Comparative Analysis of Parametric Cyclone Models for Surface Wind and Sea Level Pressure Modeling for Storm Surge Simulations

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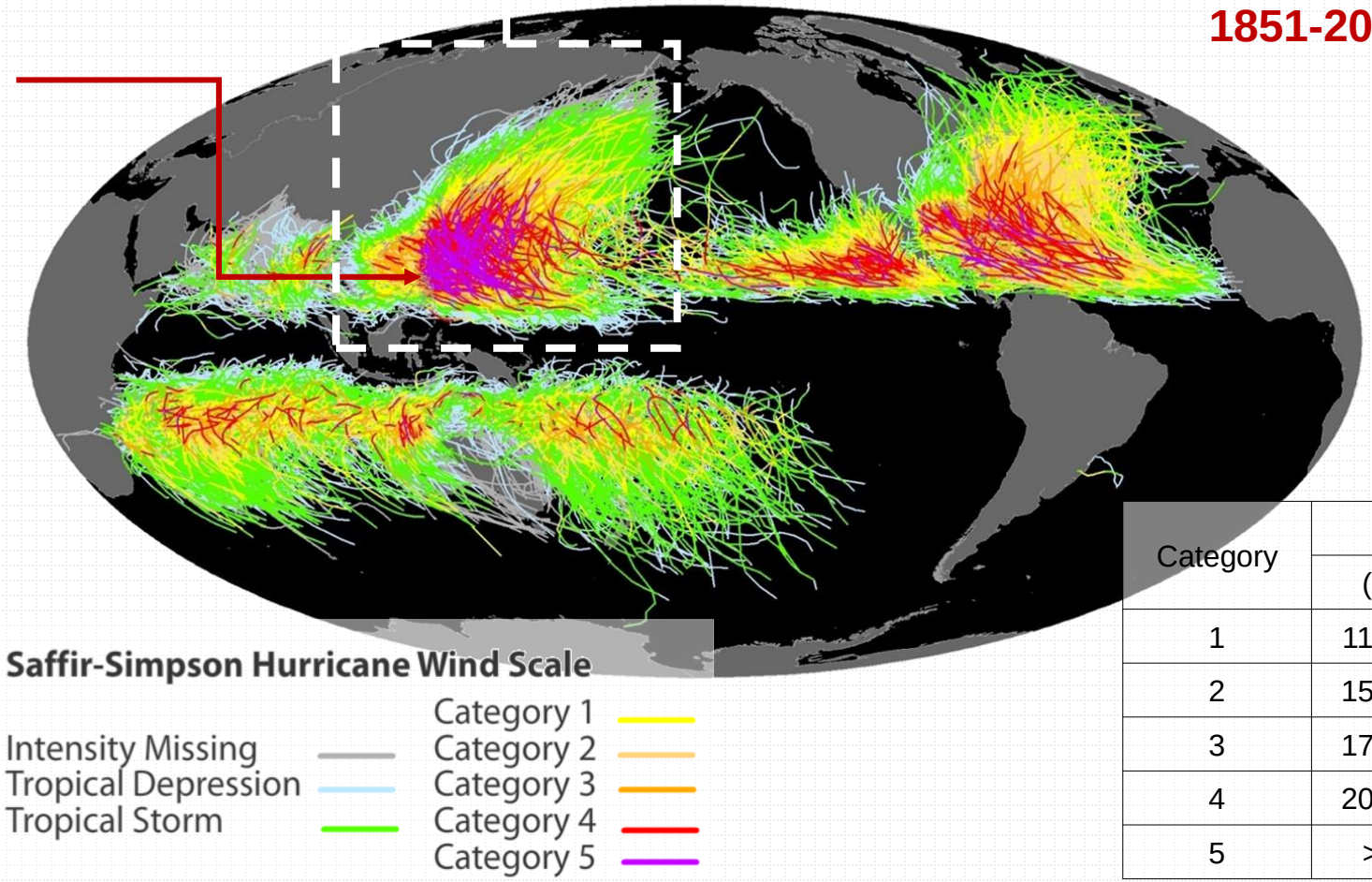
Tropical Cyclones

Western North Pacific Basin

Philippines

Tracks of all recorded cyclones 1851-2008



Category	Wind Speed	
	(kph)	(kt)
1	119-153	64-82
2	154-177	83-95
3	178-208	96-112
4	209-251	178-208
5	>252	>137

Image Credits: : https://www.climate.gov/news-features/understanding-climate/tropical-cyclone-tracks

Storm Surges

Image Credits: http://www.dailymail.co.uk/news/article-2507119/Philippines-Typhoon-Haiyan-UN-aid-chief-admits-response-slow.html

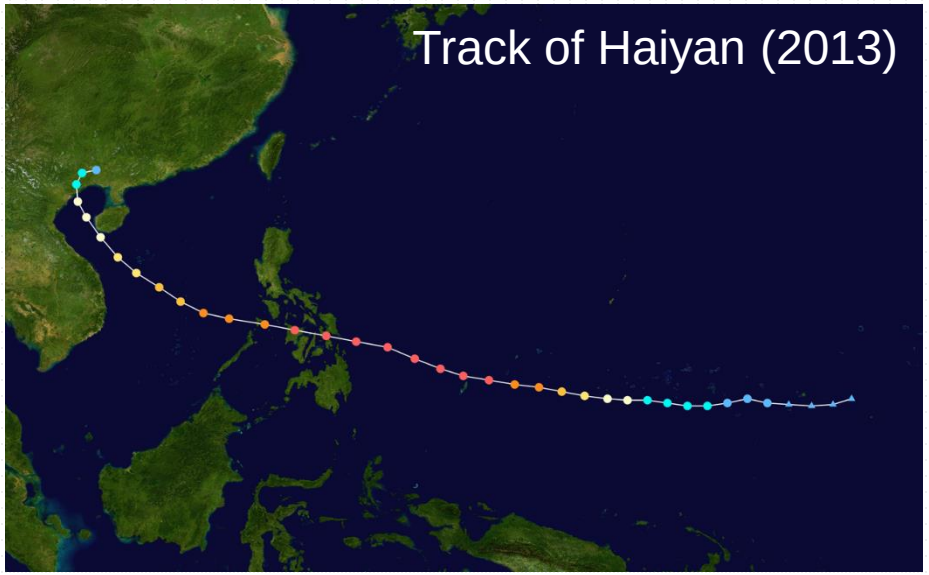


Image Credits: https://en.wikipedia.org/wiki/Meteorological_history_of_Typhoon_Haiyan

Image Credits: http://pcd07.ie/student-corner/bailiuchan-ar-shon-iospartaigh-tiofun-hayian/

Storm Surges

Image Credits: http://www.panahon.tv/blog/2016/10/faces-of-breathtaking-batanes//

