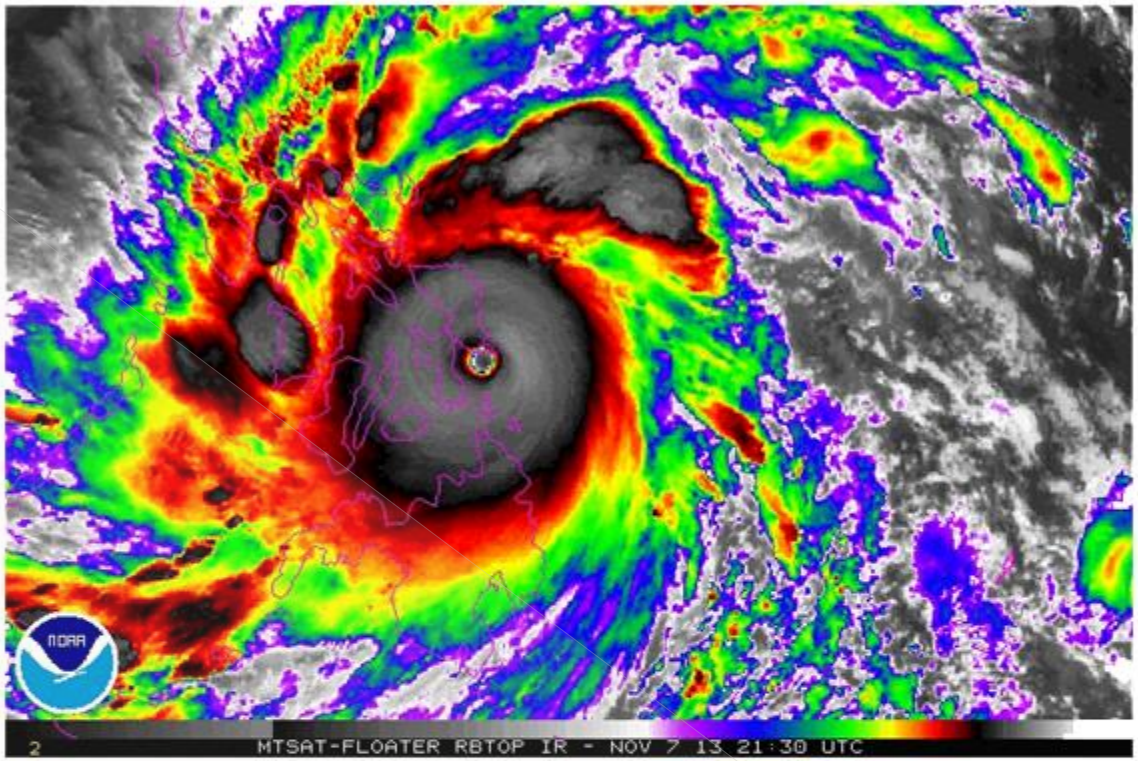


ESTIMATING TYPHOON HAIYAN'S WIND SPEEDS USING WINDICATORS AND POST-STORM VULNERABILITY ANALYSIS ON THE AFFECTED AREAS

Engr. Joshua C. Agar ; Dr. Jaime Y. Hernandez Jr. ; Engr. William L. Mata

Start

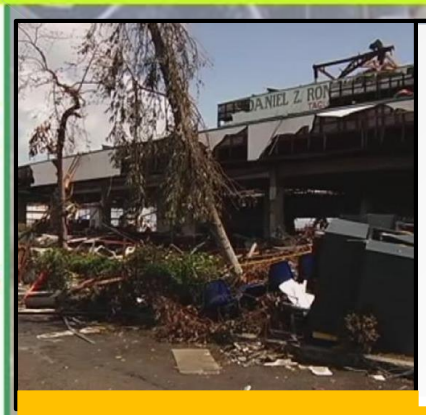
Introduction - Typhoon Haiyan (Yolanda) - 2013

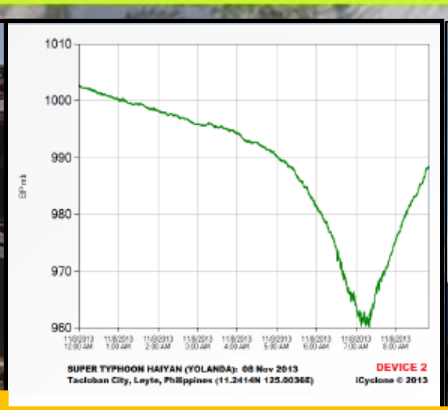
Year: 2013
Month: November
Basin: Northwestern Pacific
Areas affected: Visayas
Death Toll: 6300+
Amount of Damages: $2.86 Billion

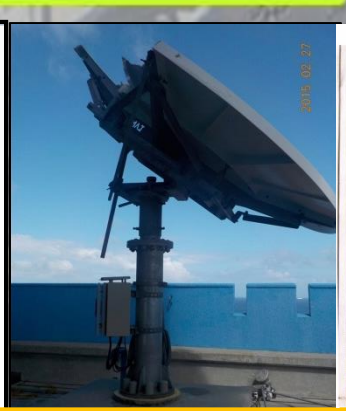
ESTIMATES:
JTWC : 315 kph (1-min)
JMA and PAGASA: 235 kph (10-min)

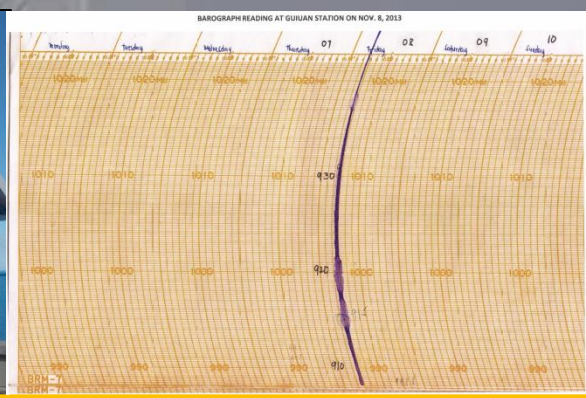
- 11 Weather stations around the Visayan Region were damaged and no in-situ meteorological data that would reflect the peak strength of Typhoon Haiyan was established (PAGASA)
- Meteorological Instruments were also damaged
- One weather observer was washed away and still missing (PAGASA)

Introduction - Typhoon Haiyan (Yolanda) - 2013









TACLOBAN STATION

Winds: 230-250 kph (Hours before Leyte landfall) (Aquino, Mata, Valdez, 2013)

7:00 AM – 277 kph

7:15 am – 955.6 mbar

iCyclone @ TACLOBAN

7:20 am – 959.9 mbar

(Severe winds were observed from 7:00 am to 7:50 am)

PAGASA - GUIUAN

4:10 am – 190 kph (S 30° W)

The station was damaged then.

PAGASA - GUIUAN

5:10 am – 910 mbar
Time of Closest Approach: 5:15 am
Time of Landfall at Guiuan – 4:45 am

MAASIN, SOUTHERN LEYTE

Winds: 175 kph

AJUY, ILOILO

Winds: 235 kph

SAN CARLOS, NEGROS OCCIDENTAL

Winds: 180 kph

ROXAS CITY, CAPIZ

Winds: 208.8 kph

BANTAYAN ISLAND

Winds: 280 kph (9:45 am)*

***Instrument was damaged at this point**

Closest Approach: 10:30 am

Historical Analysis I - Past Occurences

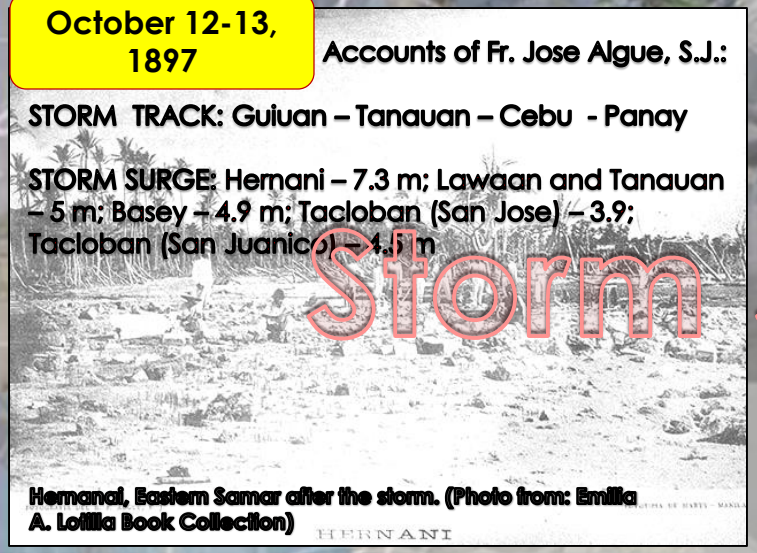
October 12-13, 1897

Accounts of Fr. Jose Algue, S.J.:

STORM TRACK: Guiuan – Tanauan – Cebu - Panay

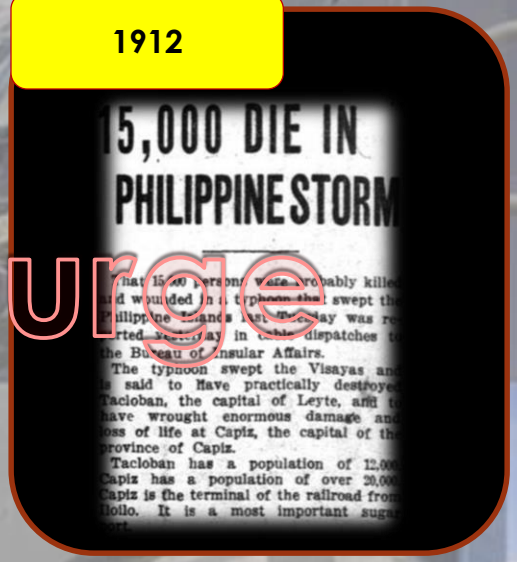
STORM SURGE: Hernani – 7.3 m; Lawaan and Tanauan – 5 m; Basey – 4.9 m; Tacloban (San Jose) – 3.9; Tacloban (San Juanico) – 4.5 m

Storm Surge



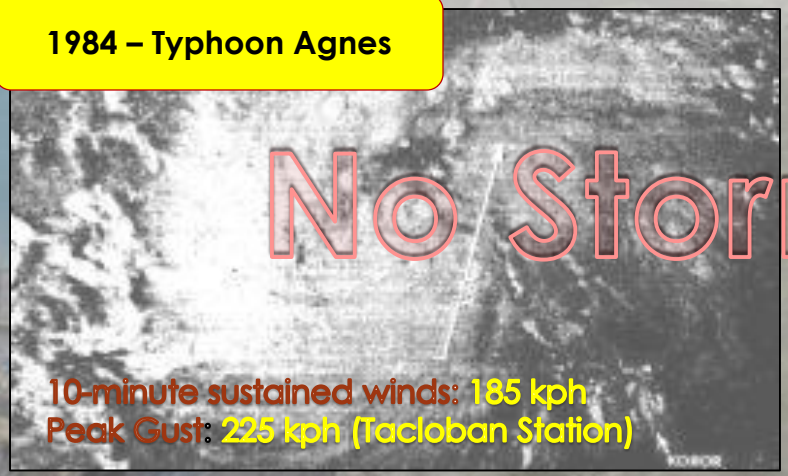
Hernani, Eastern Samar after the storm. (Photo from: Emilia A. Lofilla Book Collection)

