Generalization of the Holland Parametric Tropical Cyclone Model for Forecast Applications

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14th International Workshop on Wave Hindcasting and Forecasting / 5th Coastal Hazards Symposium / 2nd International Storm Surge Symposium

Key West, FL, November 9, 2015

Goal

Hurricane Irene Advisory 23

ZCZC MIATCMAT4 ALL
TTAA00 KNHC DDHHMM

HURRICANE IRENE FORECAST/ADVISORY NUMBER 23
NWS NATIONAL HURRICANE CENTER MIAMI FL
AL092011 **0300 UTC FRI AUG 26 2011**

.... more data ....

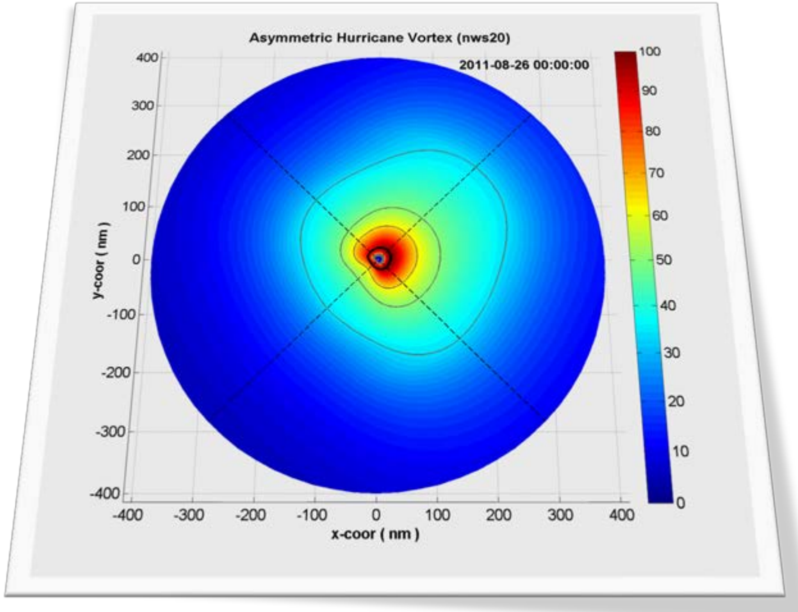
HURRICANE CENTER LOCATED NEAR **28.3N 767.3W AT 26/0300Z**
POSITION ACCURATE WITHIN 15 NM

PRESENT MOVEMENT TOWARD THE NORTH OR 350 DEGREES AT 12 KT

ESTIMATED MINIMUM CENTRAL PRESSURE **942MB**
EYE DIAMETER 25 NM
MAX SUSTAINED WINDS **100 KT** WITH GUSTS TO 120 KT.
64 KT....... 70NE 60SE 25SW 50NW.
50 KT.......110NE 100SE 50SW 75NW.
34 KT.......250NE 200SE 125SW 160NW.
12 FT SEAS..330NE 300SE 120SW 270NW.
WINDS AND SEAS VARY GREATLY IN EACH QUADRANT. RADII IN NAUTICAL
MILES ARE THE LARGEST RADII EXPECTED ANYWHERE IN THAT QUADRANT.

.... more data ....

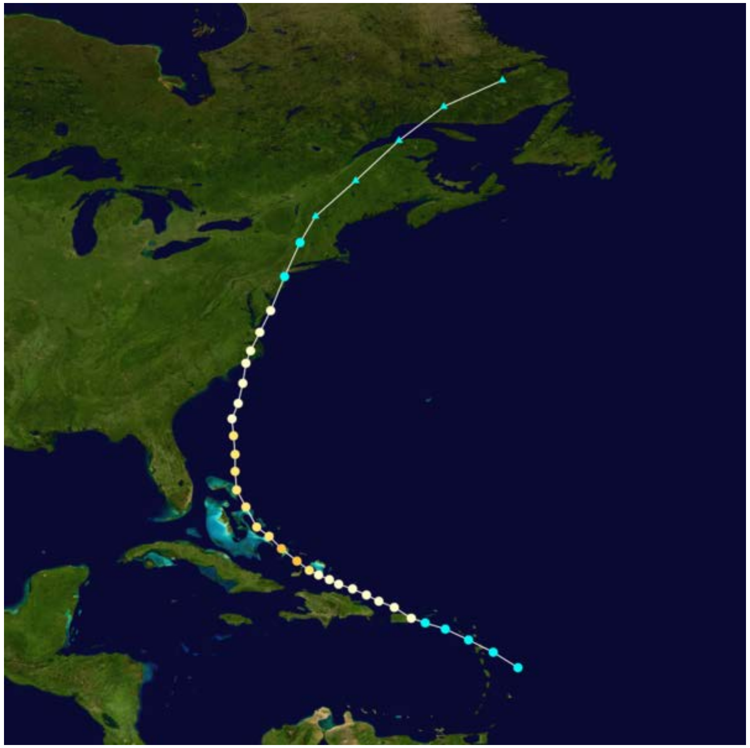
Wind Model for storm surge / wave forecasts



Advisory Information

Tropical cyclone storm parameters provided in NHC ATCF Best Track or Forecast Advisories

<u>Every 6 hours</u>



lon, lat of center of eye ➡ V_{trans}

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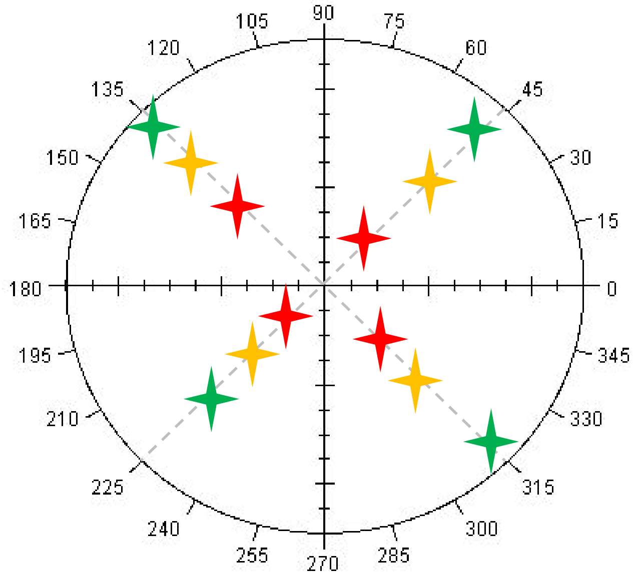
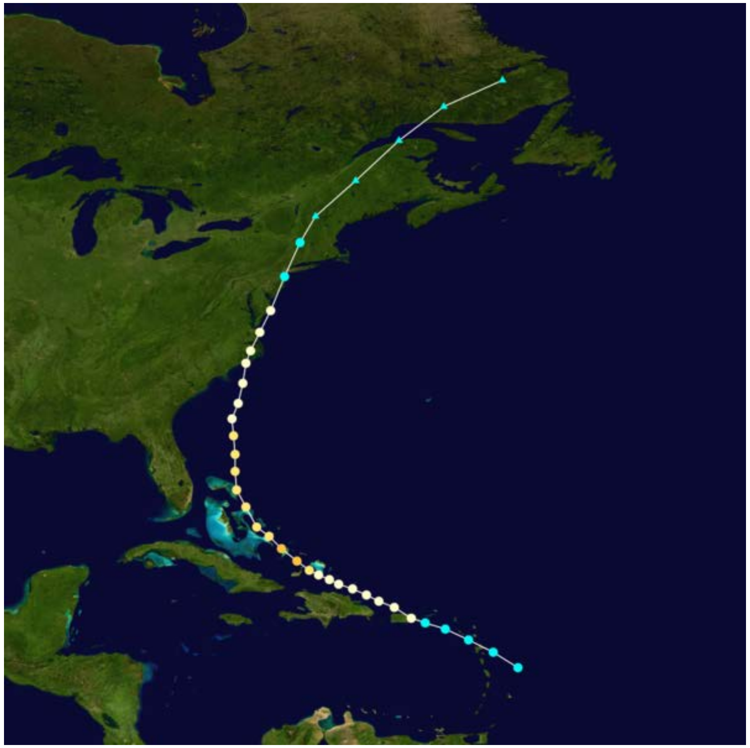
<u>Every 6 hours</u>