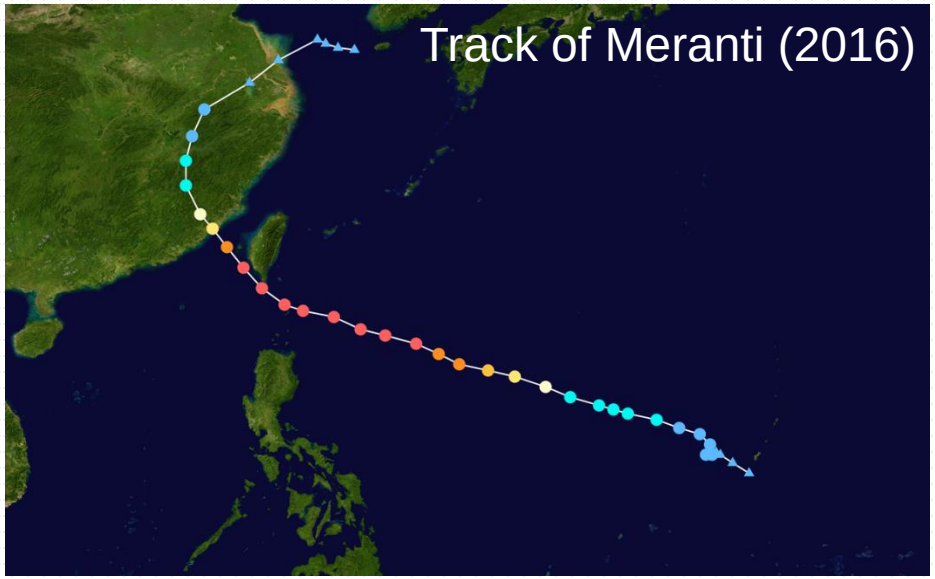
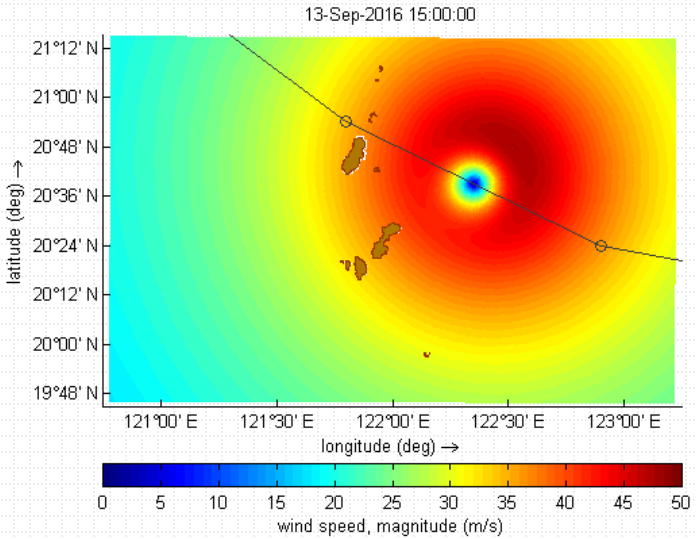
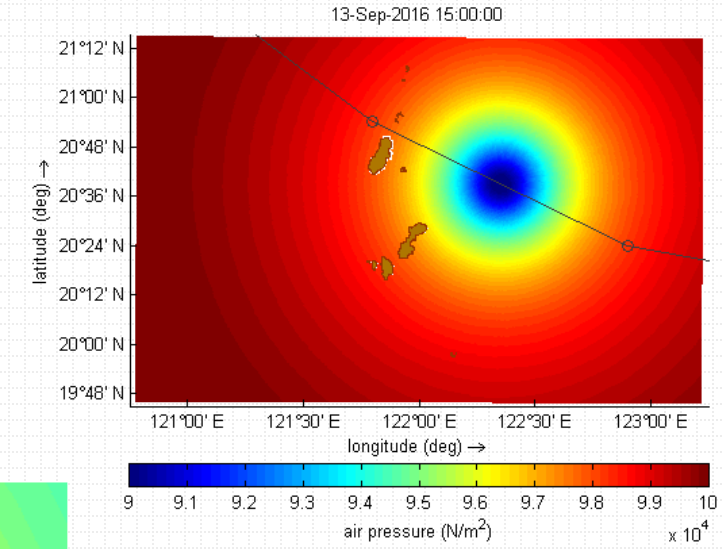
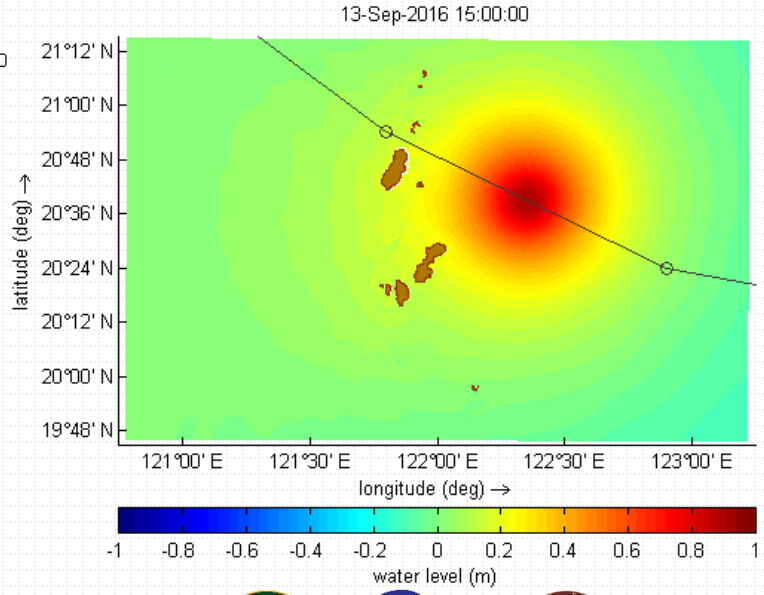