1912



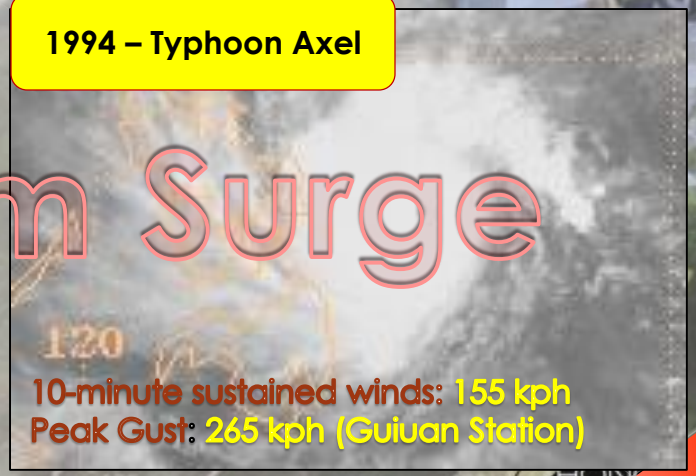
1984 – Typhoon Agnes

No Storm Surge



10-minute sustained winds: 185 kph
Peak Gust: 225 kph (Tacloban Station)

1994 – Typhoon Axel



10-minute sustained winds: 155 kph
Peak Gust: 265 kph (Guiuan Station)

Historical Analysis II - Statistical Analysis

Quantification of Severe Wind (Typhoons)

Missing

Historical Wind Data	Statistical Analysis	Return Period	Wind Resistant Design (Wind Speed)
•Daily Mean •Daily Max	•Gumbel •Gringorten		

Estimating Typhoon Haiyan's Wind Speeds Using Windicators

Wind Speed Estimation

- Satellite Estimation
- Reconnaissance Missions
- Ground Surface Measurements

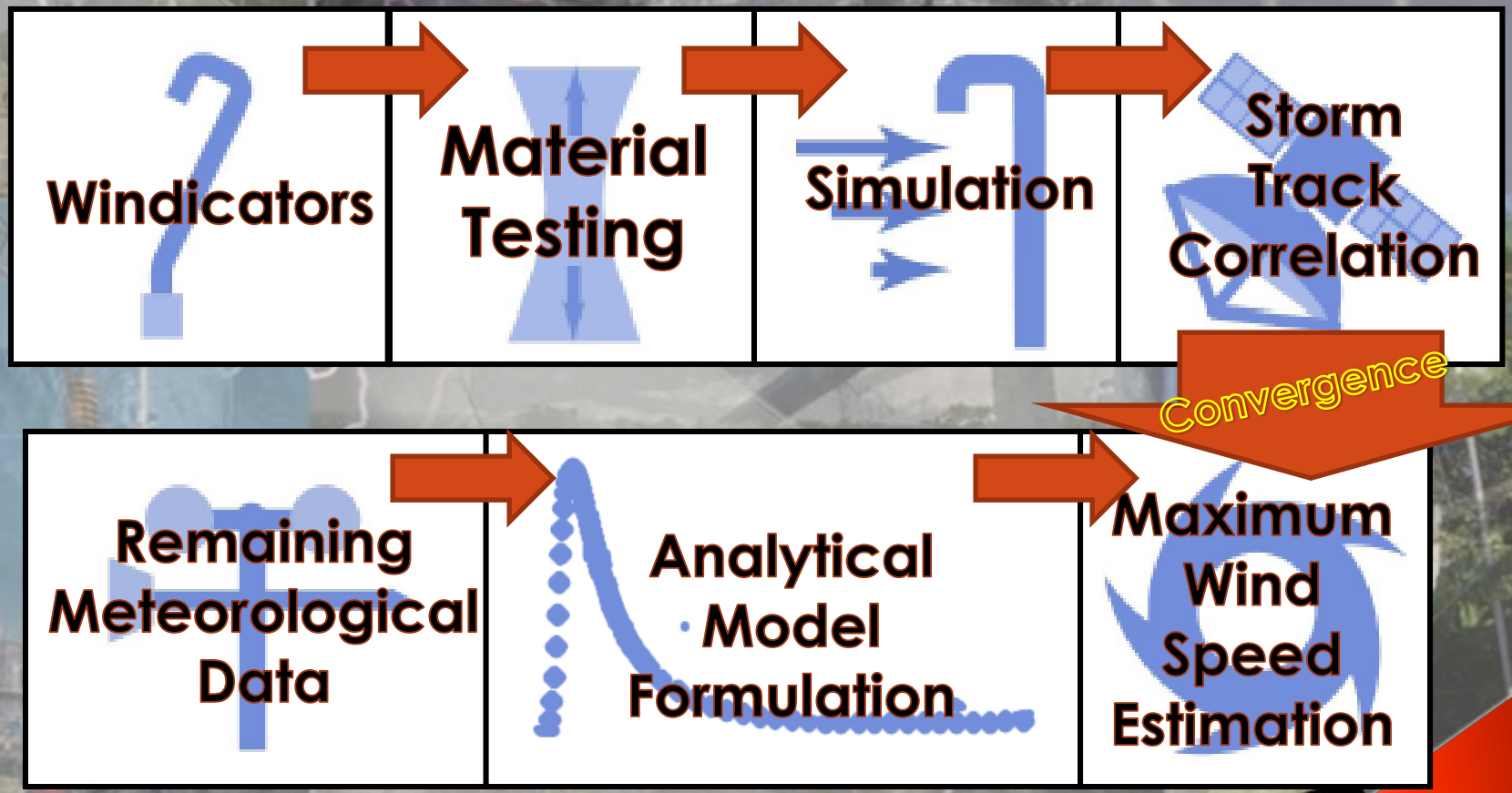
Forensic Analysis

Forensic Structural Analysis

WINDICATOR

- **Coined from the terms "Wind" and "Indicator"**
- **Structural objects of interest whose structural failure may lead to the computation of the wind speeds**

Research Framework



Estimating Typhoon Haiyan's Wind Speeds Using Windicators

Hydraulic UTM

MANUAL:
ASTM A370-21419

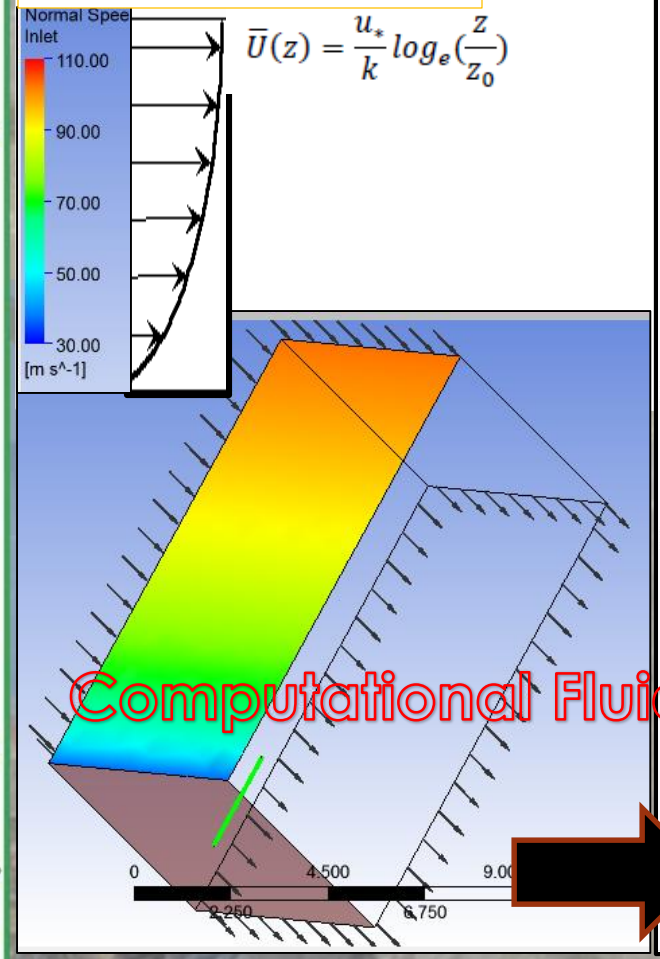
ULTIMATE STRENGTHS:
#1 – 473.71 MPa
#2 – 389.29 MPa

MATERIAL:
A36 steel

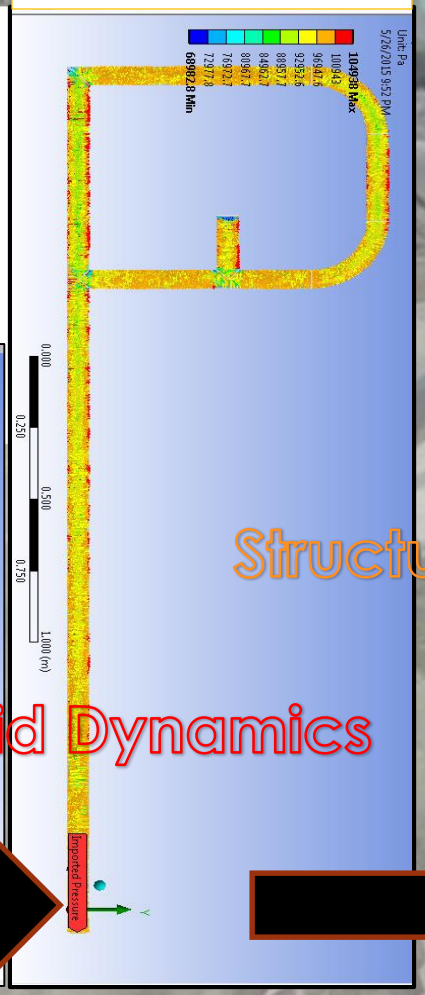
Estimating Typhoon Haiyan's Wind Speeds Using Windicators

LOGARITHMIC WIND PROFILE:
Harper et.al (2010): Values for z_0 and C_{sd}

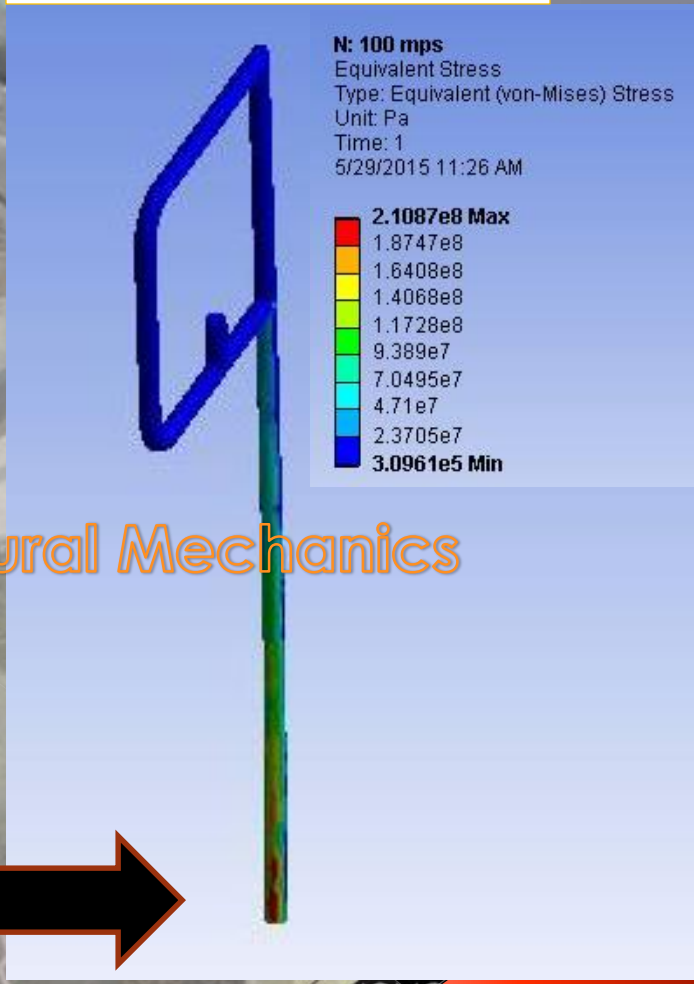
$$\bar{U}(z) = \frac{u_*}{k} log_e(\frac{z}{z_0})$$