V_{max}

R_{64} R_{50} R_{34}



R_{max} - not given in Forecast Advisories



lon, lat of center of eye ➡ V_{trans}

Radial Pressure / Wind Profile (Holland 1980)

Hyperbolic hurricane pressure profile (Schloemer 1954):

$$P(r) = P_c + (P_n - P_c)e^{-A/r^B} \qquad (1)$$

Gradient wind equation

$$\frac{{V_g}^2}{r} + fVg - \frac{1}{\rho_0}\frac{\partial p}{\partial r} = 0 \qquad (2)$$

Substitute (1) into the gradient wind equations, the gradient wind velocity is:

$$V_g(r) = \sqrt{AB(P_n - P_c)e^{-A/r^B}/\rho r^B + \left(\frac{rf}{2}\right)^2} - \left(\frac{rf}{2}\right) \qquad (3)$$

Radial Pressure / Wind Profile (Holland 1980)

To derive relationships for scaling parameters A, B assume @ $r = R_{max}$

- $V_g = V_{max}$
- $dV_g/dr = 0$
- cyclostrophic wind balance $R_o = V_{max}/f\,R_{max} >> 1$

Radial Pressure / Wind Profile (Holland 1980)

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- $V_g = V_{max}$
- $dV_g/dr = 0$
- cyclostrophic wind balance $R_o = V_{max}/f\,R_{max} >> 1$

$$A = R_{max}{}^{B} \qquad (4)$$

Holland "*B*" $\quad B = V_{max}^2\,\rho e/(P_n - P_c) \qquad (5)$

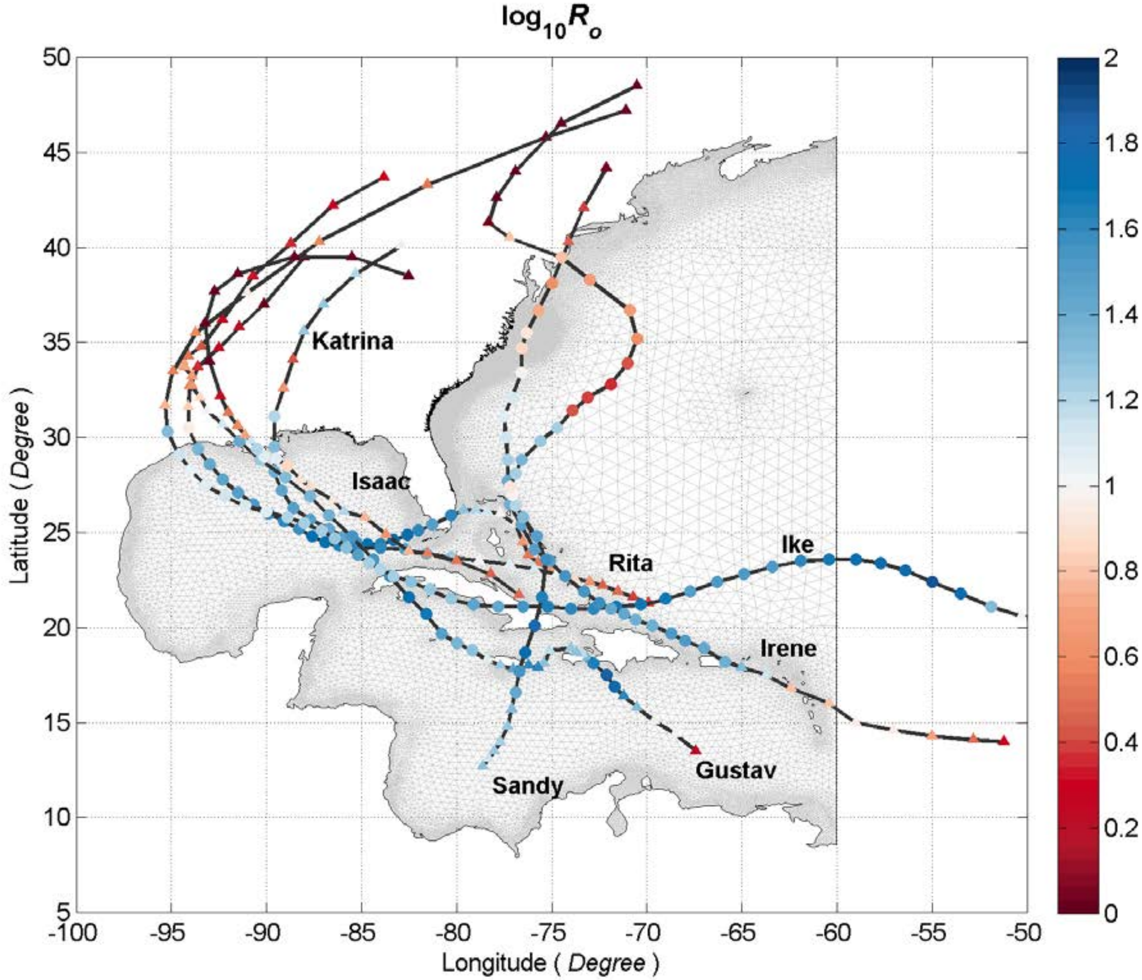
Substitute Eqs. (4) & (5) into Eqs. (1) & (3) - final Holland equations:

$$P(r) = P_c + (P_n - P_c)e^{-(R_{max}/r)^B} \qquad (6)$$

$$V_g(r) = \sqrt{V_{max}^2 e^{(1-(R_{max}/r)^B)}(R_{max}/r)^B + \left(\frac{rf}{2}\right)^2} - \left(\frac{rf}{2}\right) \qquad (7)$$

$\log_{10} R_o$

$R_o = V_{max} / f R_{max}$



Generalized Holland Wind Model

Hyperbolic hurricane pressure profile (Schloemer 1954):

$$P(r) = P_c + (P_n - P_c)e^{-A/r^B} \qquad (1)$$

Gradient wind equation

$$\frac{{V_g}^2}{r} + fVg - \frac{1}{\rho_0}\frac{\partial p}{\partial r} = 0 \qquad (2)$$