Image Credits:
https://commons.wikimedia.org/wiki/File:Meranti_2016_track.png

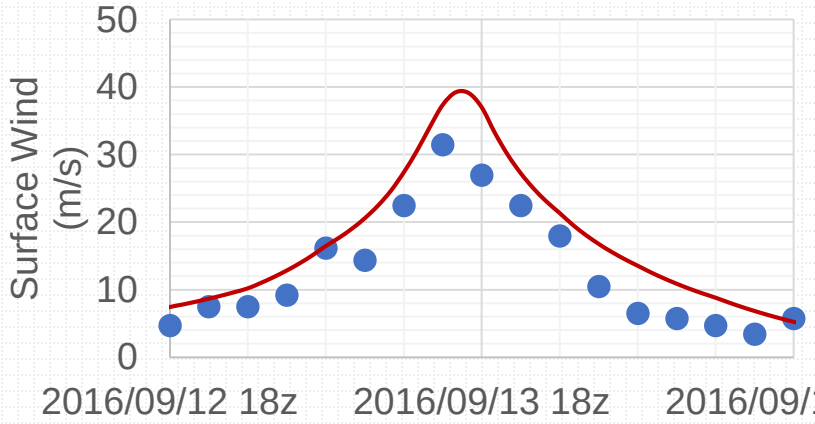
Storm Surge Modeling

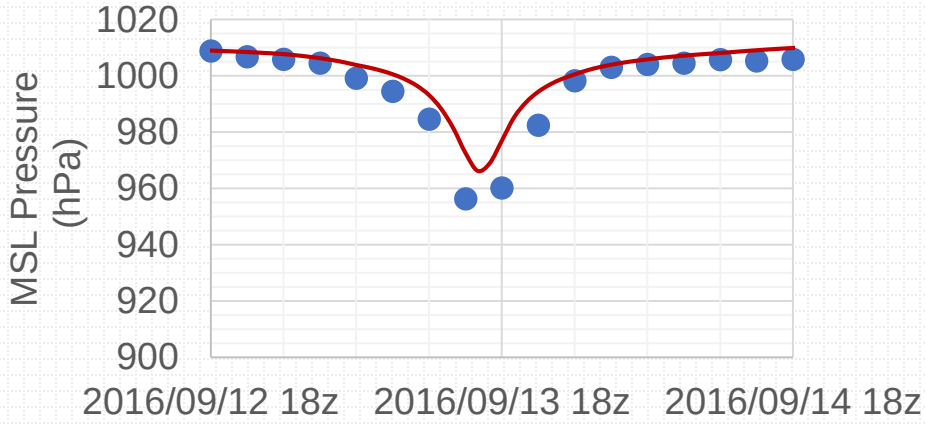


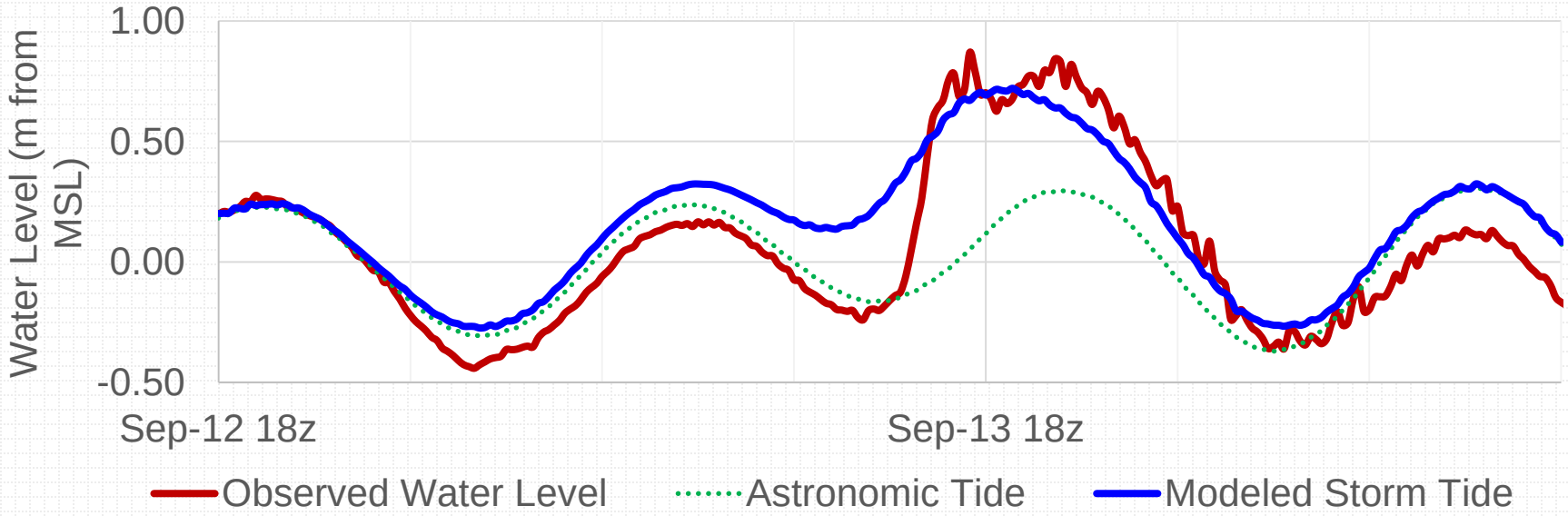




Storm Surge Modeling







Parametric Cyclone Models

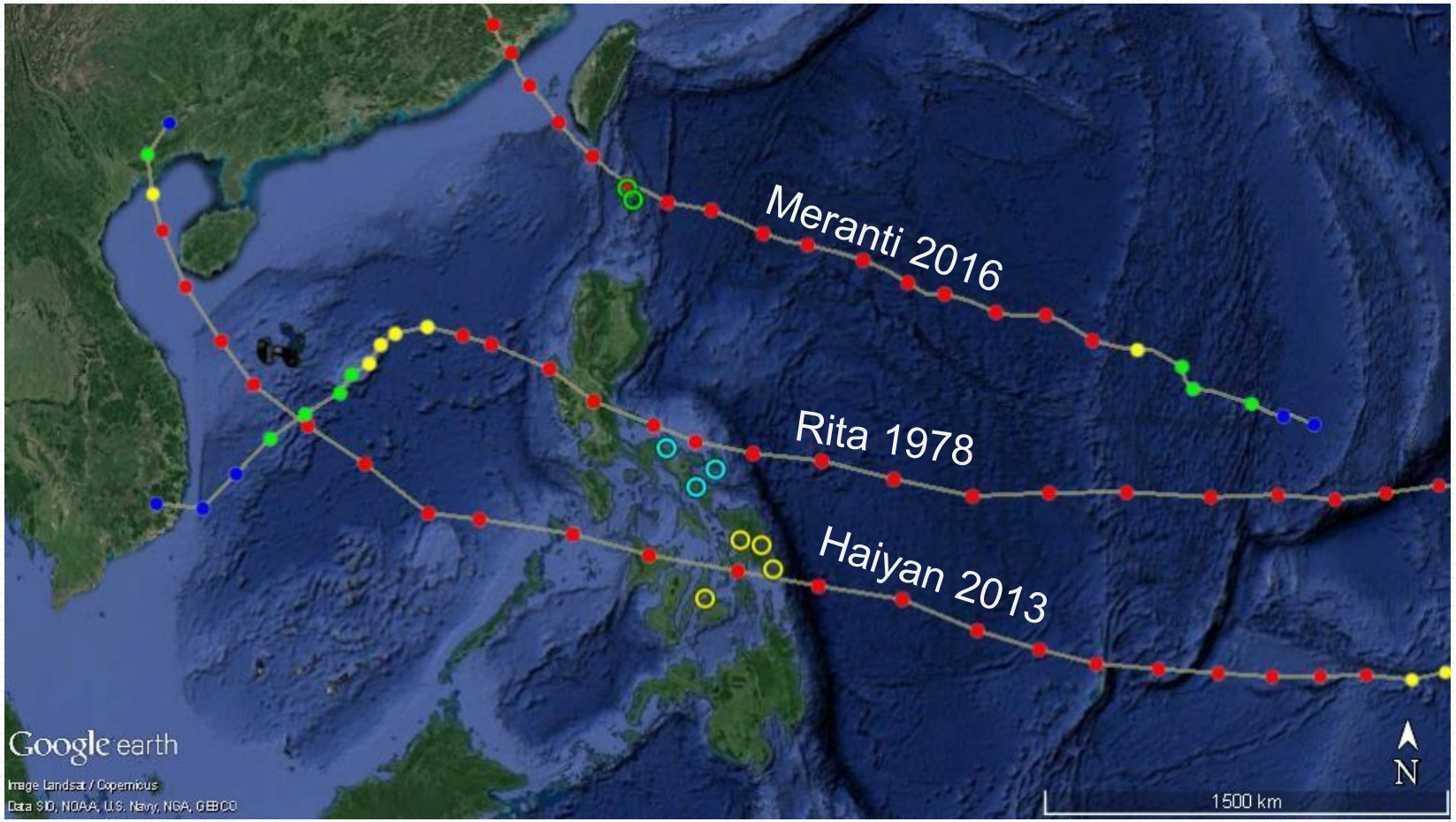
- **Sea Level Pressure Field**
  - Fujita (1952)
  - Schloemer (1954)
  - Holland (1980)
- **Surface Wind Field**
  - Modified Rankine Vortex Model
  - Fujita (1952)
  - Holland (1980)
  - Young and Sobey (1980)
  - Holland et al. (2010)
- **Radius of Maximum Winds**
  - Gross et al. (2004)
  - Vickery and Wadhera (2008)

Methods

Typhoon Cases

Typhoon	Maximum Wind (kt)	MSLP (hPa)
Meranti (2016)	120	890
Rita (1978)	120	880
Haiyan (2013)	125	895