EXTERNAL PRESSURE DISTRIBUTION



INTERNAL STRESS DISTRIBUTION
von Mises stresses



Computational Fluid Dynamics

Structural Mechanics

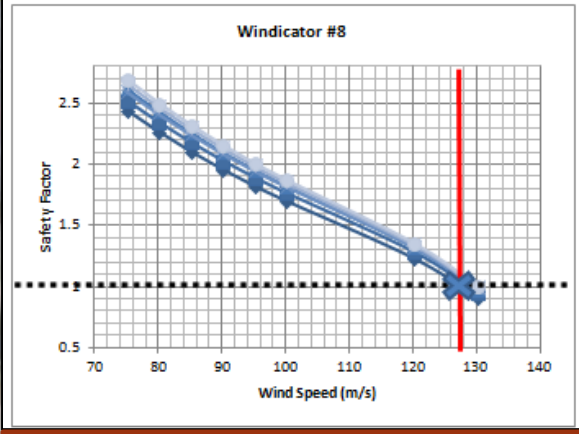
Estimating Typhoon Haiyan's Wind Speeds Using Windicators

Windicator	Gust (m/s)	10-min sustained wind (m/s)*
#4	109.43	65.95
#8	127.4	76.77
#9	104.77	63.11
#10	**113.48**	**68.36**

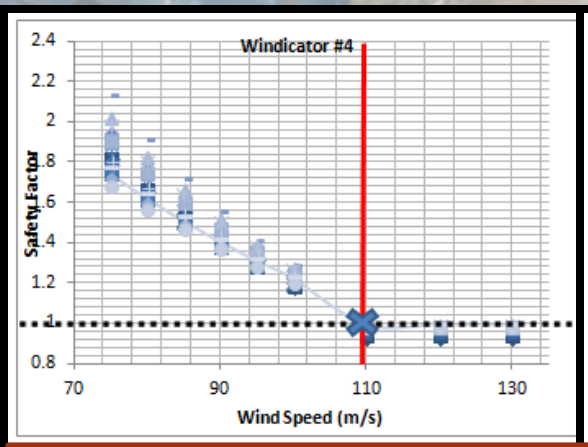
*converted using the recommended values by WMO

Harper, B., Kepert, J. and Ginger, J. (2010):

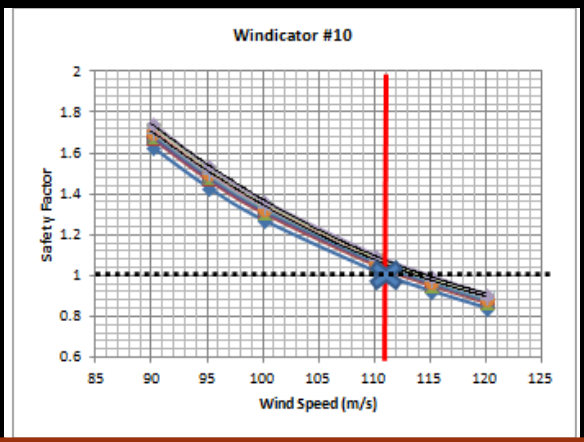
Exposure at +10 m		Reference Period	Gust Factor G_{t,T_0}				
			Gust Duration t (s)				
Class	Description	T_0 (s)	3	60	120	180	600
In-Land	Roughly open terrain	3600	1.75	1.28	1.19	1.15	1.08
		600	1.66	1.21	1.12	1.09	1.00
		180	1.58	1.15	1.07	1.00	
		120	1.55	1.13	1.00		
		60	1.49	1.00			
Off-Land	Offshore winds at a coastline	3600	1.60	1.22	1.15	1.12	1.06
		600	1.52	1.16	1.09	1.06	1.00
		180	1.44	1.10	1.04	1.00	
		120	1.42	1.08	1.00		
		60	1.36	1.00			
Off-Sea	Onshore winds at a coastline	3600	1.45	1.17	1.11	1.09	1.05
		600	1.38	1.11	1.05	1.03	1.00
		180	1.31	1.05	1.00	1.00	
		120	1.28	1.03	1.00		
		60	1.23	1.00			
At-Sea	> 20 km offshore	3600	1.30	1.11	1.07	1.06	1.03
		600	1.23	1.05	1.02	1.00	1.00
		180	1.17	1.00	1.00	1.00	
		120	1.15	1.00	1.00		
		60	1.11	1.00			



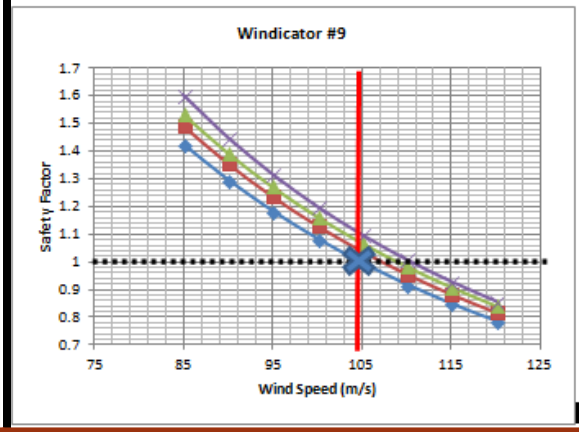
Windicator #8 – **127.4 m/s**



Windicator #4 – 109.43 m/s



Windicator #10 – 113.48 m/s



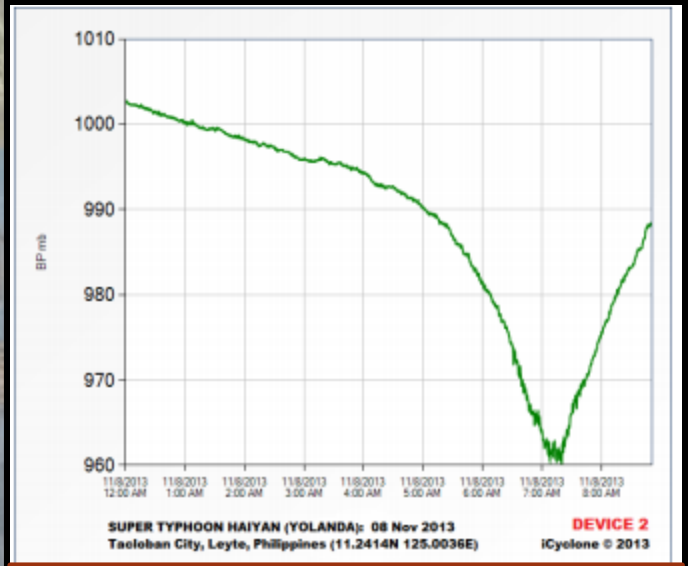
Windicator #9 – 104.77 m/s

Estimating Typhoon Haiyan's Wind Speeds Using Windicators

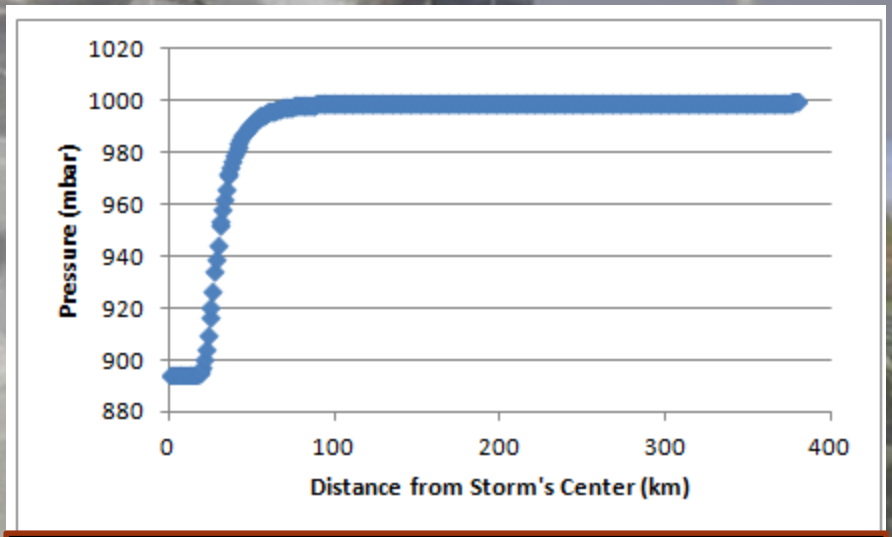
Holland's Analytical Model for Pressure Profile of Tropical Cyclones

$$\frac{p - p_o}{p_n - p_o} = \exp\left(\frac{-A}{r^B}\right)$$

A = 2.44572×10^{18} ; B= 4.148688

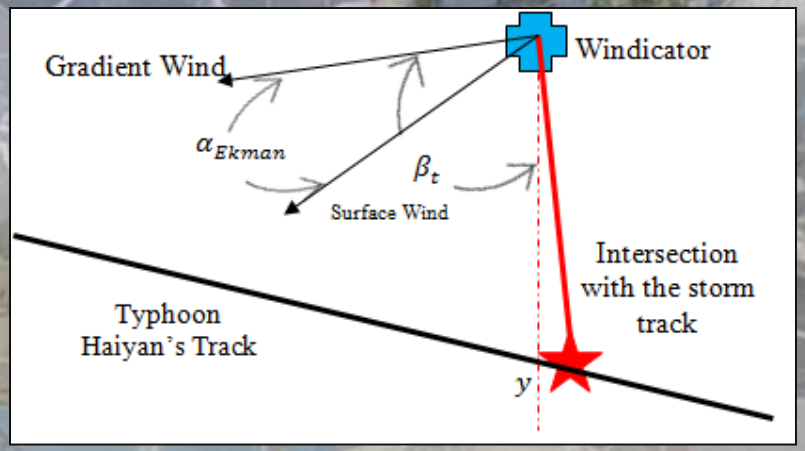


Barometer 2 - Hotel Alejandro – Tacloban City (Morgerman, 2013)



Typhoon Haiyan's Pressure Profile using values of A and B

Estimating Typhoon Haiyan's Wind Speeds Using Windicators



Storm Track (Source: Wikimedia Commons)

Height of Boundary Layer	$H_{ABL} = e^{(2.5(fz_0{}^{-0.09})+\ln(z_0)}$
Height of Ekman Layer	$\pi\sqrt{\frac{2v_E}{f_c}}$
Ekman Spiral	$u = U_{gr}(1 - e^{-\beta}cos\beta)$ $v = e^{-\beta}sin\beta$
Eddy Viscosity (Constant on Rotating Fluids)	v_E
Coriolis Parameter	f_c

$$\beta = z\sqrt{\frac{f_c}{2v_E}}$$

TIME OF FAILURE

Windicator	Time of Failure	Distance from the Storm's Center (km)	Radius of Maximum Winds (km)
Windicator #4	7:50 AM	**30.57**	**32**
Windicator #8	6:41 AM	**35.93**	**32**
Windicator #9	7:20 AM	**24.41**	**32**
Windicator #10	7:02 AM	**27.31**	**32**