Substitute (1) into the gradient wind equations, the gradient wind velocity is:

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Generalized Holland Wind Model

To derive relationships for scaling parameters A, B assume @ $r = R_{max}$

- $V_g = V_{max}$
- $dV_g/dr = 0$

NO ASSUMPTION ON R_o

Generalized Holland Wind Model

To derive relationships for scaling parameters A, B assume @ $r = R_{max}$

- $V_g = V_{max}$
- $dV_g/dr = 0$

NO ASSUMPTION ON R_o

$$A = \varphi {R_{max}}^{B} \qquad (4)$$

Generalized Holland "B_g"

$$B_g = B\,\frac{(1 + 1/R_0)e^{\varphi - 1}}{\varphi} \qquad (5)$$

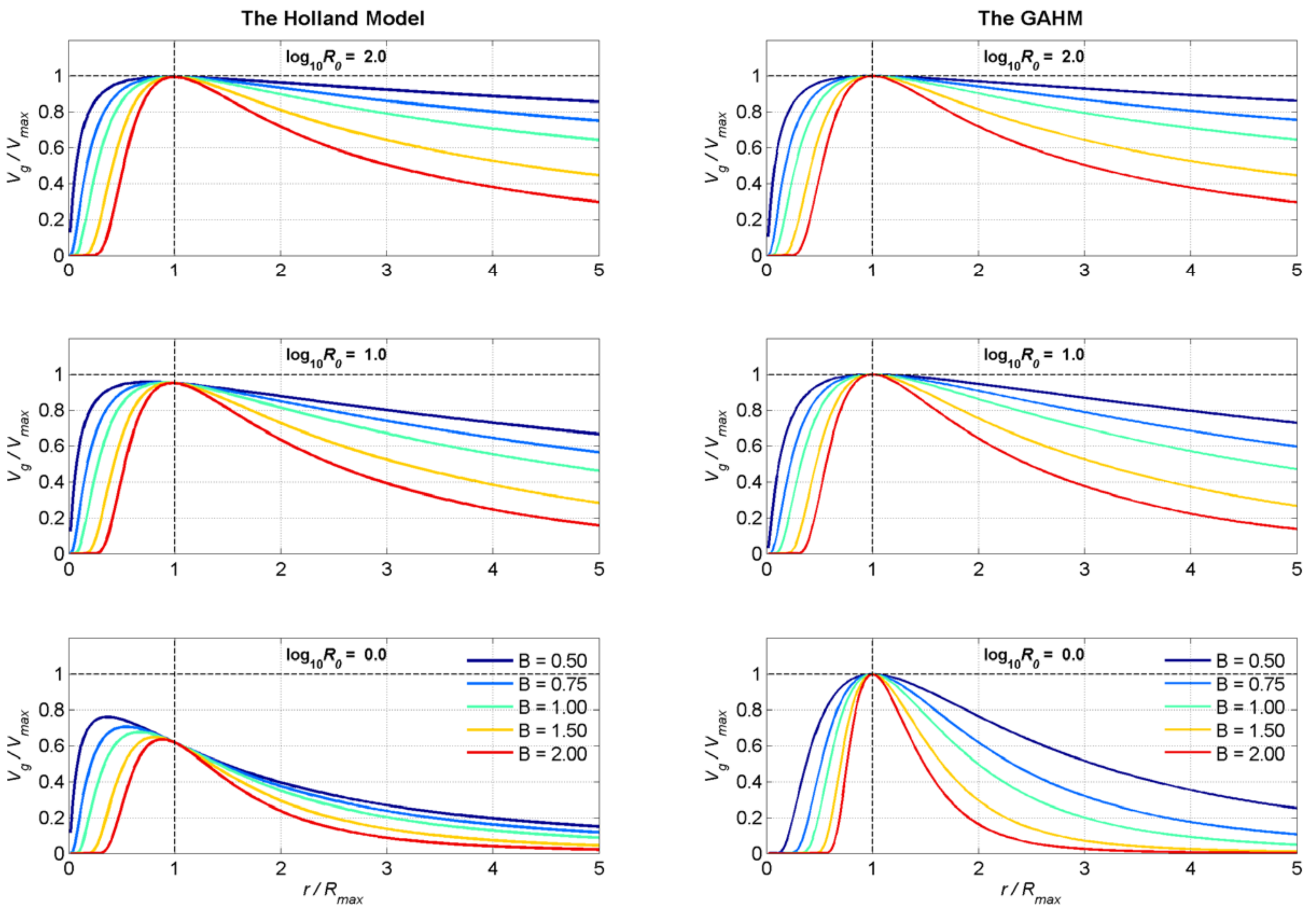
where $B = V_{max}^2\,\rho e/(P_n - P_c)$ $\qquad \varphi = 1 + \frac{1/R_o}{B_g(1+1/R_o)}$

Substitute Eqs. (4) & (5) into Eqs. (1) & (3) - Generalized Holland equations:

$$P(r) = P_c + (P_n - P_c)e^{-\varphi (R_{max}/r)^{B_g}} \qquad (6)$$

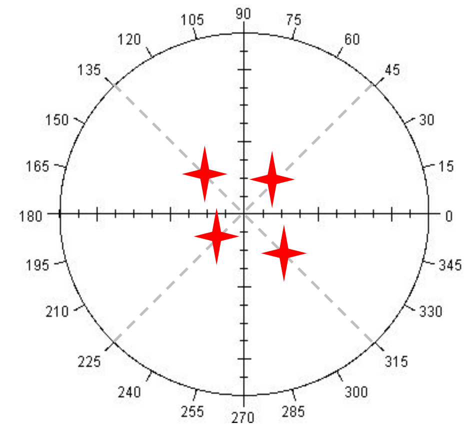
$$V_g(r) = \sqrt{V_{max}^2 (1 + 1/Ro)e^{\varphi(1-(R_{max}/r)^{B_g})}(R_{max}/r)^{B_g} + \left(\frac{rf}{2}\right)^2} - \left(\frac{rf}{2}\right) \qquad (7)$$

So What?