JMA Best Track Archive

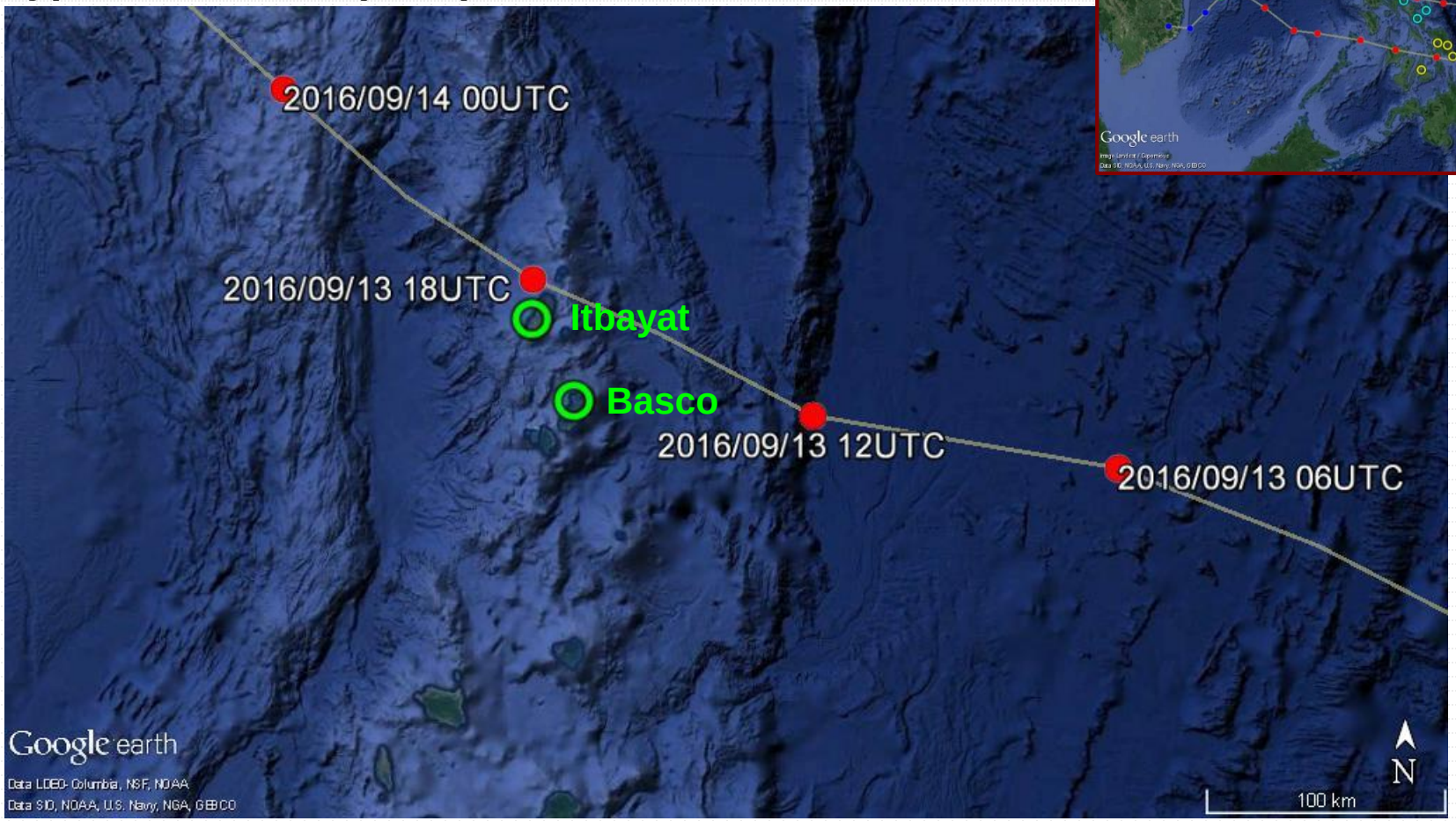


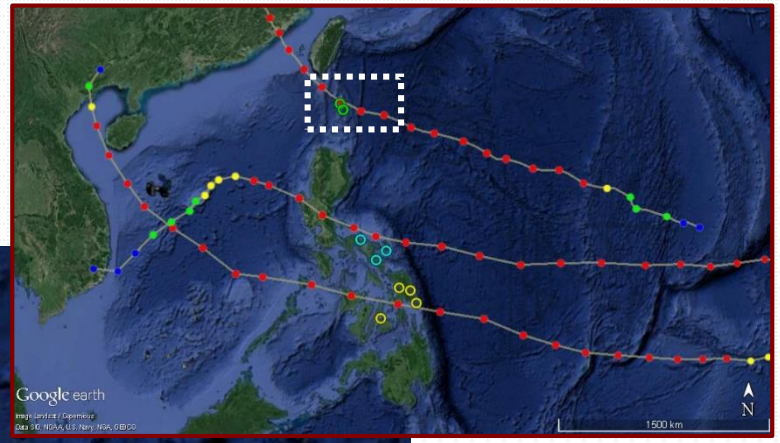
Typhoon Cases

Station	Latitude (°N)	Longitude (°E)	Station Elevation (m above MSL)	Location Description
Itbayat, Batanes	20°48’	121°51’	124	Small remote island
Basco, Batanes	20°26’	121°57’	167	Small remote island
Daet, Camarines Norte	14°07’	122°57’	4	East coast of the Philippines, upwind of a topographic feature
Virac, Catanduanes	13°35’	124°14’	40	South coast of Catanduanes island, with topographic feature north of the station
Legazpi, Albay	13°08’	123°44’	19	Immediately south of a prominent topographic feature
Guiuan, Samar	11°02’	125°44’	6.0	Eastern part of Samar island; vicinity has relatively flat terrain
Borongan, Samar	11°39’	125°26’	2.4	East coast of Samar island, upwind of a topographic feature
Catbalogan, Samar	11°47’	124°53’	5	West coast of Samar island, downwind of a topographic feature
Mactan, Cebu	10°19’	123°59’	2.3	Island in Central Visayas; vicinity has relatively flat terrain

Typhoon Cases

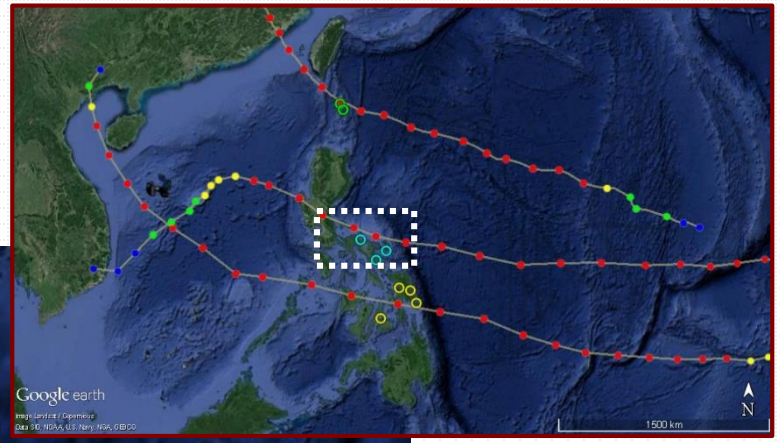
Typhoon Meranti (2016)





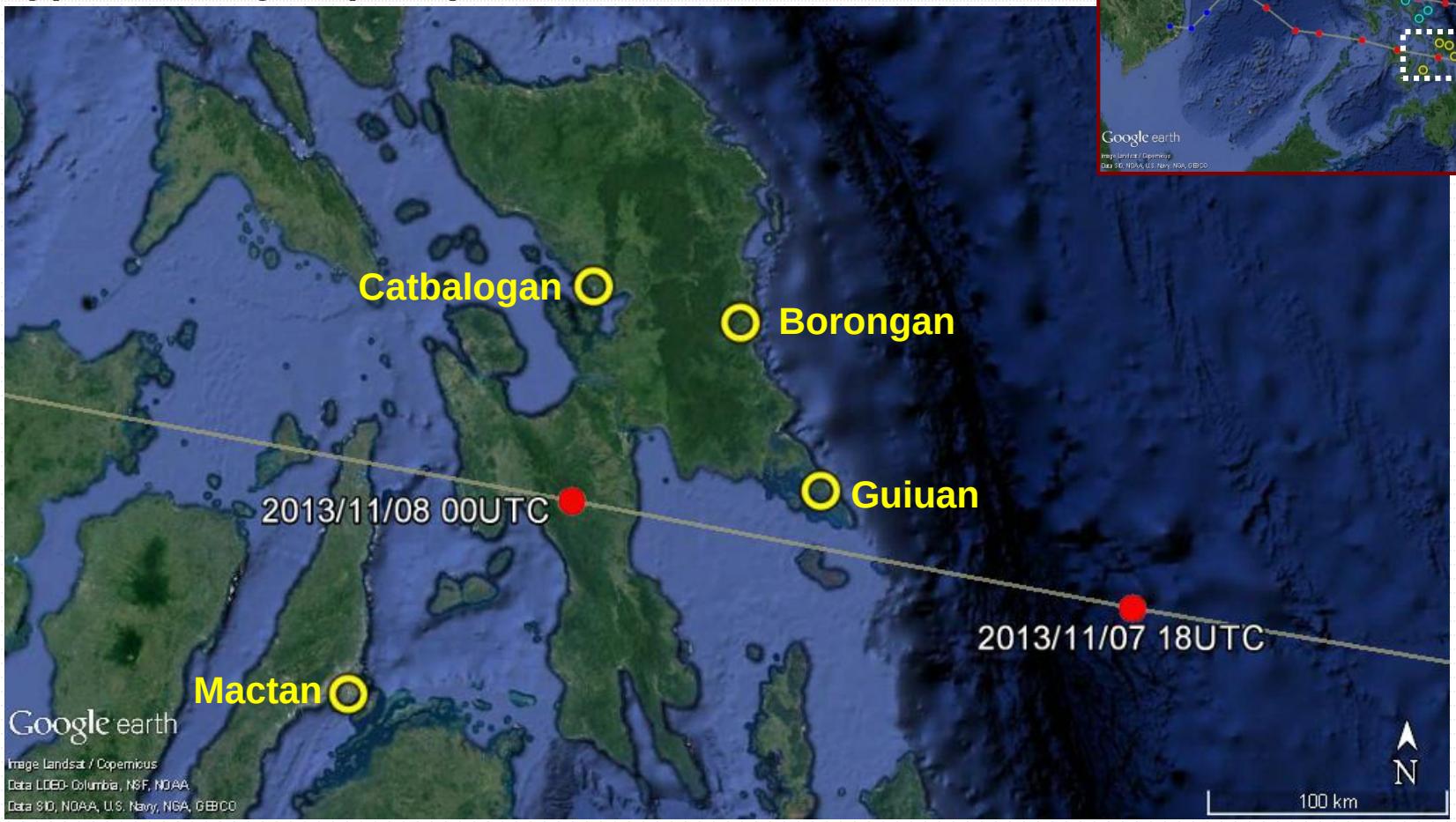
Typhoon Cases

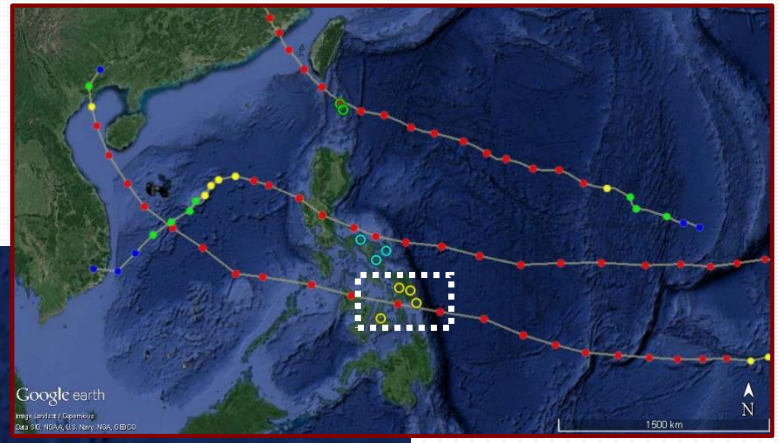
Typhoon Rita (1978)



Typhoon Cases

Typhoon Haiyan (2013)





Parametric Cyclone Models

- **Sea Level Pressure Field**
  - Fujita (1952)

$$P = P_\infty - \frac{P_\infty - P_c}{\sqrt{1 + (r/r_0)^2}}$$

  - Schloemer (1954)

$$P = P_c + (P_\infty - P_c)\mathrm{e}^{-r_{max}/r}$$

  - Holland (1980)

$$P = P_c + (P_\infty - P_c)\mathrm{e}^{\left(-r_{max}/r\right)^B}$$

Parametric Cyclone Models

- **Surface Wind Field**
  - Modified Rankine Vortex Model

$$V_g = \begin{cases} V_{max}\left(\frac{r}{r_{max}}\right), & for\ 0 \le r < r_{max} \\ V_{max}\left(\frac{r}{r_{max}}\right)^{-X}, & for\ r > r_{max} \end{cases}$$

  - Fujita (1952)

$$V_g = -fr + r\sqrt{f^2 - \frac{4}{\rho {r_0}^2}\frac{P_\infty - P_c}{\left[1 + ({}^{r}/_{r_0})^2\right]^{3/2}}}$$