Estimating Typhoon Haiyan's Wind Speeds Using Windicators

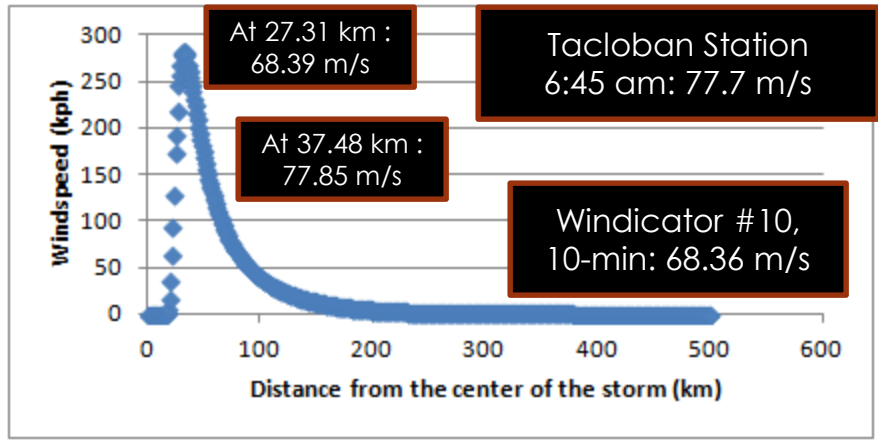
Holland's Analytical Model on the Gradient Wind

$$\bar{U}_{gr} = -\frac{|f_c r|}{2} + \sqrt{\left(\frac{f_c r}{2}\right)^2 + \frac{(p-p_o)AB}{\rho r^B}\exp\left(\frac{-A}{r^B}\right)}$$

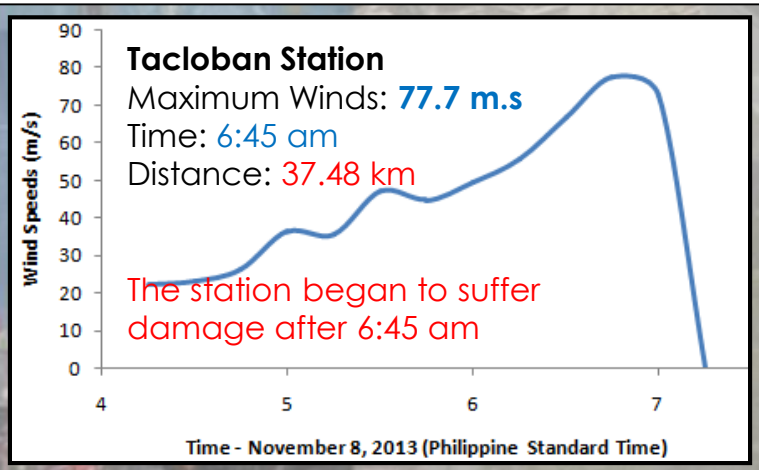
$A = 2.44572 \times 10^{18}$; $B = 4.148688$

Windicator	Gust (m/s)	10-min sustained wind (m/s)*	Time of Failure
#4	109.43	65.95	7:50 AM
#8	127.4	76.77	6:41 AM
#9	104.77	63.11	7:20 AM
#10	**113.48**	**68.36**	**7:02 AM⁺**

* -converted using recommended conversion factors from WMO
⁺- around the time of landfall; around the time of lowest barometric pressure recording at Tacloban

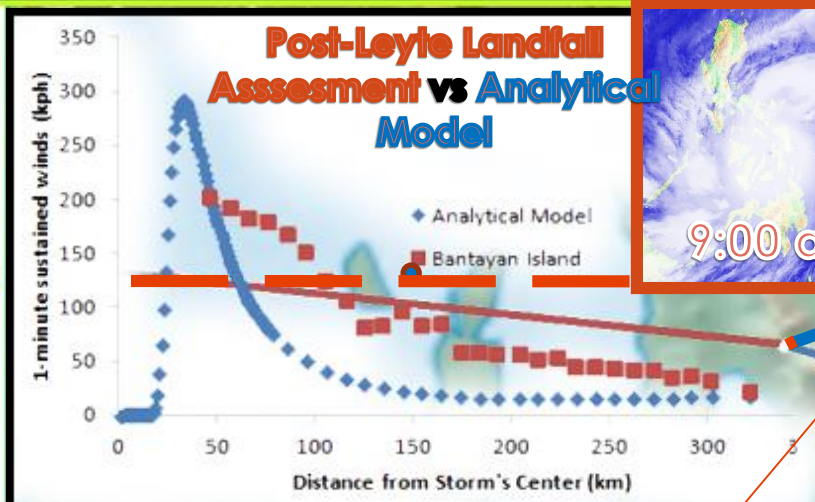


Typhoon Haiyan's Velocity Profile using values of A and B



Fujii, T., Maeda, J., Ishida, N., Hayashi, T. (1999):
Formulation of Analytical Model of Storm with comparison of in-situ data

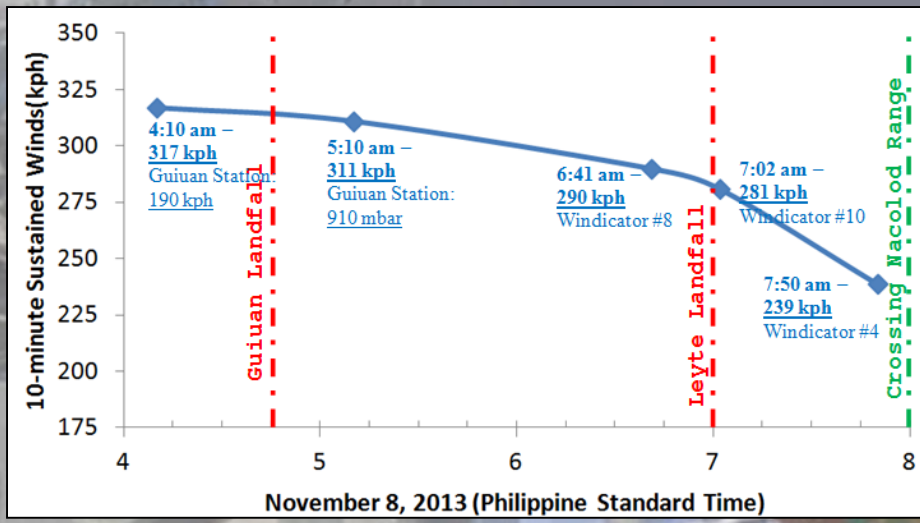
Estimating Typhoon Haiyan's Wind Speeds Using Windicators

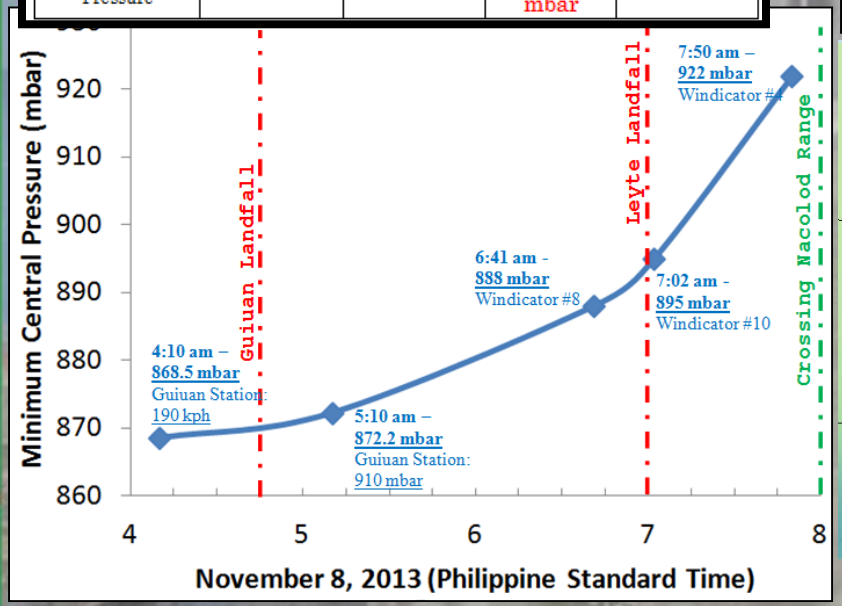


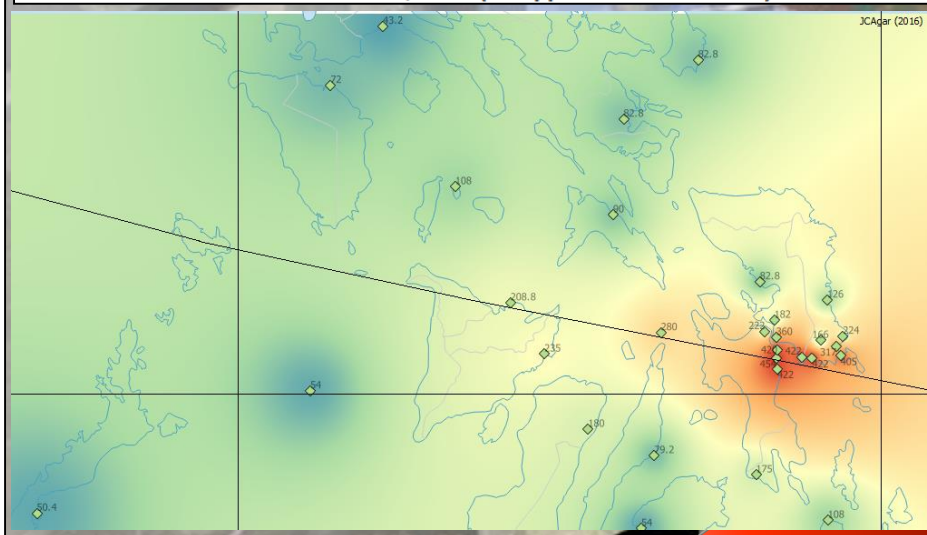
Estimating Typhoon Haiyan's Wind Speeds Using Windicators

Summary of Values

	#4	#8	#9	#10
Time of Failure (UTC)	2350	2241	2320	2302
10-minute sustained winds (kph)	**239.6**	**290.81**	371.82	**281.67**
1-minute sustained winds (kph)	**289.91**	**351.87**	449.90	**340.83**
Percent Deviation from JTWC(1-min)	**8.65%**	-10.48%	-	**-7.58%**
Percent Deviation from JMA/PAGASA(10-min)	19.17%	71.55%	-	23.57%
Minimum Central Pressure	922 mbar	888 mbar	500~ mbar	895 mbar