The Holland Model
The GAHM
$\log_{10}R_0 = 2.0$
$\log_{10}R_0 = 1.0$
$\log_{10}R_0 = 0.0$
V_g / V_{max}
r / R_{max}
B = 0.50
B = 0.75
B = 1.00
B = 1.50
B = 2.00

Asymmetric Holland Model (Xie et al 2006)

- Forecast Advisory don't know R_{max}
- Use $V_g = 64$ knots @ r=R_{64}, to solve for R_{max} in each storm quadrant (NE, NW, SW, SE)
- Interpolate R_{max} around storm → $R_{max}(\theta)$
- Doesn't use R_{50} , R_{35}



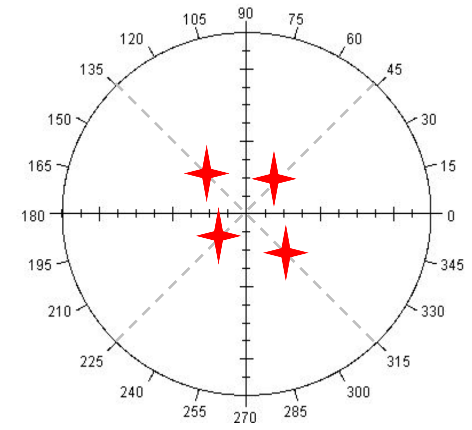
$$V_g(r,\theta) = \sqrt{V_{max}^2 e^{(1-(R_{max}/r)^B)}(R_{max}/r)^B + \left(\frac{rf}{2}\right)^2} - \left(\frac{rf}{2}\right)$$

$$B = V_{max}^2\, \rho e/(P_n - P_c)$$

$$P(r) = P_c + (P_n - P_c)e^{-(R_{max}/r)^B}$$

Generalized Asymmeyric Holland Wind Model - 1

- Forecast Advisory don't know R_{max}
- Use $V_g = 64$ knots @ r=R_{64}, to solve for R_{max} in each storm quadrant (NE, NW, SW, SE)
- Interpolate R_{max} around storm → $R_{max}(\theta)$



$$V_g(r,\theta) = \sqrt{V_{max}^2(1+1/Ro)e^{\varphi(1-(R_{max}/r)^{B_g})}(R_{max}/r)^{B_g} + \left(\frac{rf}{2}\right)^2} - \left(\frac{rf}{2}\right)$$

$$B_g = B\frac{(1+1/R_0)e^{\varphi-1}}{\varphi} \qquad \varphi = 1 + \frac{1/R_o}{B_g(1+1/R_o)}$$

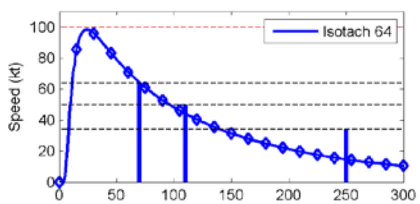
$$B = V_{max}^2\,\rho e/(P_n - P_c)$$

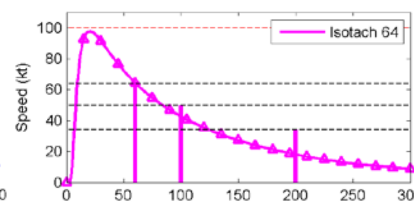
$$P(r) = P_c + (P_n - P_c)e^{-\varphi(R_{max}/r)^{B_g}}$$

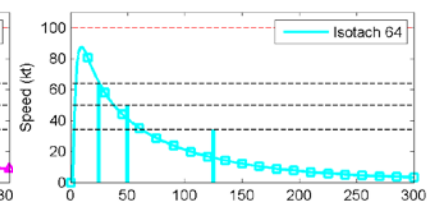
Radial Wind Profiles using R_{64}

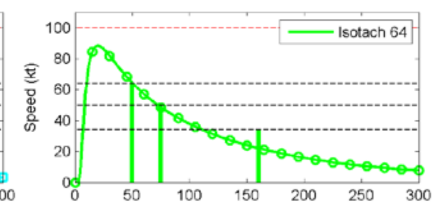
	NE	SE	SW	NW

Isot 64



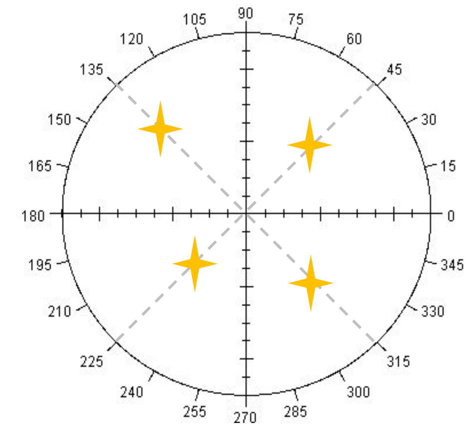






Generalized Asymmetric Holland Wind Model - 2

- Forecast Advisory don't know R_{max}
- Use $V_g = 50$ knots @ r=R_{50}, to solve for R_{max} in each storm quadrant (NE, NW, SW, SE)
- Interpolate R_{max} around storm → $R_{max}(\theta)$



$$V_g(r,\theta) = \sqrt{V_{max}^2(1 + 1/Ro)e^{\varphi(1-(R_{max}/r)^{B_g})}(R_{max}/r)^{B_g} + \left(\frac{rf}{2}\right)^2} - \left(\frac{rf}{2}\right)$$

$$B_g = B\frac{(1 + 1/R_0)e^{\varphi-1}}{\varphi} \qquad \varphi = 1 + \frac{1/R_o}{B_g(1+1/R_o)}$$

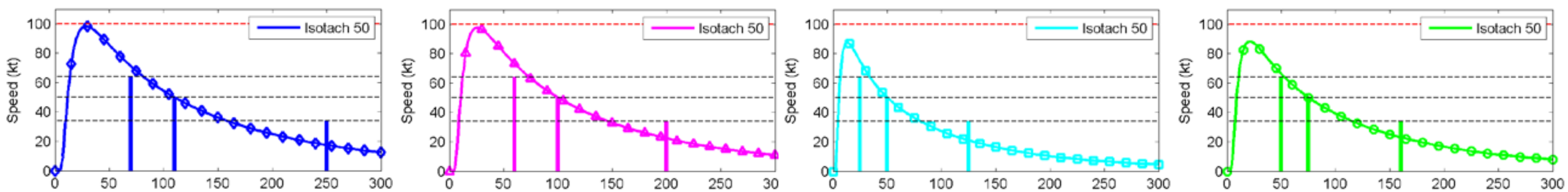
$$B = V_{max}^2\,\rho e/(P_n - P_c)$$

$$P(r) = P_c + (P_n - P_c)e^{-\varphi(R_{max}/r)^{B_g}}$$

Radial Wind Profiles using R_{50}

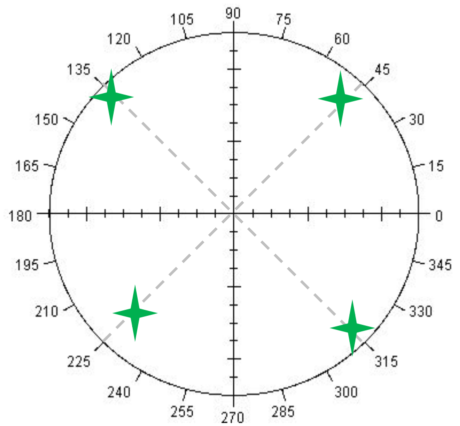
	NE	SE	SW	NW

Isot 50



Generalized Asymmetric Holland Wind Model - 3

- Forecast Advisory don't know R_{max}
- Use $V_g = 35$ knots @ r=R_{35}, to solve for R_{max} in each storm quadrant (NE, NW, SW, SE)
- Interpolate R_{max} around storm → $R_{max}(\theta)$



$$V_g(r,\theta) = \sqrt{V_{max}^2(1 + 1/Ro)e^{\varphi(1-(R_{max}/r)^{B_g})}(R_{max}/r)^{B_g} + \left(\frac{rf}{2}\right)^2} - \left(\frac{rf}{2}\right)$$

$$B_g = B\,\frac{(1 + 1/R_0)e^{\varphi - 1}}{\varphi} \qquad \varphi = 1 + \frac{1/R_o}{B_g(1+1/R_o)}$$