  - Holland (1980)

$$V_c = \left[r_{max}^B B(P_\infty - P_c)\ \mathrm{e}^{\left(-{}^{r_{max}}/_{r}\right)^B}\frac{1}{\rho r^B}\right]^{1/2}$$

  - Young and Sobey (1980)

$$V_g = \begin{cases} V_{max}\left(\frac{r}{r_{max}}\right)^7 \mathrm{e}^{\left(7\left(1-\frac{r}{r_{max}}\right)\right)}, & for\ r < r_{max} \\ V_{max}\mathrm{e}^{\left((0.0025r_{max}+0.05)\left(1-\frac{r}{r_{max}}\right)\right)}, & for\ r \ge r_{max} \end{cases}$$

  - Holland et al. (2010)

$$V_c = V_{max}\left\{\left(\frac{r_{max}}{r}\right)^{B_s}\mathrm{e}^{\left[1-\left({}^{r_{max}}/_{r}\right)^{B_s}\right]}\right\}^{\mathrm{x}}$$

Parametric Cyclone Models

- **Radius of Maximum Winds**
  - Gross et al. (2004)

    $r_{max} = 35.37 - 0.111V_{max} + 0.570(\Psi - 25)$
  - Vickery and Wadhera (2008)

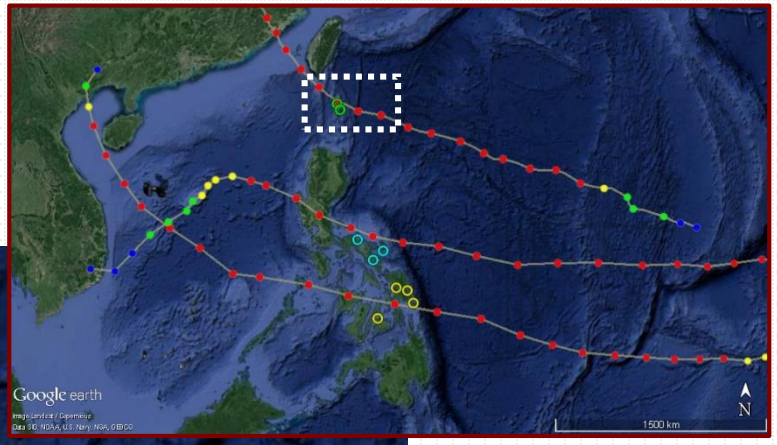
    $\ln(r_{max}) = 3.015 - 6.291 \times 10^{-5}(\Delta p)^2 + 0.0337\Psi$

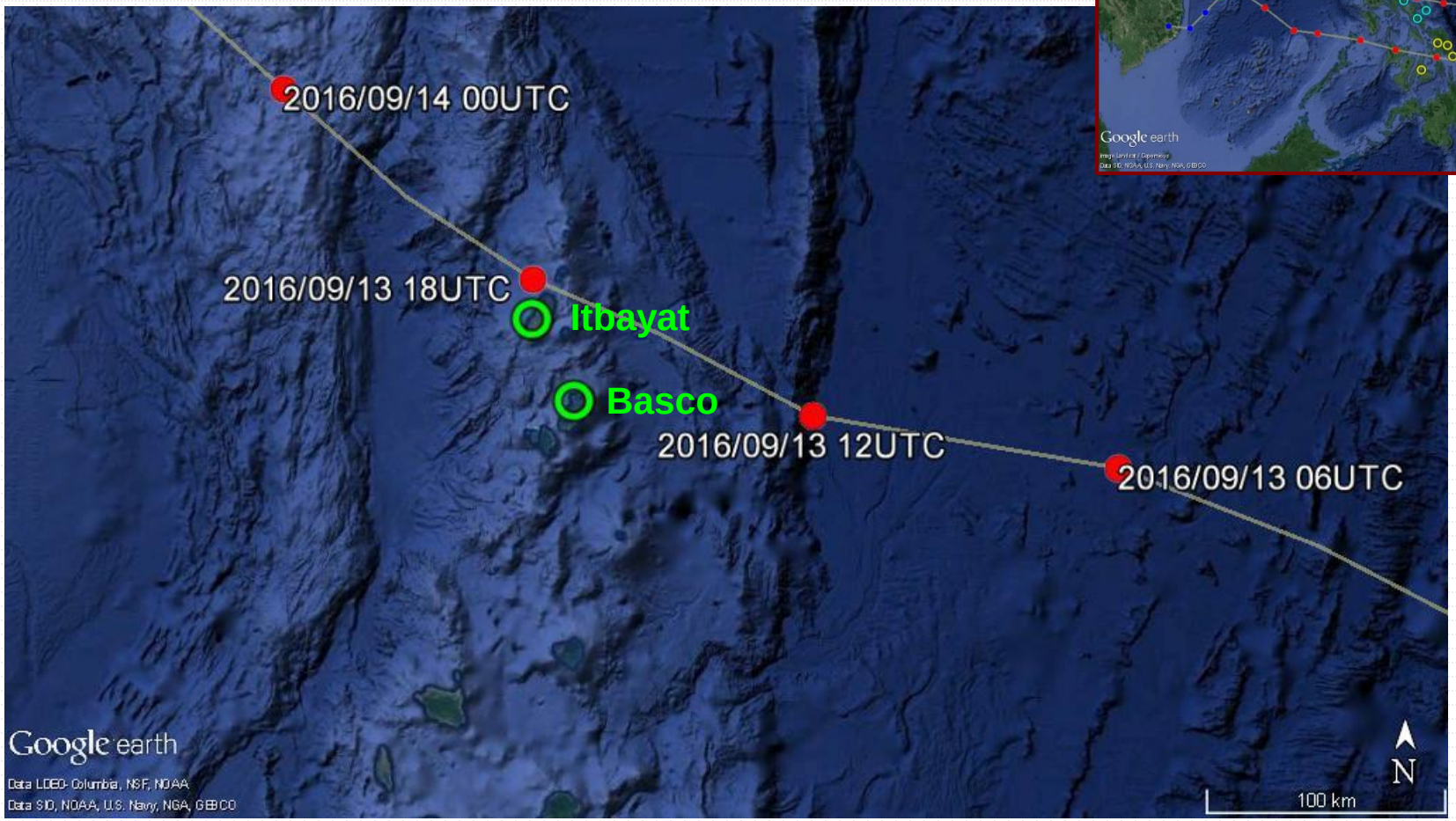
Tropical Cyclone Modeling

- JMA Best Track Archive
- Gradient to surface wind transformation factor = 0.7 (Harper et al., 2001)
- Over-land to over-water surface wind conversion following CEM (2005)
- Ambient Atmospheric Pressure = 1010 hPa
- Delft Dashboard Tool
  - Holland et al. (2010), Holland (1980), Fujita (1952)
- Mike21 by DHI Cyclone Toolbox
  - Young and Sobey (1981), Modified Rankine Vortex Model

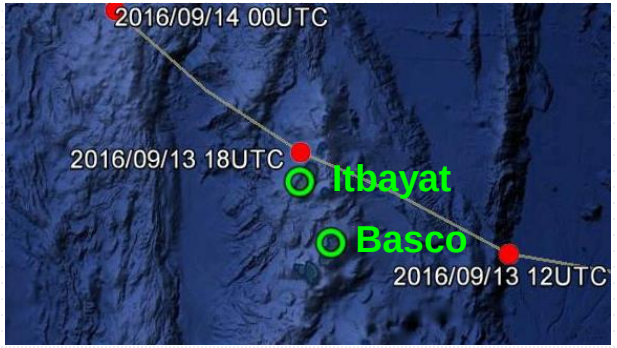
Results

Typhoon Meranti (2016)