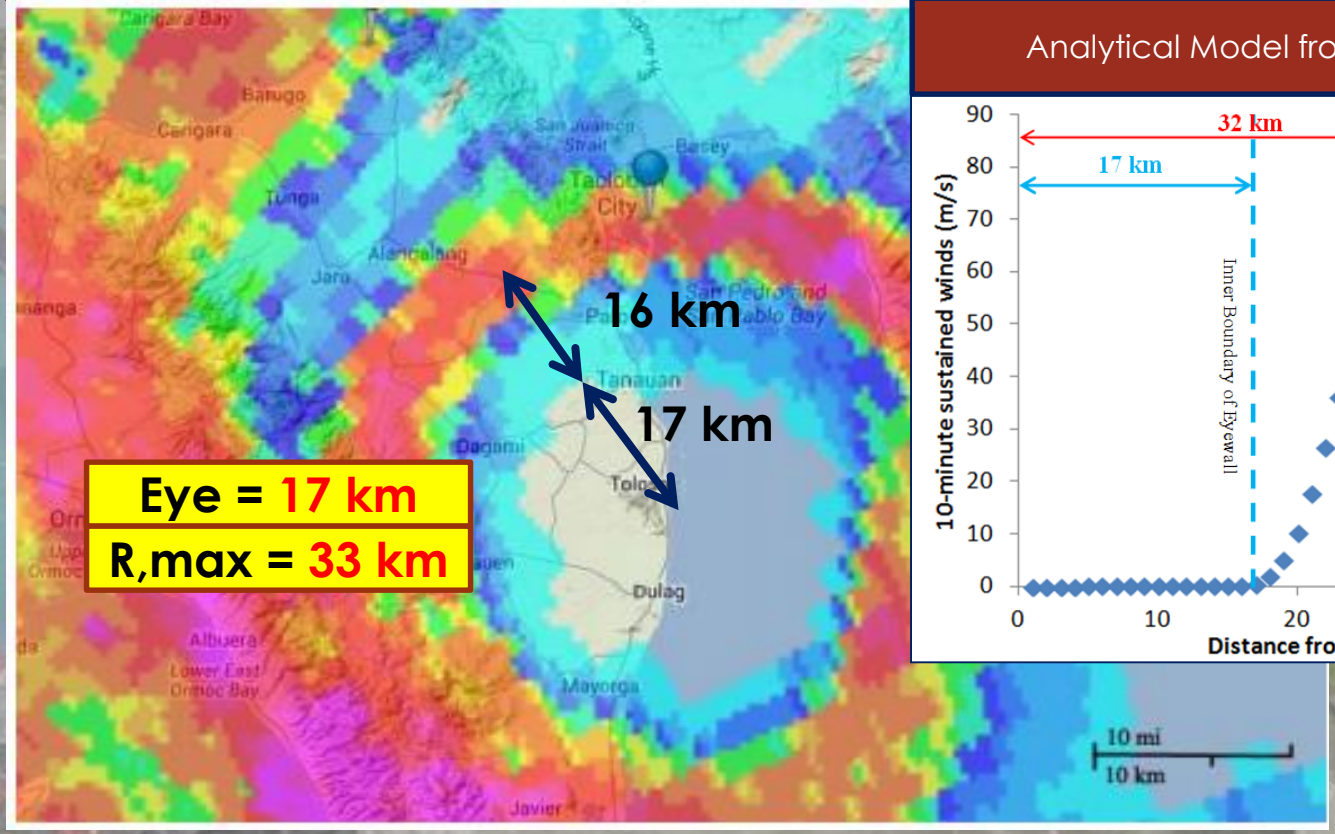






VERIFICATION

Doppler Radar:



Analytical Model from Windicator #10

Estimating Typhoon Haiyan's Wind Speeds Using Windicators

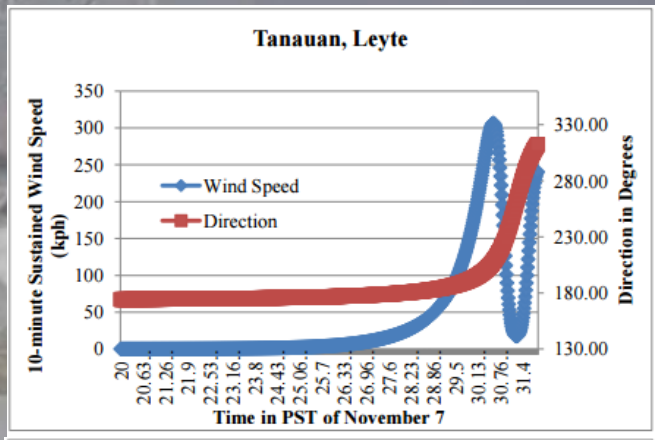
VERIFICATION

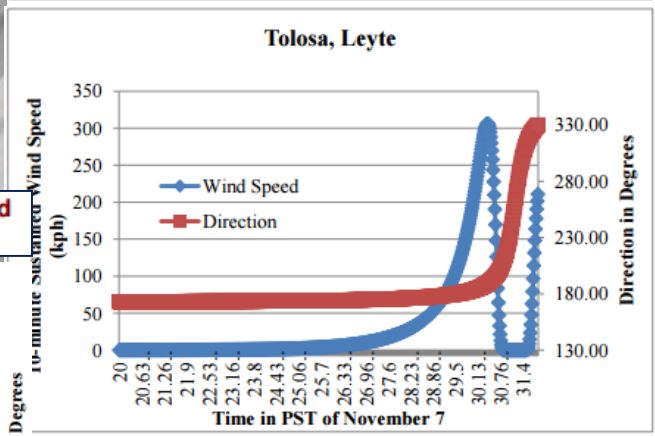
iCyclone storm chase report(iCyclone.com):

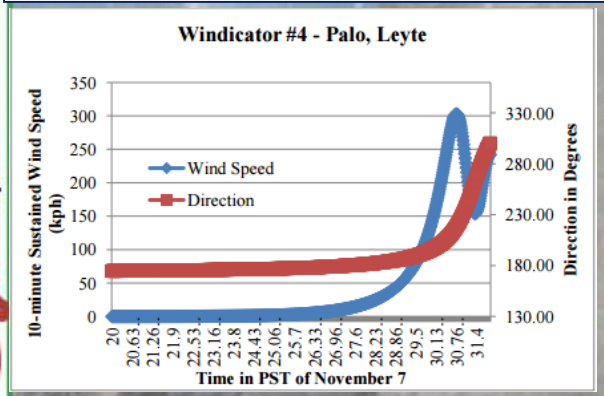
Y = definitely experienced distinct calm
N = definitely experienced no calm
M = experienced fluctuations, lessening, or can't remember

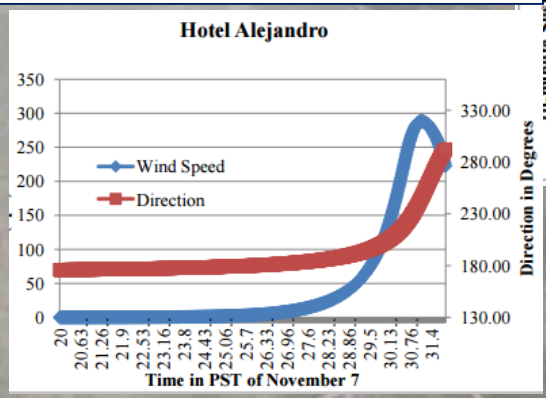
- **Tacloban City:** numerous N (includes author's firsthand recollection)
- **Palo:** 6N, 1Y
- **San Joaquin:** 1N, 3M (includes group interview—with father & daughter)
- **Tanauan:** 2N, 3M (includes group interview—with husband & wife), 2Y, 1?
- **Tolosa (Downtown):** 4Y
- **Tolosa (S):** 2Y (group interview—with husband & wife)
- **San Jose:** 3Y(group interview—with extended family)
- **Dulag:** 3Y, 1N
- **Mayorga:** 2M (group interview—with relatives), 1N, 1?
- **MacArthur:** 2N
- **Abuyog:** 2N

Given the above: **the N boundary of the eye is estimated to have passed between San Joaquin and Tanauan,** with Downtown **Tanauan** clipping the N edge of the eye and experiencing a very brief calm.





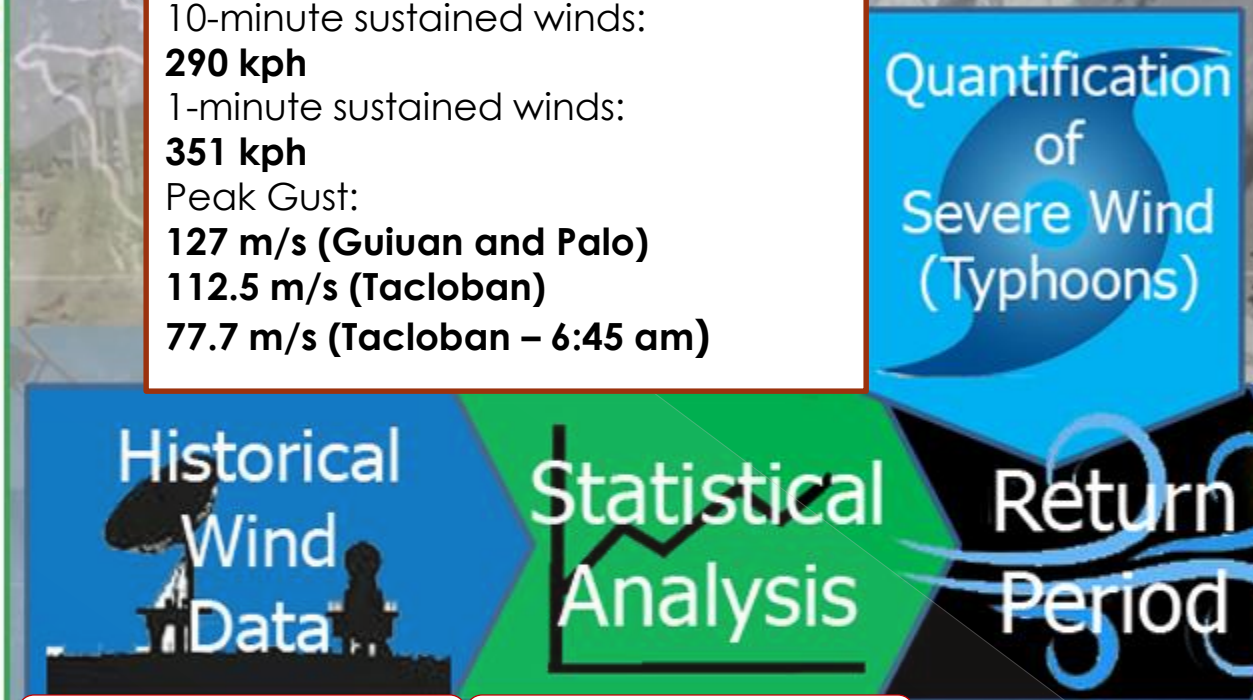




Historical Analysis II - Statistical Analysis

Typhoon Haiyan

10-minute sustained winds:
290 kph
1-minute sustained winds:
351 kph
Peak Gust:
127 m/s (Guiuan and Palo)
112.5 m/s (Tacloban)
77.7 m/s (Tacloban – 6:45 am)