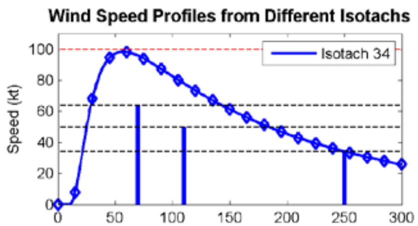
$$B = V_{max}^2\,\rho e/(P_n - P_c)$$

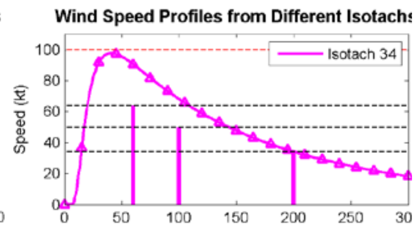
$$P(r) = P_c + (P_n - P_c)e^{-\varphi(R_{max}/r)^{B_g}}$$

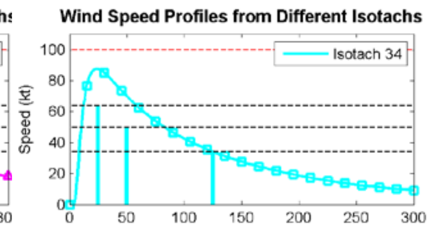
Radial Wind Profiles using R_{34}

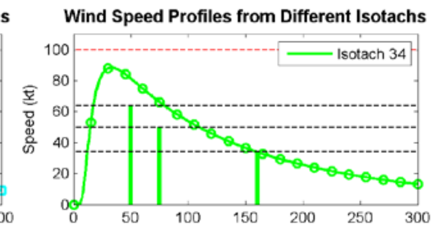
NE **SE** **SW** **NW**

Isot 34









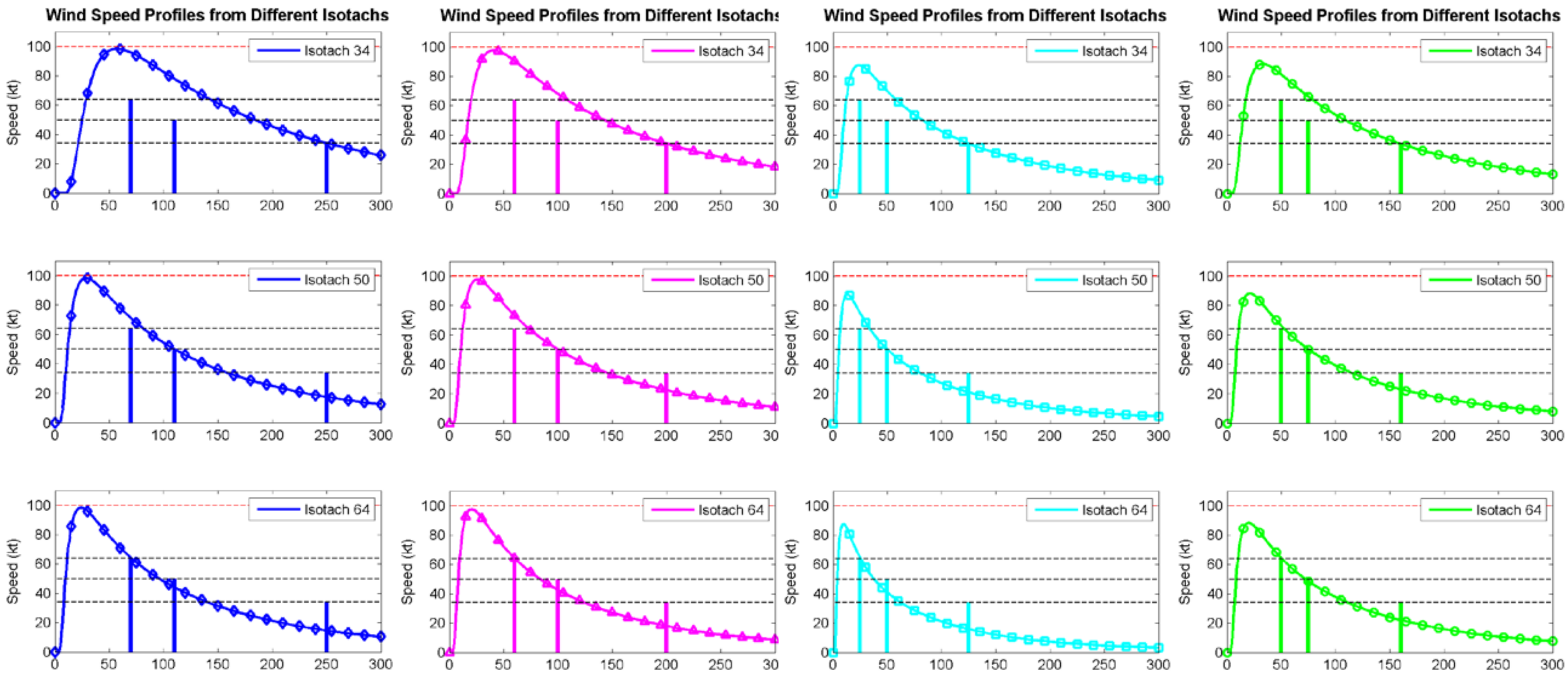
Summary of Radial Wind Profiles

NE SE SW NW

Isot 34

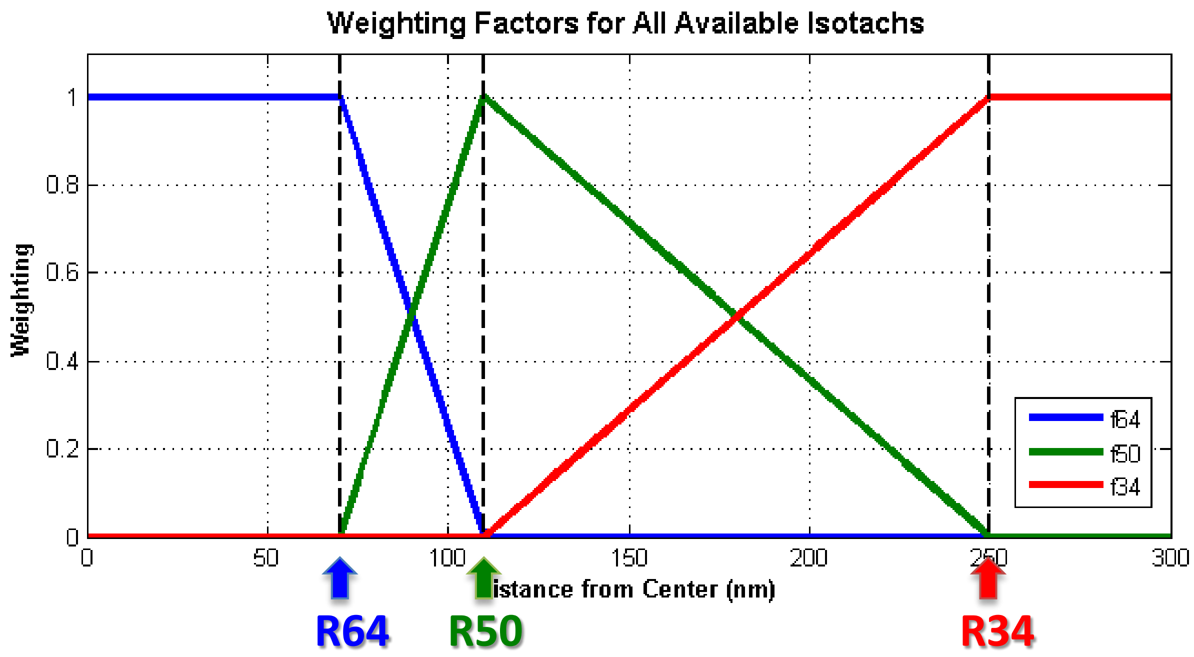
Isot 50

Isot 64



Weighted Composite Wind Field in GAHM

GAHM uses a linear weighting of parameter sets computed from all available isotachs in each quadrant.