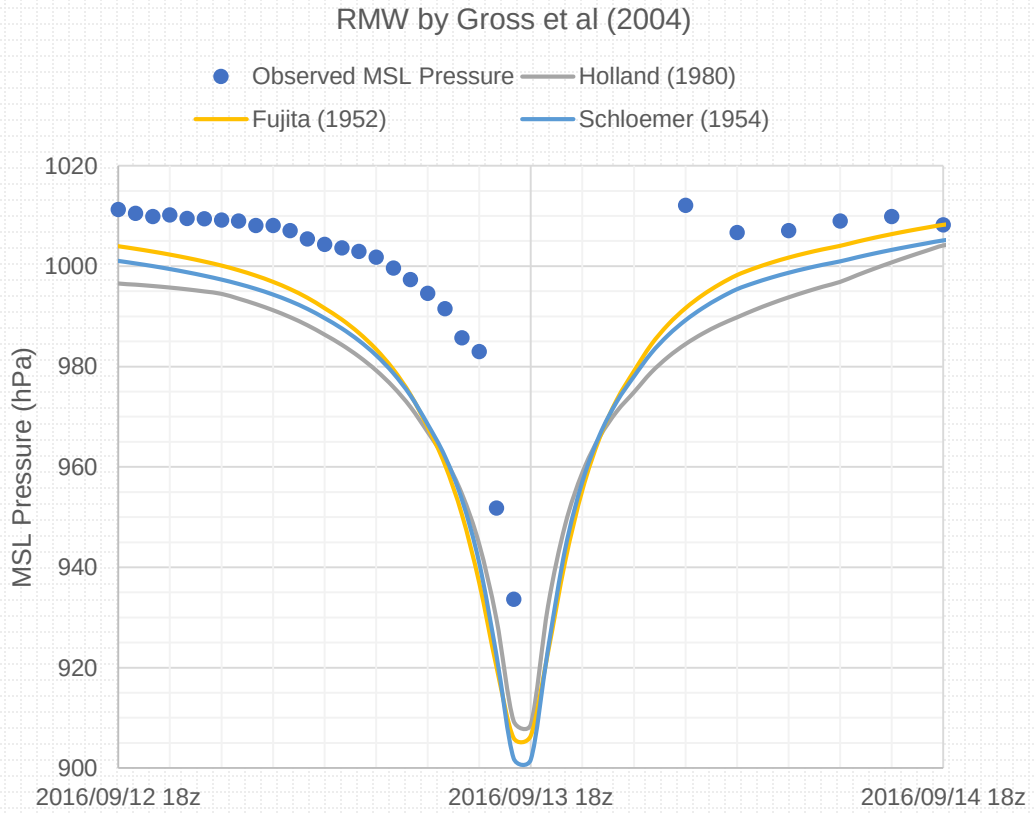


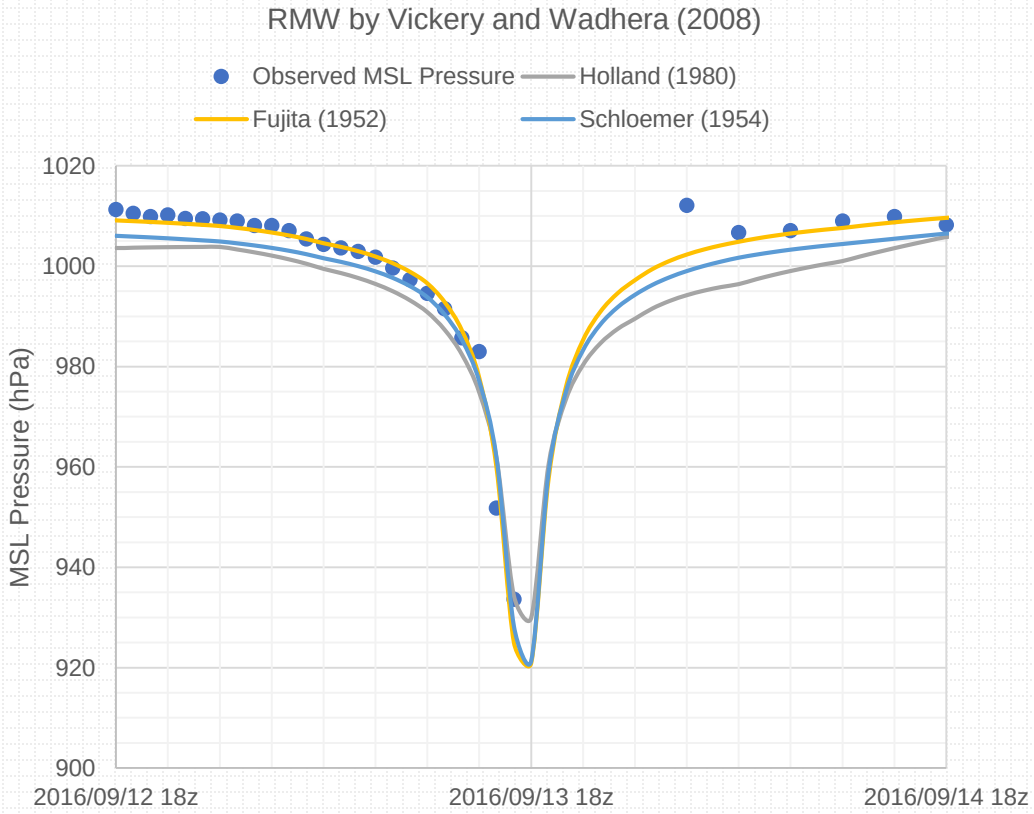
Typhoon Meranti (2016)