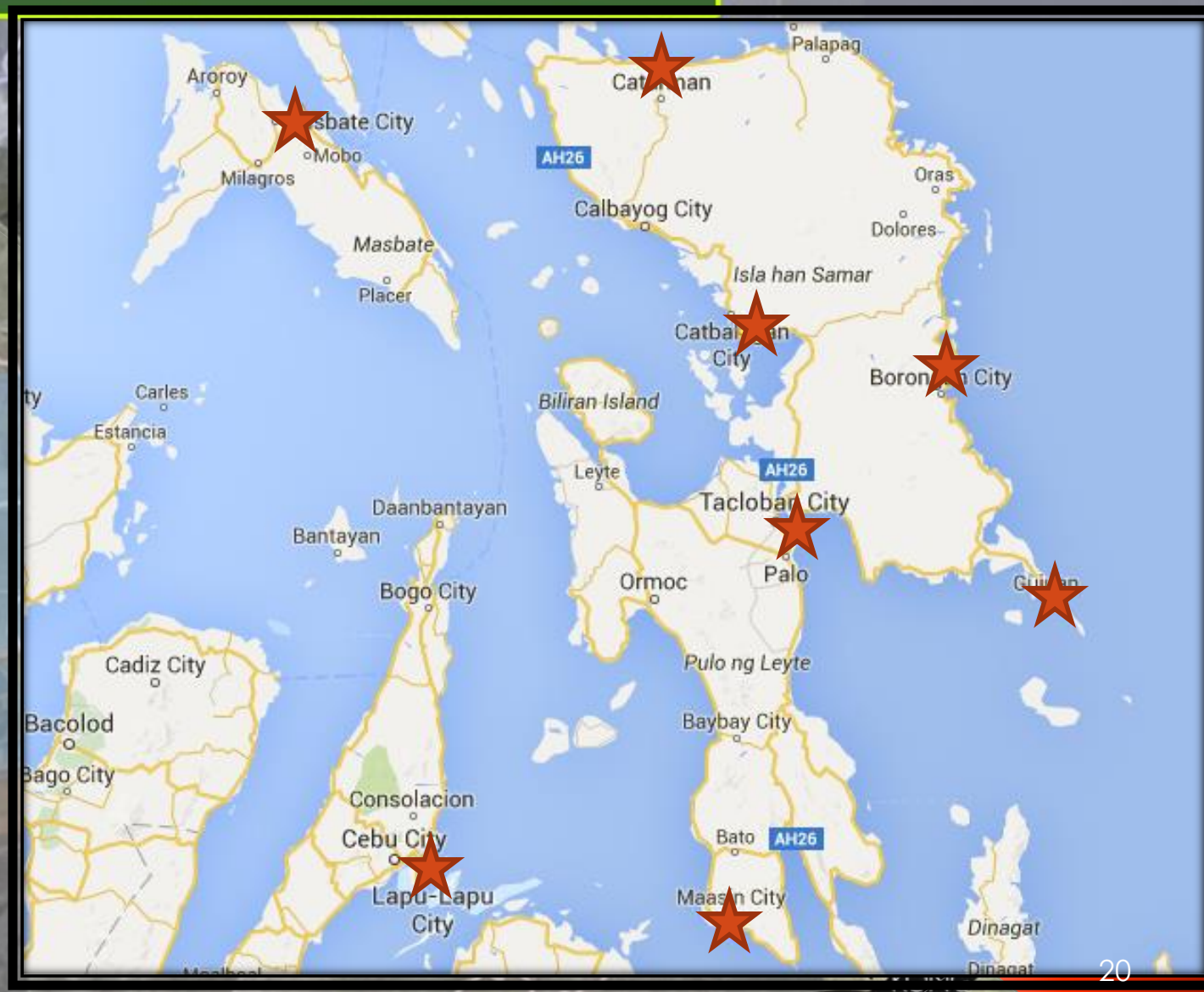


Annual Maximum Winds	**Extreme Value Functions**
Tropical Cyclone Strengths	**Type I - Gumbel**
	Type II - Gringorten


ITBAYAT - 270 kph (Elsie, 1975)
BASCO - 306 kph (Usagi, 2013)
CALAYAN - 194.4 kph (Sally, 1996)
APARRI - 208.8 kph (Carla, 1967)
LAOAG - 154.8 kph (Utor, 2001)
IGAN-SINAIT - 216 kph (Peggy, 1986)
TUGUEGARAO - 205.2 kph (Dinah, 1977)
BAGUIO - 169.2 kph (Ivy, 1974)
DAGUPAN - 201.6 kph (Bess, 1974)
ASIGURAN - 255.6 kph (Freda, 1959)
ALER - 219.6 kph (Ira, 1993)
IBA - 169.2 kph (Ruby, 1976)
ABANATUAN - 158.4 kph (Dot, 1985)
CLARK - 169.2 kph
SCIENCE GARDEN - 180 kph (Angela, 1995)
INFANTA - 190.8 kph (Patsy, 1970)
SANGLEY POINT - 194.4 kph (Conson, 2010)
ANAY - 151.2 kph (Conson, 2010)
AMBULONG - 270 kph (Vera, 1983)
AET - 248.4 kph (Angela, 1995)
TAYABAS - 144 kph (Lola, 1993)
VIRAC SYNOP - 277.2 kph (Joan, 1970)
VIRAC RADAR - 320.4 kph (Durian, 2006)
CALAPAN - 165.6 kph (Betty, 1987)
EGAZPI - 234 kph (Nina, 1987)
ROMBLON - 223.2 kph (Harriet, 1971)
CATARMAN - 194.4 kph (Emma, 1967)
SAN JOSE - 126 kph (Chanchu, 2006)
MASBATE - 270 kph (Phyllis, 1987)
CORON - 144 kph (Mike, 1990)
CATBALOGAN - 183.6 kph (Emma, 1967)
ROXAS CITY - 208.8 kph (Haiyan, 2013)
ORONGAN - 216 kph (Hagupit, 2014)
PAGASA ISLAND - 151.2 kph
TACLOBAN - 223.2 kph (Agnes, 1984)
GUIUAN - 259.2 kph (Axel, 1995)
CUYO - 100.8 kph (Skip, 1988)
ILOILO - 162 kph (Nina, 1968)
MACTAN - 198 kph (Mike, 1990)
MASIN - 180 kph (Ike, 1984)
PUERTO PRINCESA - 176.4 kph (Nina, 1968)
URIGAO - 216 kph (Ike, 1984)
TAGBILARAN-DAUIS - 129.6 kph (Mamie, 1968)
DUMAGUETE - 90 kph (Mike, 1990)
BUTUAN CITY - 108 kph (Amber, 1997)
DIPOLOG - 100.8 kph
LUMBIA-EL SALVADOR - 122.4 kph (Bopha, 2012)
INATUAN - 129.6 kph (Mamie, 1982)
MALAYBALAY - 79.2 kph
COTABATO - 100.8 kph
AVAO CITY - 111.6 kph (Olga, 1976)
AMBOANGA - 82.8 kph
GENERAL SANTOS - 90 kph

Historical Analysis II - Statistical Analysis

Statistical Analysis of Weather Station Data



Historical Analysis II - Statistical Analysis

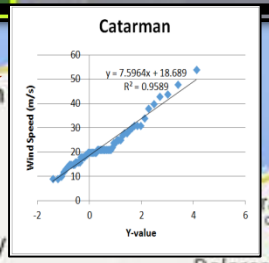
Statistical Analysis of Weather Station Data

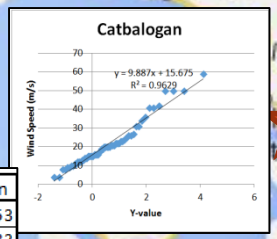
Station	Daily Max			
	Type I		Type II	
	A	B	A	B
Mactan	18.44143	7.261625	18.52069	6.828771
Maasin	17.15099	8.410334	17.26715	7.865964
Catbalogan	15.6749	9.886965	15.80301	9.361444
Catarman	18.68947	7.596423	18.77932	7.207723
Borongan	16.46741	8.97078	16.60539	8.411409
Tacloban	20.07591	7.793412	20.1574	7.345179
Guiuan	23.11989	11.11882	23.26805	10.42299

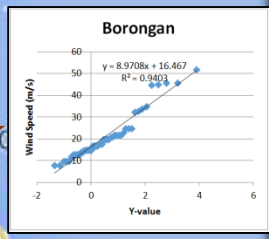
Coefficients of the Extreme Value Functions

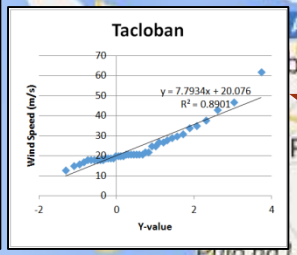
EV	Return Period	Mactan	Maasin	Catbalogan	Catarman	Borongan	Tacloban
Type I	10	126.583	131.4594	138.3857216	130.2512	133.6442	136.8753
	25	150.5365	159.2021	170.9993254	155.3091	163.2357	162.583
	50	168.6567	180.1887	195.6705643	174.2647	185.6207	182.0301
	100	186.7768	201.1752	220.3418032	193.2202	208.0058	201.4772
	200	204.897	222.1618	245.0130421	212.1758	230.3908	220.9244
	500	228.8505	249.9045	277.6266459	237.2337	259.9823	246.6321
Type II	10	123.2803	127.3651	134.4907131	127.3526	129.5041	133.4531
	25	145.806	153.3122	165.3708088	151.1283	157.2504	157.6822
	50	162.846	172.9403	188.7306995	169.114	178.2397	176.0109
	100	179.886	192.5685	212.0905901	187.0996	199.2289	194.3395
	200	196.9261	212.1967	235.4504808	205.0852	220.2181	212.6682
	500	219.4518	238.1437	266.3305765	228.861	247.9644	236.8973

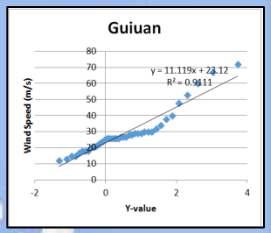
Wind speeds at the corresponding return periods

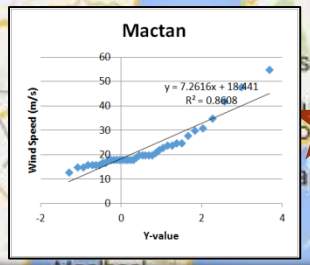


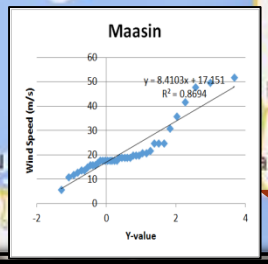




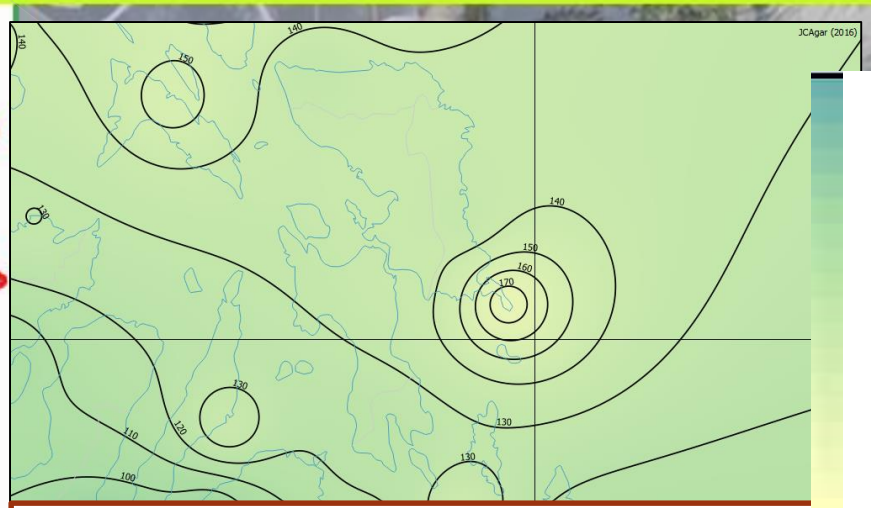




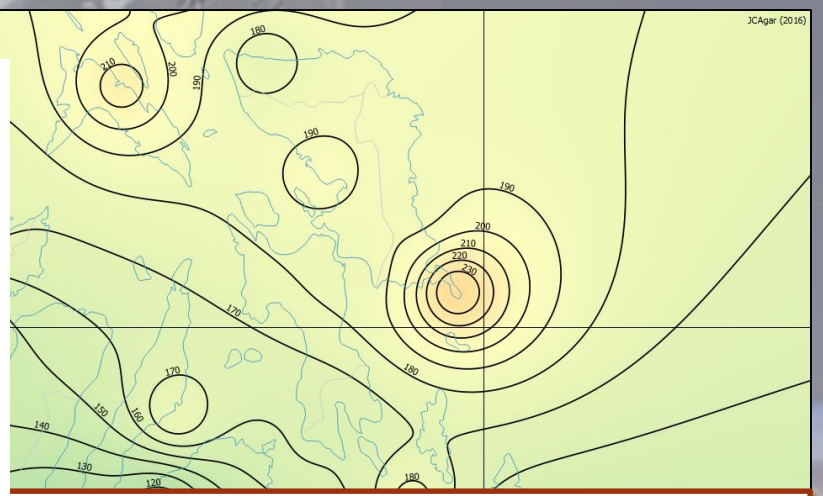




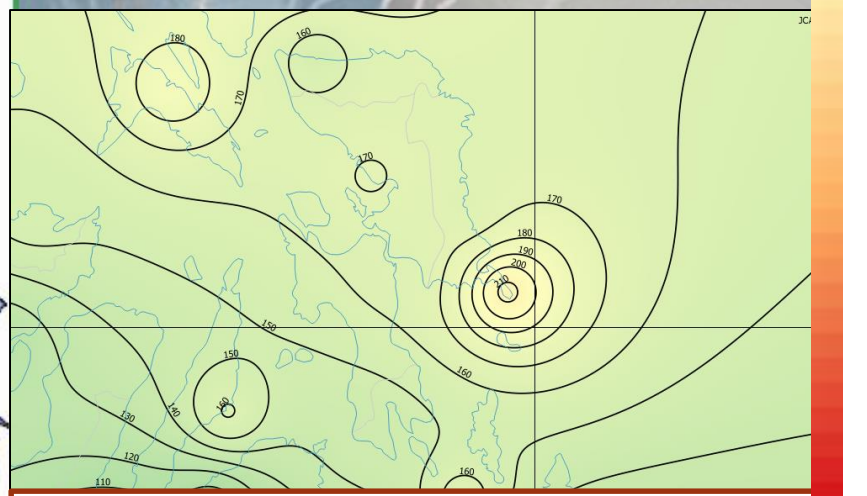
Historical Analysis II - Statistical Analysis