GAHM Composited Radial Wind Profiles

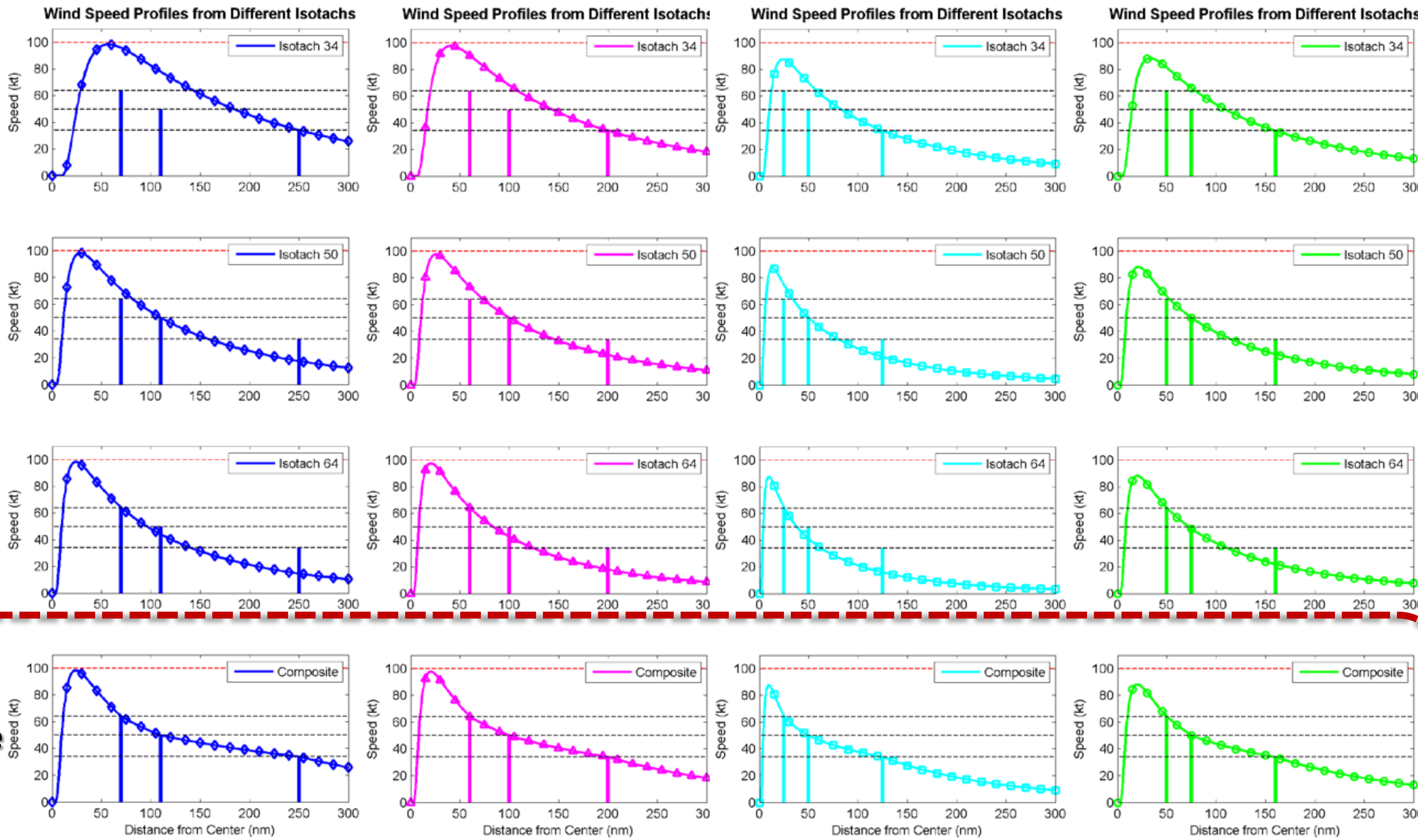
NE | **SE** | **SW** | **NW**

Isot 34

Isot 50

Isot 64

Composite

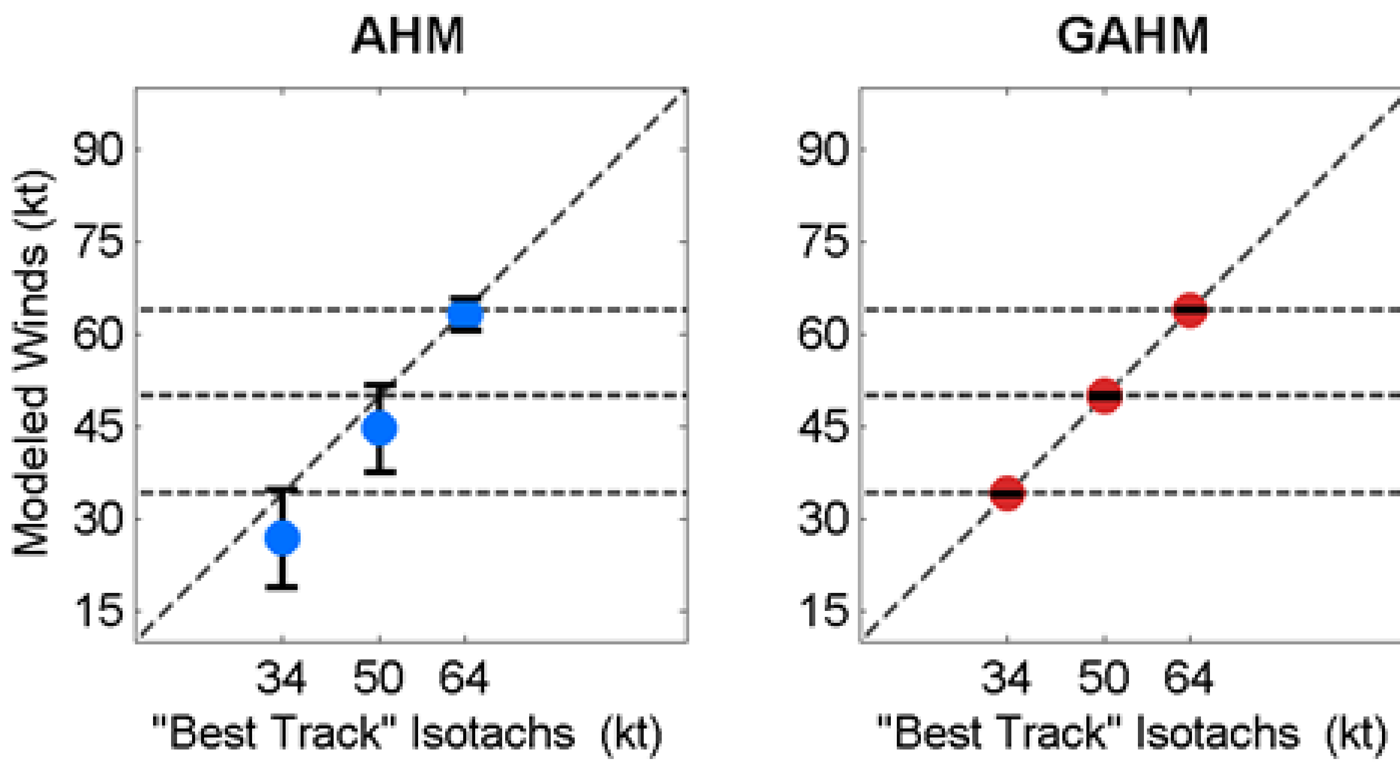


Validation

Use Best Track data for 7 storms (Does contain R_{max})

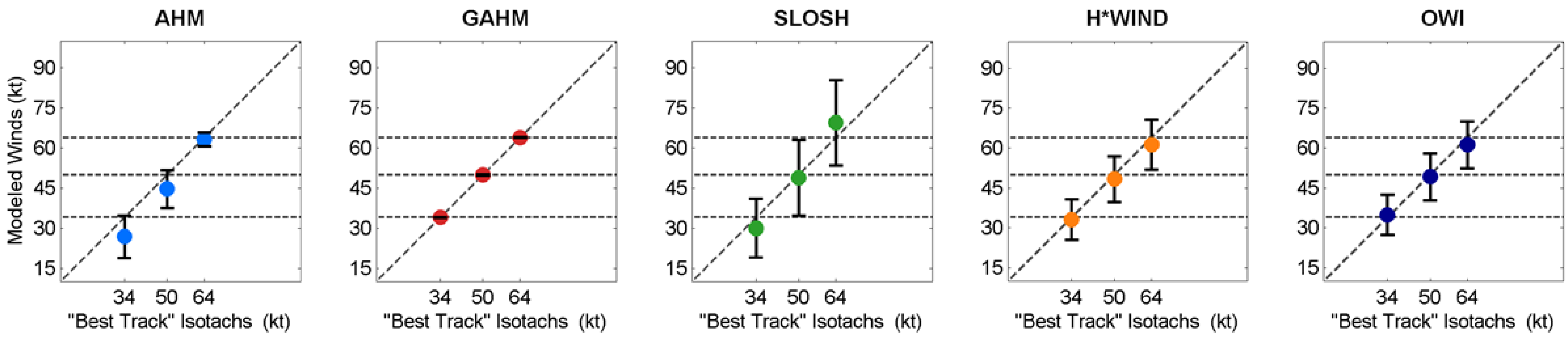
	Hurricane Category	Maximum Sustained Wind (kt)	Minimum Central Pressure (mbar)	Period Lasted Formed - Dissipated
Katrina	5	175	902	Aug 23, 2005 - Aug 30, 2005
Rita	5	180	895	Sep 18, 2005 - Sep 26, 2005
Gustav	4	155	941	Aug 23, 2008 - Sep 4, 2008
Ike	4	145	935	Sep 01, 2008 - Sep 14, 2008
Irene	3	120	942	Aug 21, 2011 - Aug 30, 2011
Isaac	1	80	965	Aug 21, 2012 - Sep 03, 2012
Sandy	3	115	940	Oct 22, 2012 - Oct 31, 2012

Validation



AHM
GAHM
Modeled Winds (kt)
90
75
60
45
30
15
34
50
64
"Best Track" Isotachs (kt)