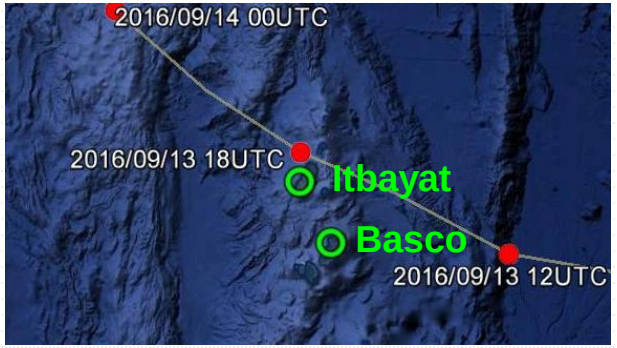
Sea Level Pressure

Itbayat Station



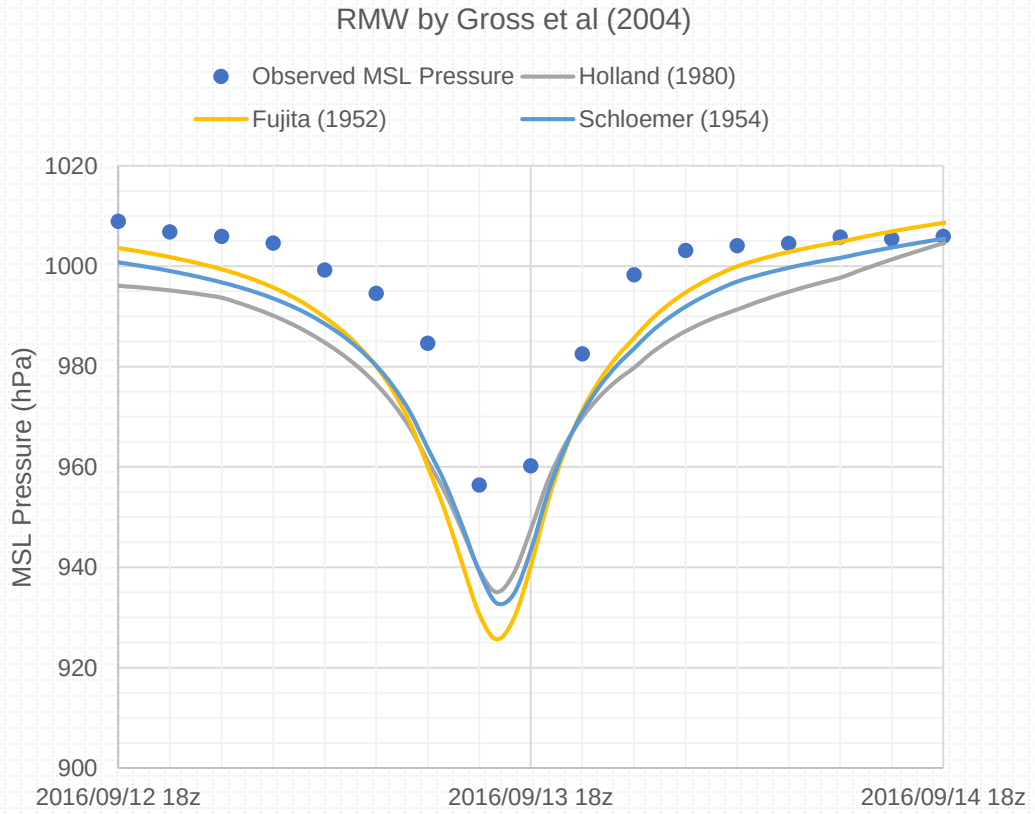


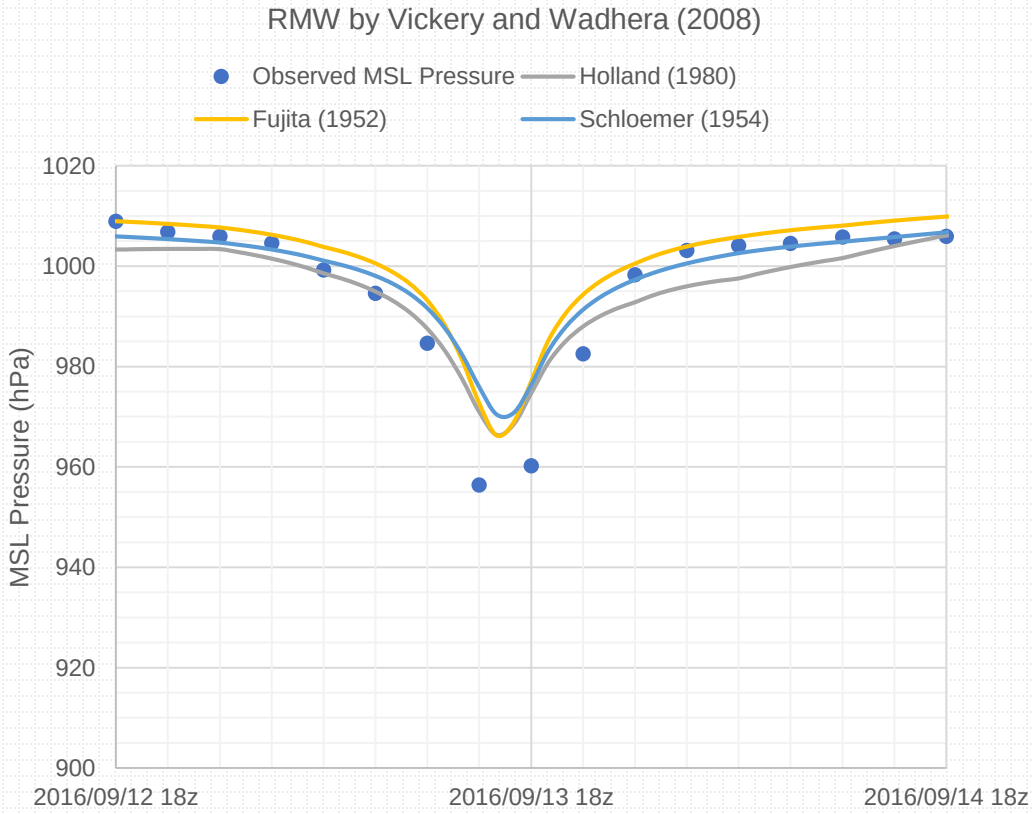
Typhoon Meranti (2016)



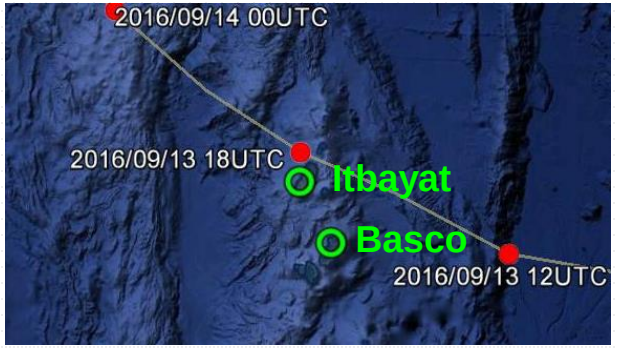
Sea Level Pressure

Basco Station

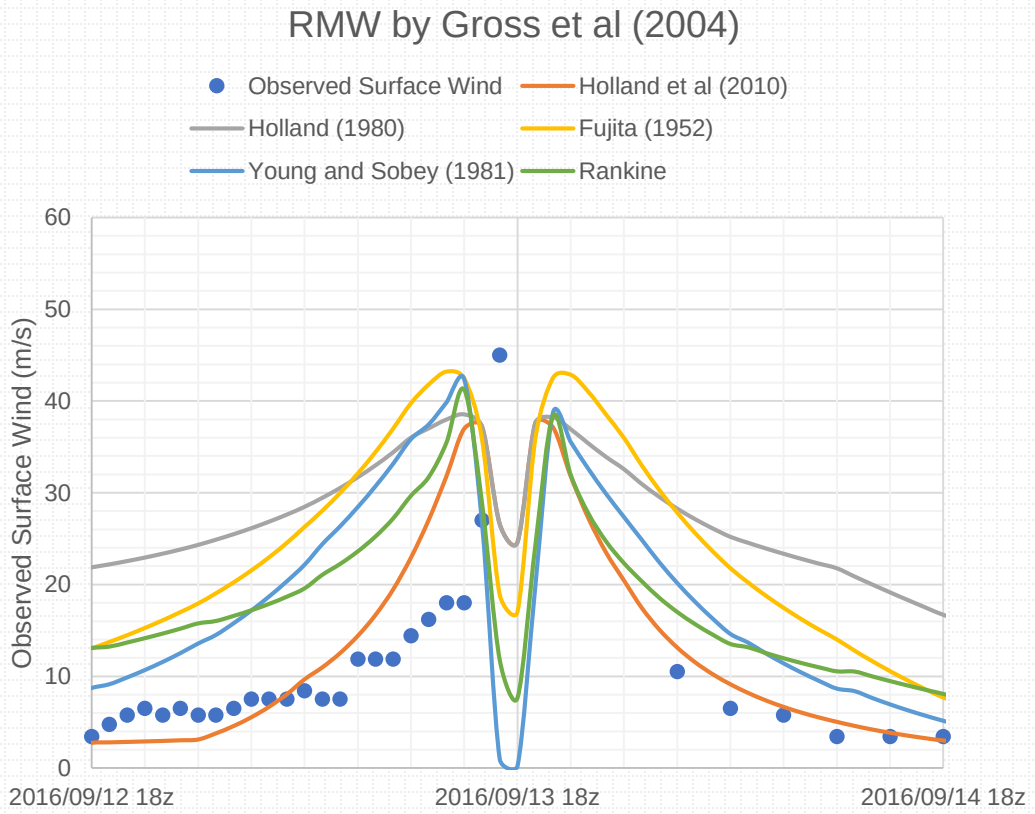


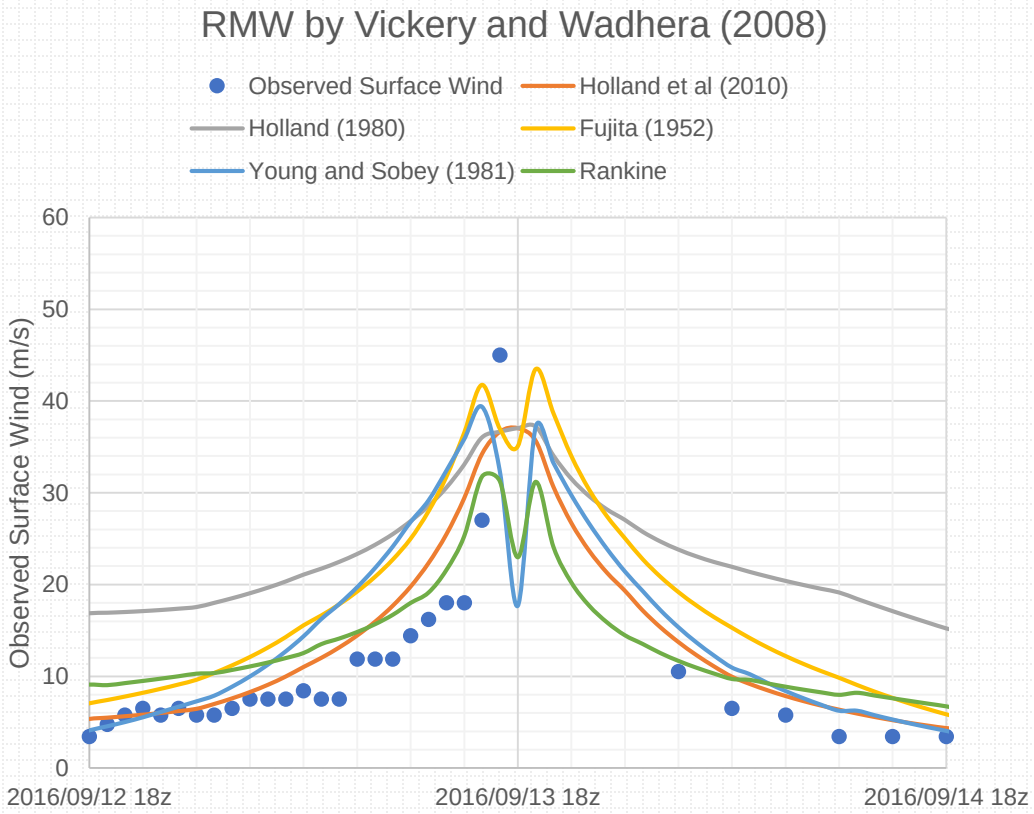


Typhoon Meranti (2016)