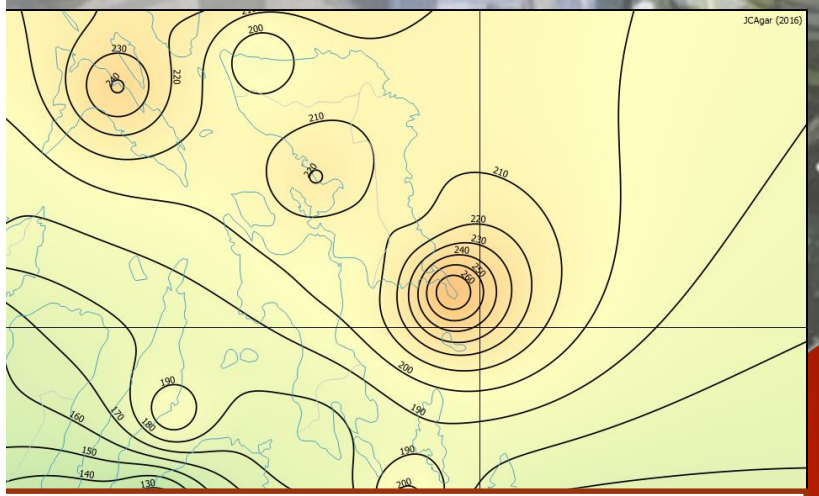
10-year winds (170 kph)



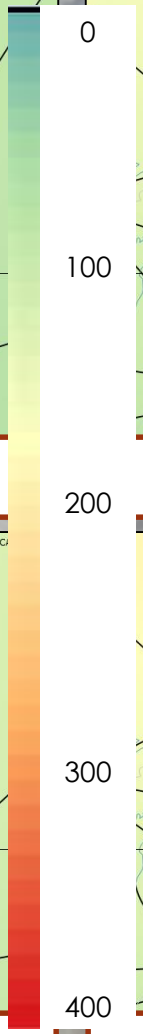
50-year winds (230 kph)



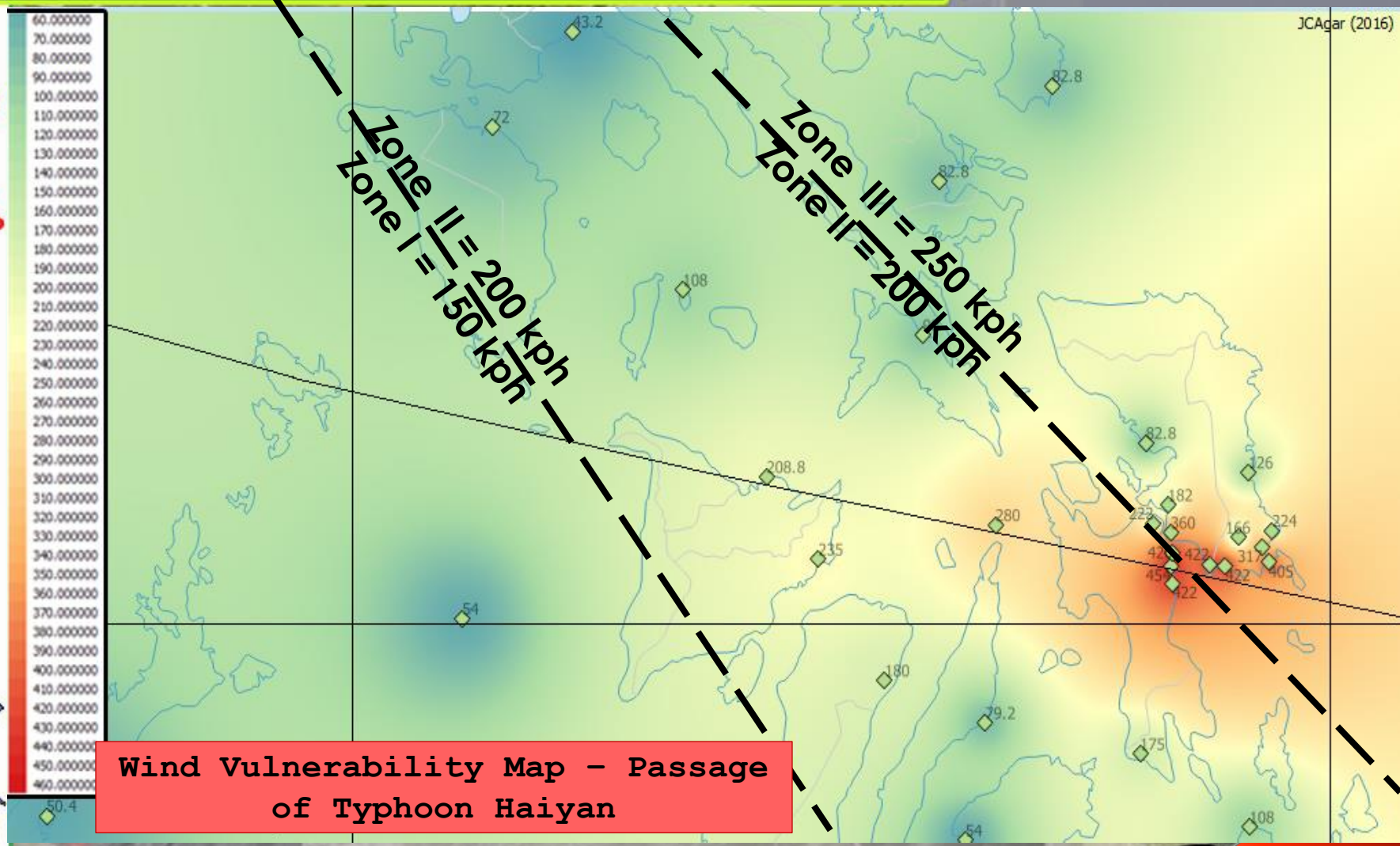
25-year winds (210 kph)



100-year winds (260 kph)



Historical Analysis II - Statistical Analysis



Wind Vulnerability Map – Passage of Typhoon Haiyan

Historical Analysis II - Statistical Analysis

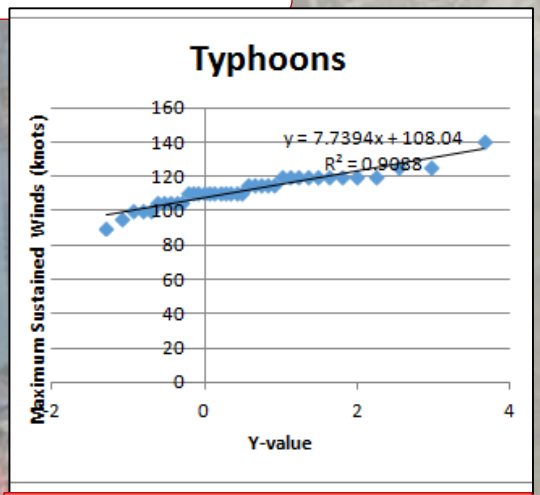
Statistical Analysis of Pacific Typhoons

気象庁
Japan Meteorological Agency

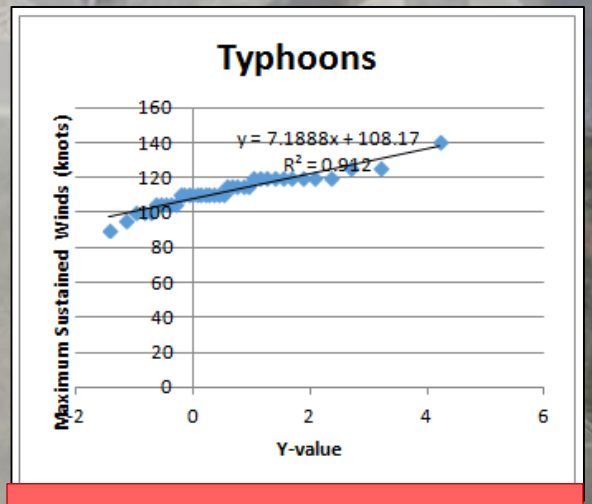
Japan Meteorological Agency
Data:
10-minute maximum sustained winds of Typhoons

Coverage period: 1978-present

Results



Type I (Gumbel)

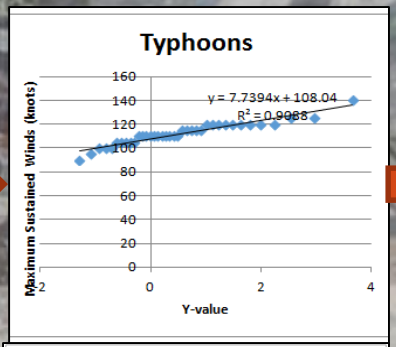


Type II (Gringorten)

Historical Analysis II - Statistical Analysis

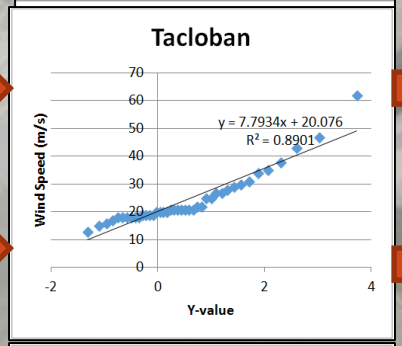
Results

10-minute sustained winds:
290 kph



Return Period:
501 years (Type I)
793 years (Type II)

Peak Gust Estimated at Tacloban:
112.5 m/s

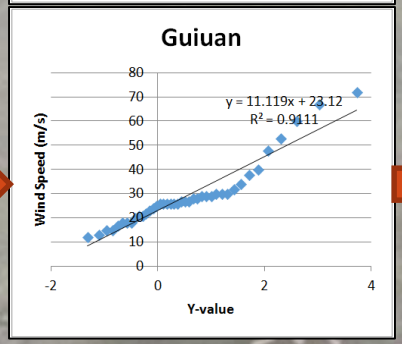


Return Period:
89479 years (Type I)
195021 years (Type II)

