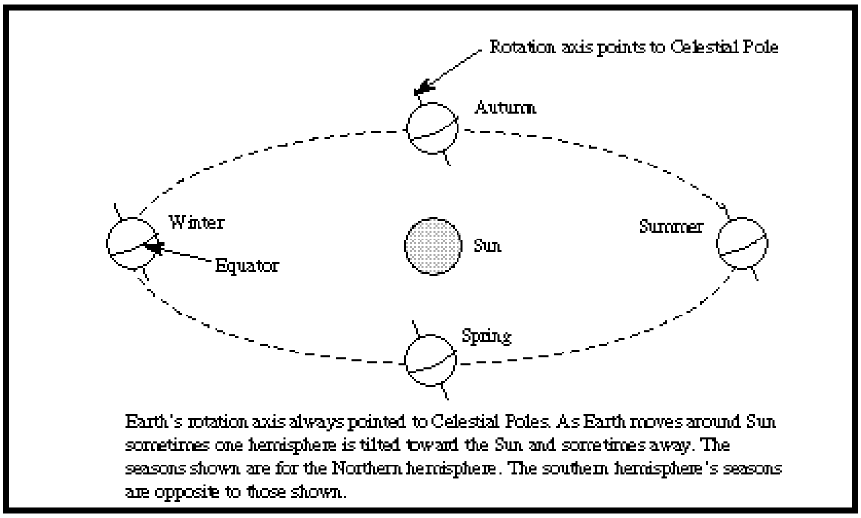
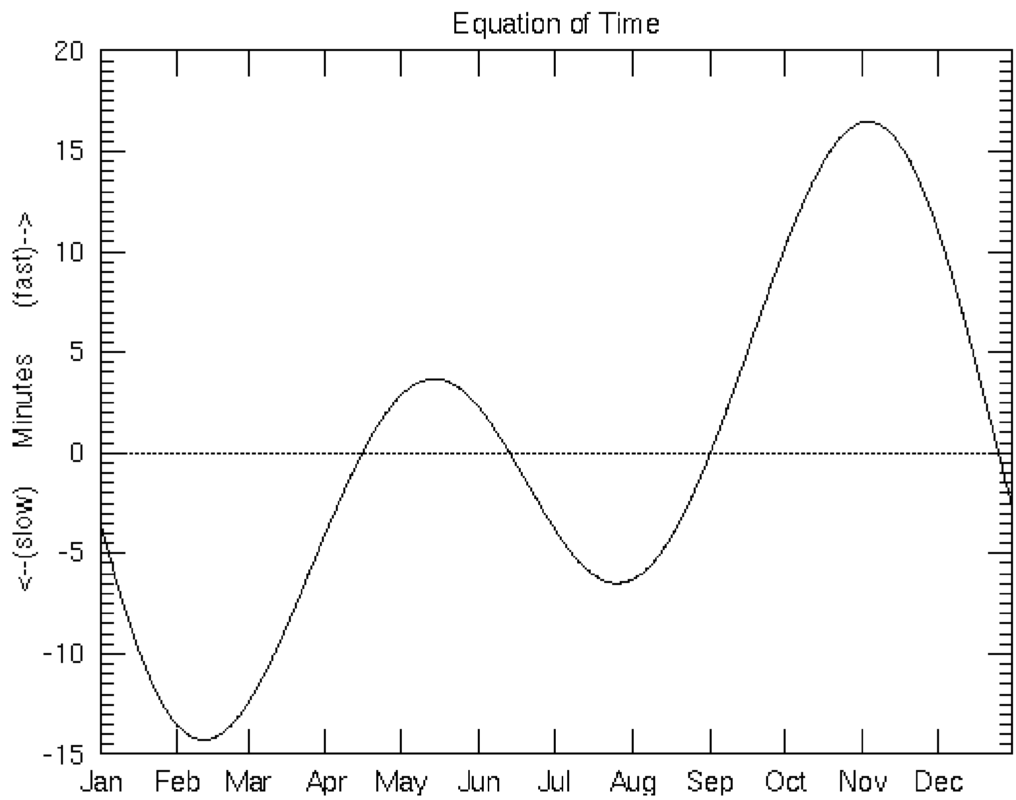
Appendix A: Celestial Rotations





Images by Nick Strobel, Bakersfield College, Physical Science Department, Bakersfield, CA. Website: http://www.star.ucl.ac.uk/~idh/STROBEL/book.htm