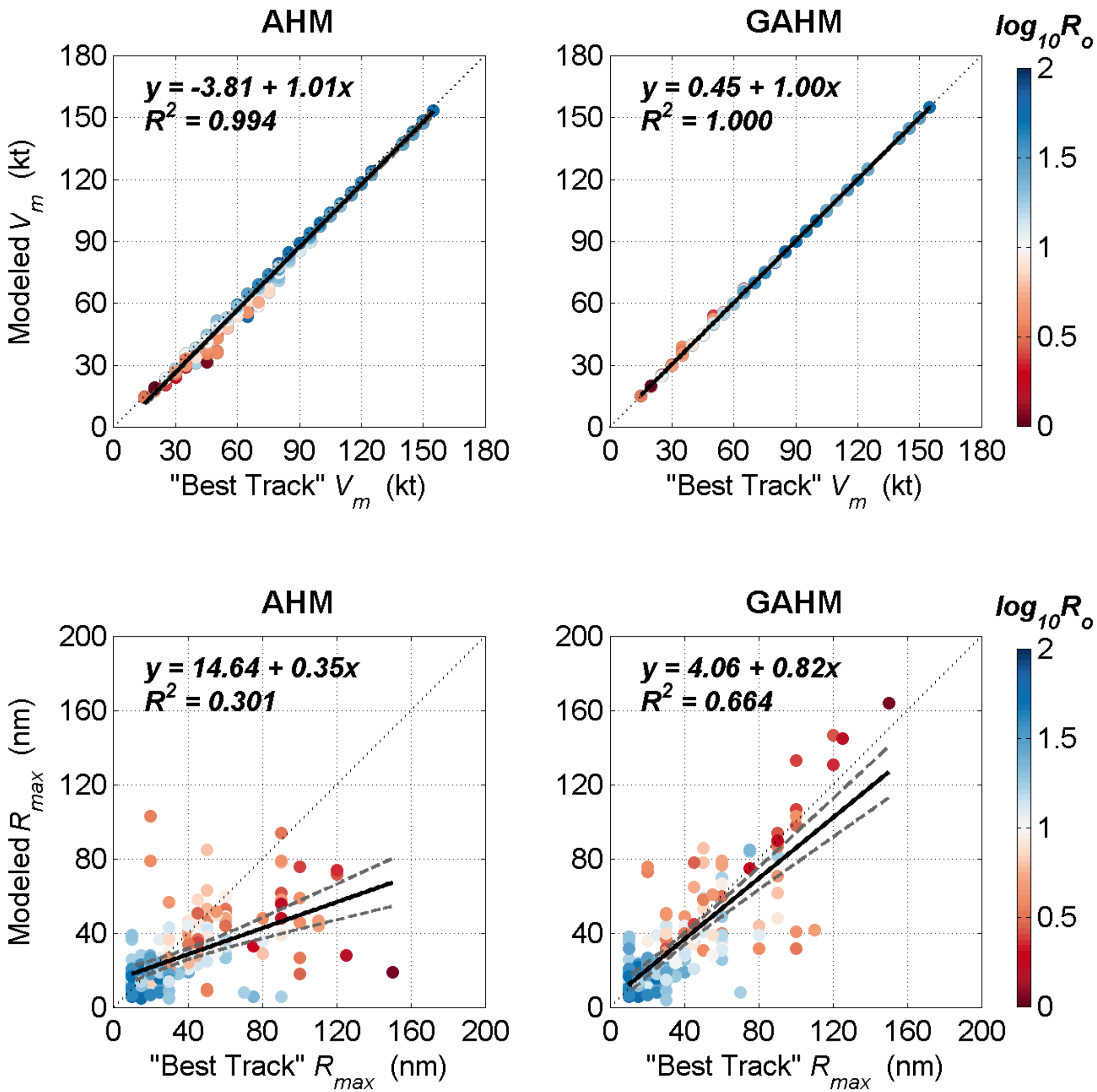
Validation



Statistical analysis of modeled winds at distances to all isotachs based on all seven storms

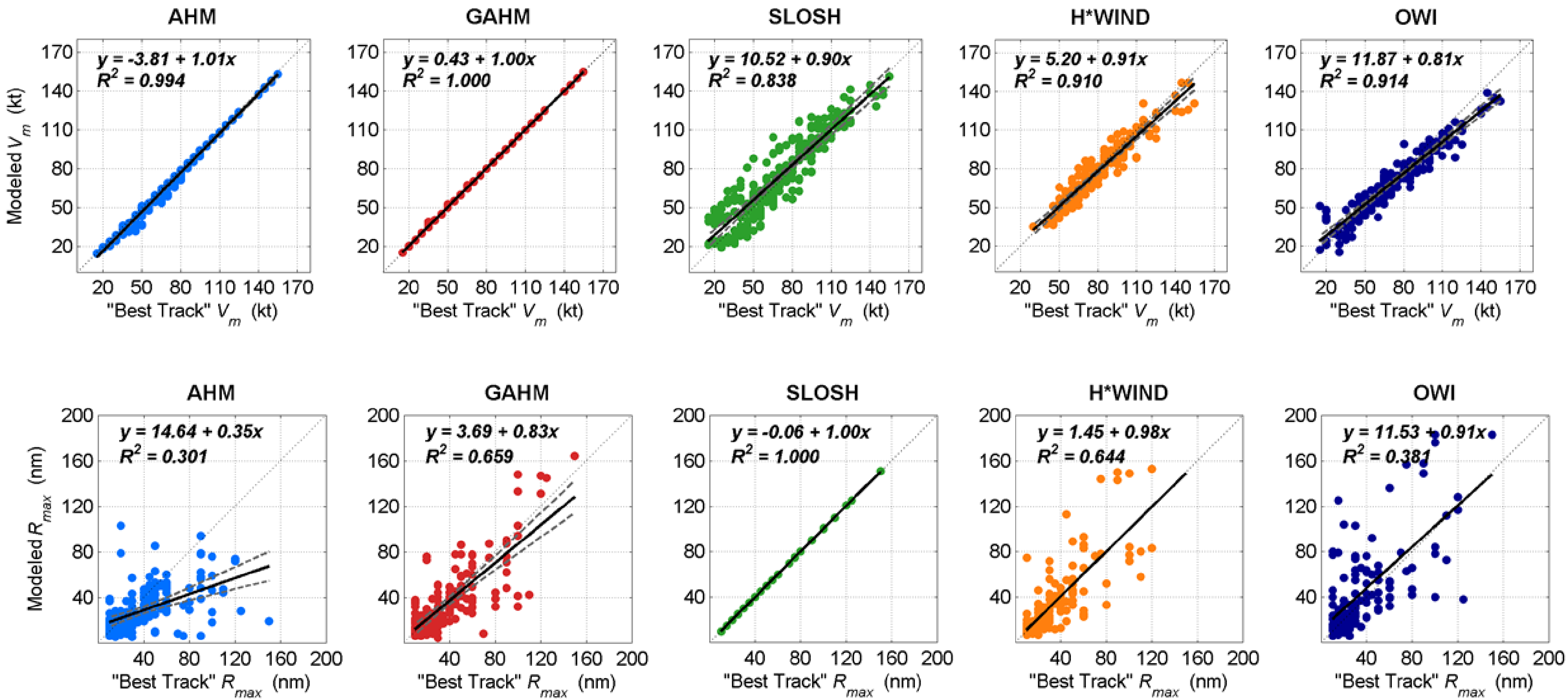
	MEAN (kt)			Standard Deviation (kt)		
	Iso-34	Iso-50	Iso-64	Iso-34	Iso-50	Iso-64
AHM	26.9	44.7	63.3	7.96	7.09	2.55
GAHM	34.0	50.0	64.0	0.10	0.12	0.10
SLOSH	30.0	48.9	69.5	11.00	14.11	16.08
OWI	33.1	48.3	61.3	7.65	8.71	9.42
H*Wind	34.9	49.2	61.2	7.55	8.88	8.89

Validation



AHM
GAHM
$y = -3.81 + 1.01x$
$R^2 = 0.994$
$y = 0.45 + 1.00x$
$R^2 = 1.000$
Modeled V_m (kt)
"Best Track" V_m (kt)
0
30
60
90
120
150
180
$log_{10}R_o$
0
0.5
1
1.5
2
AHM
GAHM
$y = 14.64 + 0.35x$
$R^2 = 0.301$
$y = 4.06 + 0.82x$
$R^2 = 0.664$
Modeled R_{max} (nm)
"Best Track" R_{max} (nm)
0
40
80
120
160
200

Validation


AHM
GAHM
SLOSH
H*WIND
OWI
y = -3.81 + 1.01x
R2 = 0.994
y = 0.43 + 1.00x
R2 = 1.000
y = 10.52 + 0.90x
R2 = 0.838
y = 5.20 + 0.91x
R2 = 0.910
y = 11.87 + 0.81x
R2 = 0.914
Modeled Vm (kt)
"Best Track" Vm (kt)
y = 14.64 + 0.35x
R2 = 0.301
y = 3.69 + 0.83x
R2 = 0.659
y = -0.06 + 1.00x
R2 = 1.000
y = 1.45 + 0.98x
R2 = 0.644
y = 11.53 + 0.91x
R2 = 0.381
Modeled Rmax (nm)
"Best Track" Rmax (nm)

Conclusions

A new “Generalized Asymmetric Holland Model" developed for Tropical Cyclone wind fields

- Expands range of storm conditions (larger storms, weaker storms) often typical near landfall
- Fits multiple isotachs, provides reasonable winds over large areal extent
- Reasonably captures complexities of storm within constraints of a parametric model

Comparisons between GAHM and H*Wind & OWI wind fields provide confidence for using in storm surge calculations

Available as part of ADCIRC storm surge model