Peak Gust Recorded at Tacloban (6:45 am(:
77.7 m/s

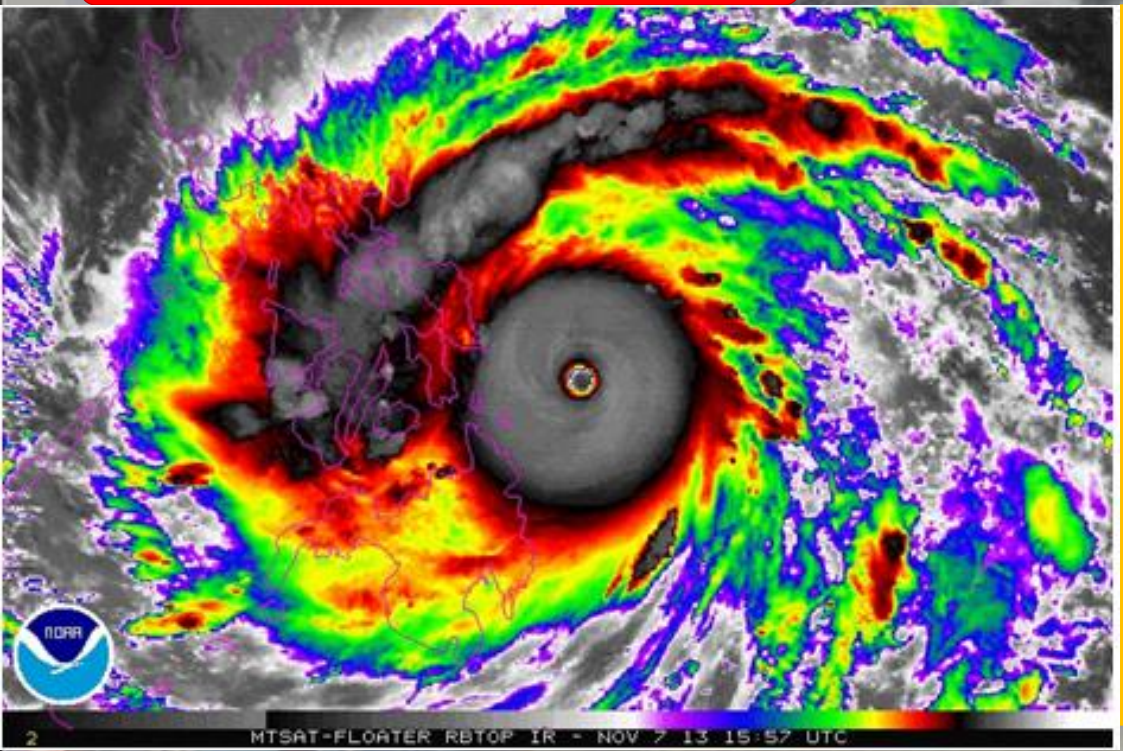
Return Period:
1625 years (Type I)
2625 years (Type II)

Peak Gust Estimated at Guiuan and Palo:
127 m/s



Return Period:
5691 years (Type I)
9993 years (Type II)

Typhoon Haiyan



10-minute sustained winds:
290 kph (Pre-Leyte Landfall)

1-minute sustained winds:
351 kph (Pre-Leyte Landfall)

Minimum Central Pressure:
872.2 mbar (Post-Guiuan Landfall)

Recurrence Period:

Existence: 500 years
Making Landfall: 1600-5600 years

Comparisons

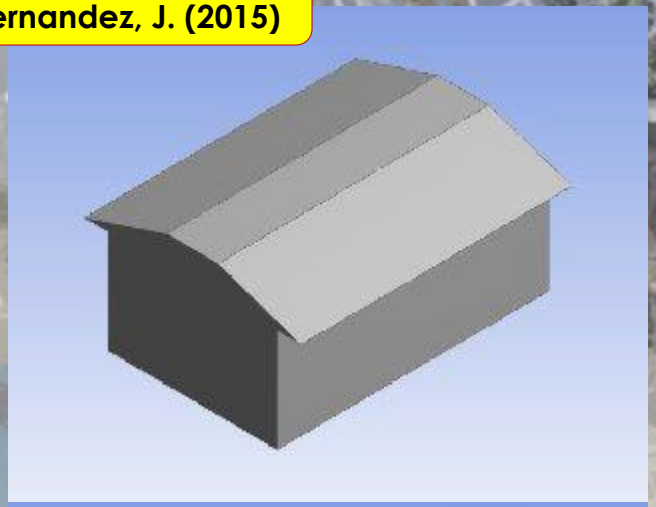
Typhoon Haiyan			
10-minute sustained winds	290 kph	280 kph	Typhoon Tip (1979)
1-minute sustained winds	351 kph	345 kph	Typhoon Nancy (1961)
		345 kph	Hurricane Patricia (2015)
Minimum Central Pressure	872.2 mbar	870 mbar	Typhoon Tip (1979)
		872 mbar	Hurricane Patricia (2015)
Minimum Central Pressure at Landfall	888 mbar	885 mbar	Typhoon Megi (2010)
Strongest Gust	127 m/s	113 m/s	Cyclone Olivia(2010)

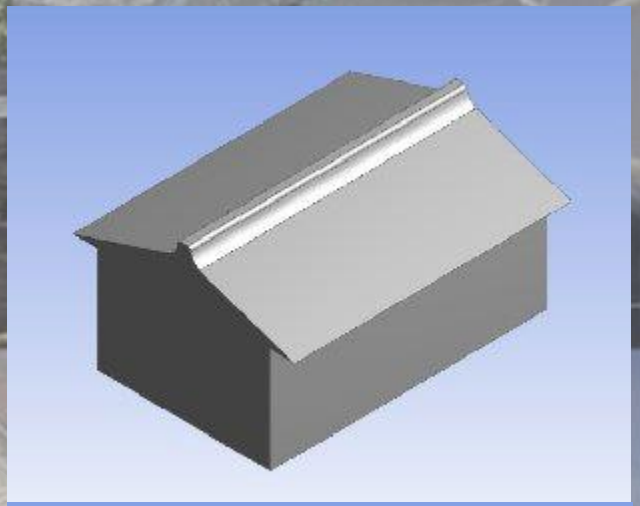
Category
Five
Four
Three
Two
One

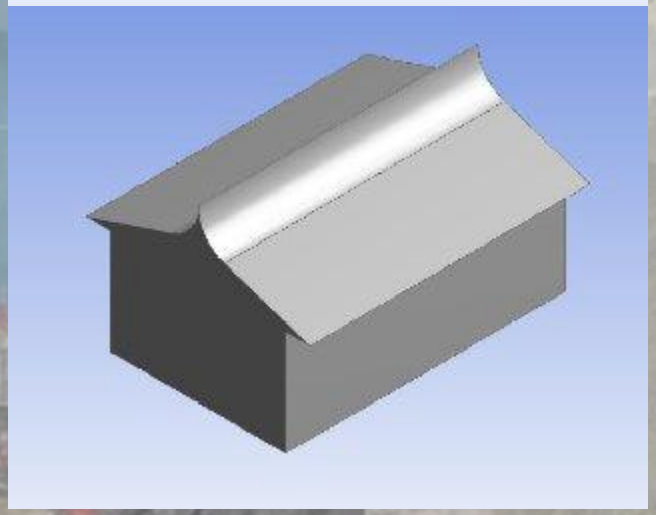
Recommendations

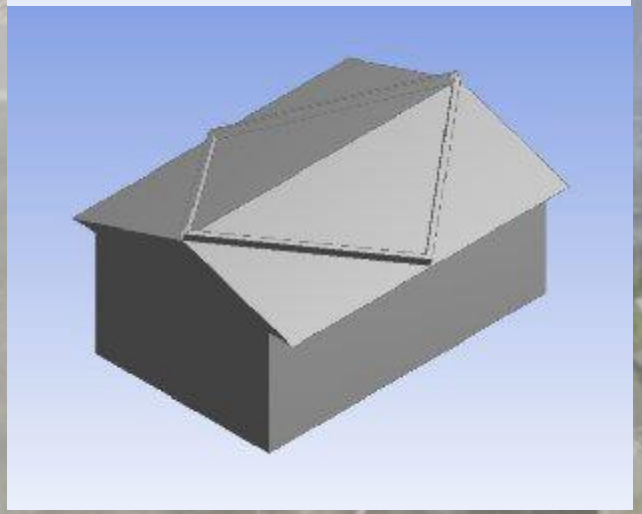
AERODYNAMIC MODIFICATION OF BUILDINGS TO REDUCE WIND DEMAND

Maliwanag, J. , Tan, L. , and Hernandez, J. (2015)









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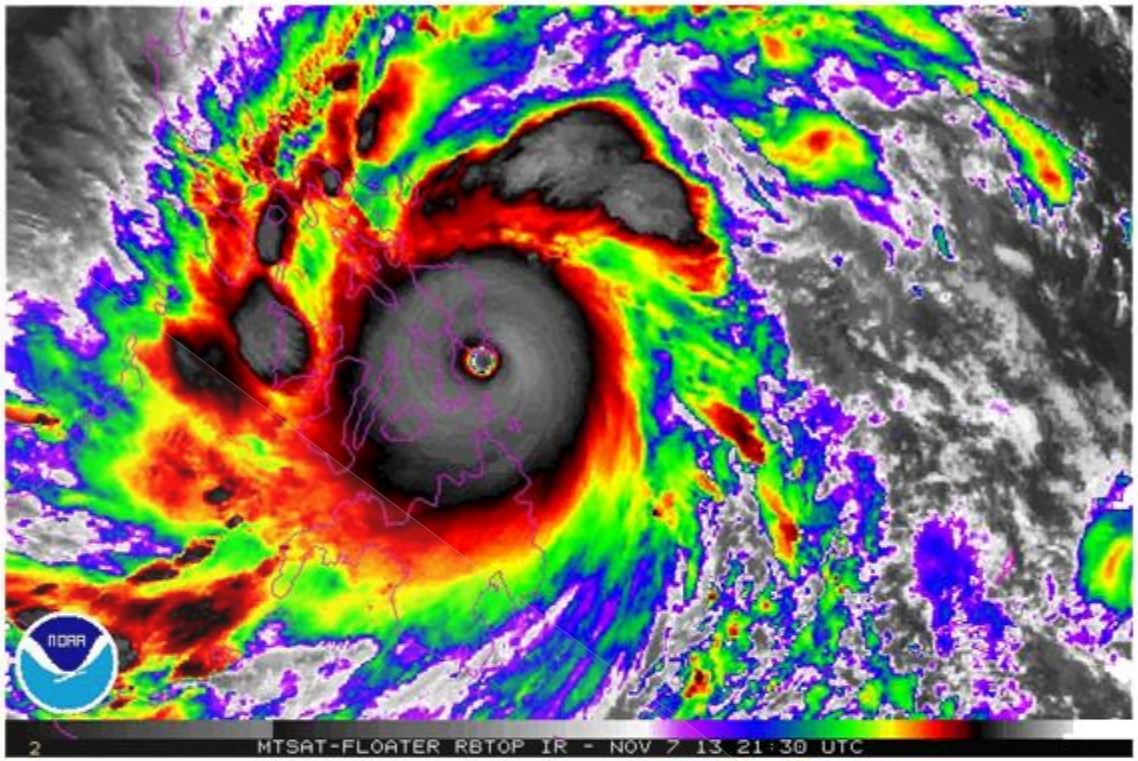
Thank you very much!
ありがとうございます!
감사합니다!



ESTIMATING TYPHOON HAIYAN'S WIND SPEEDS USING WINDICATORS AND POST-STORM VULNERABILITY ANALYSIS ON THE AFFECTED AREAS

Engr. Joshua C. Agar ; Dr. Jaime Y. Hernandez Jr. ; Engr. William L. Mata

End