Surface Wind
Itbayat Station





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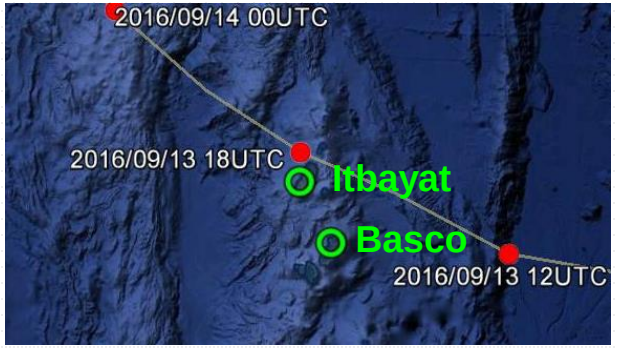
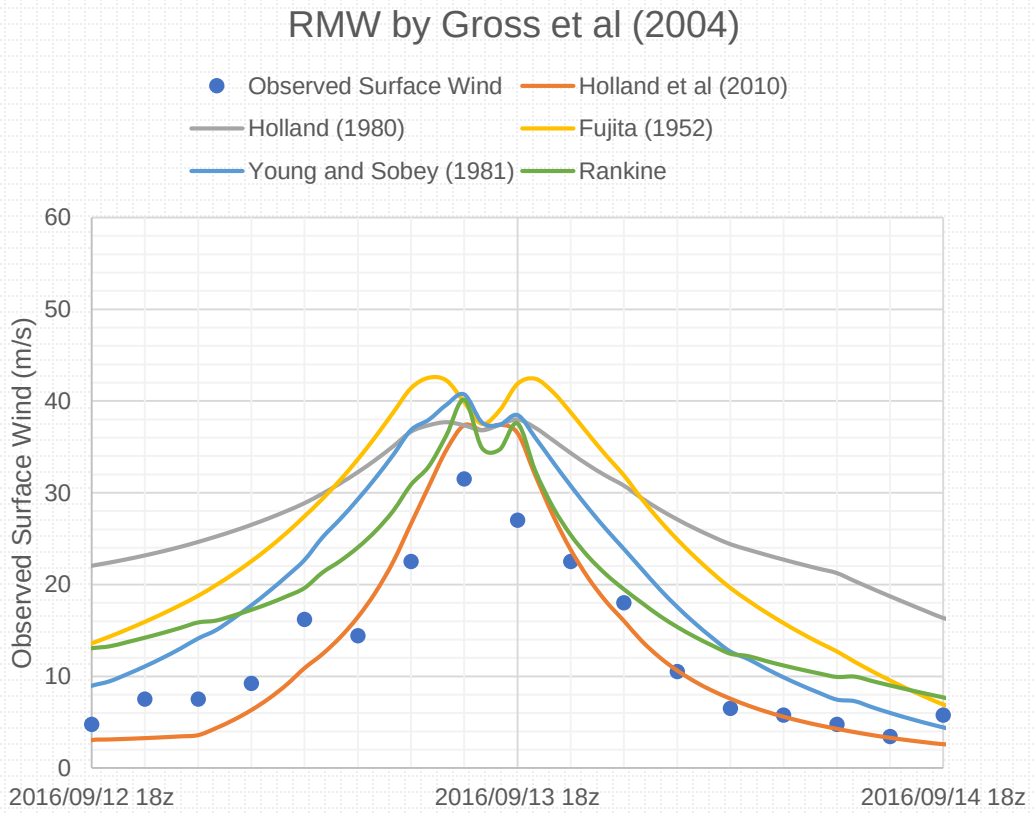
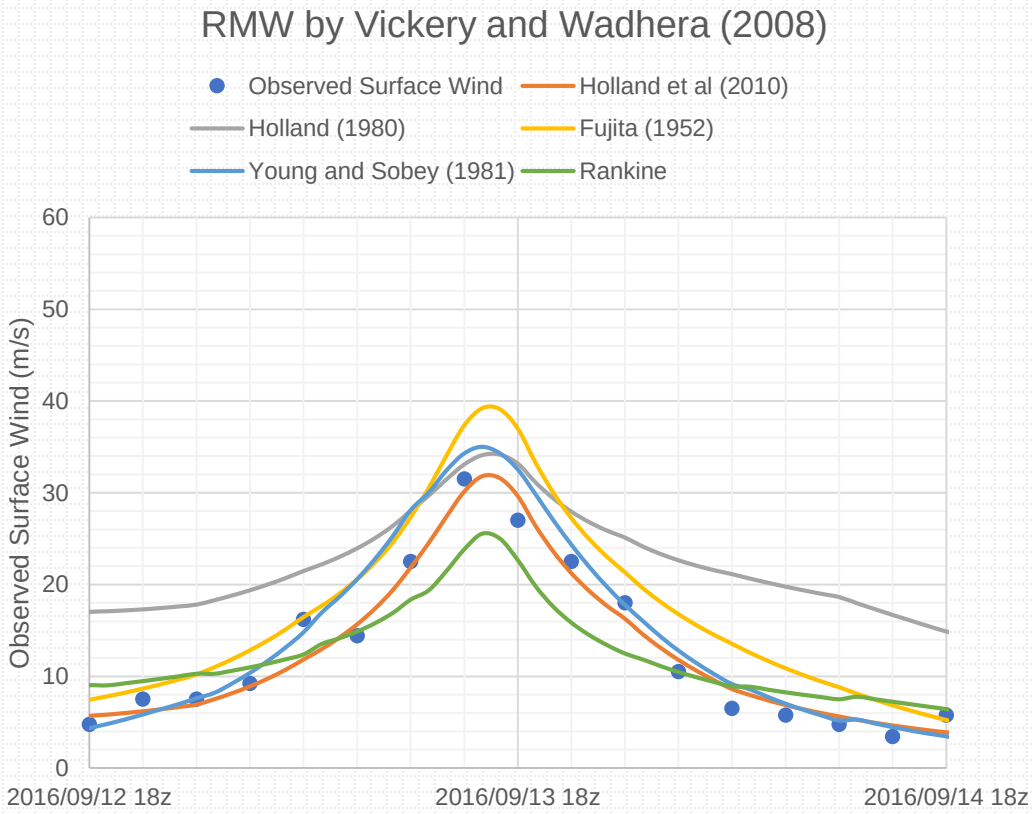
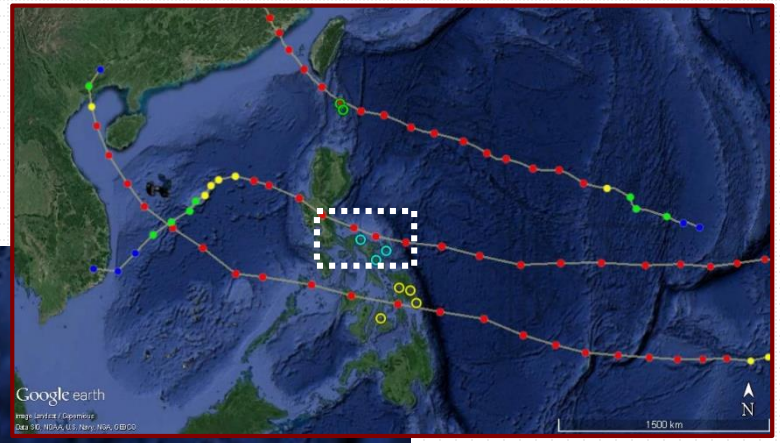


Surface Wind
Basco Station





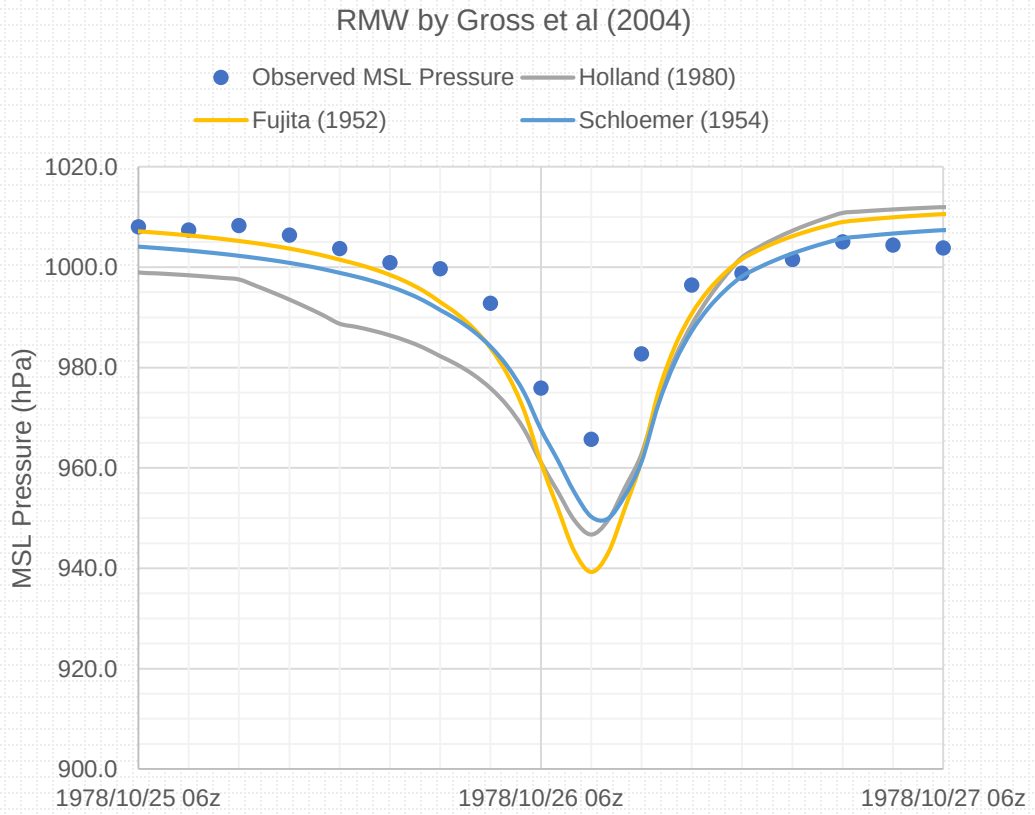
Typhoon Rita (1978)

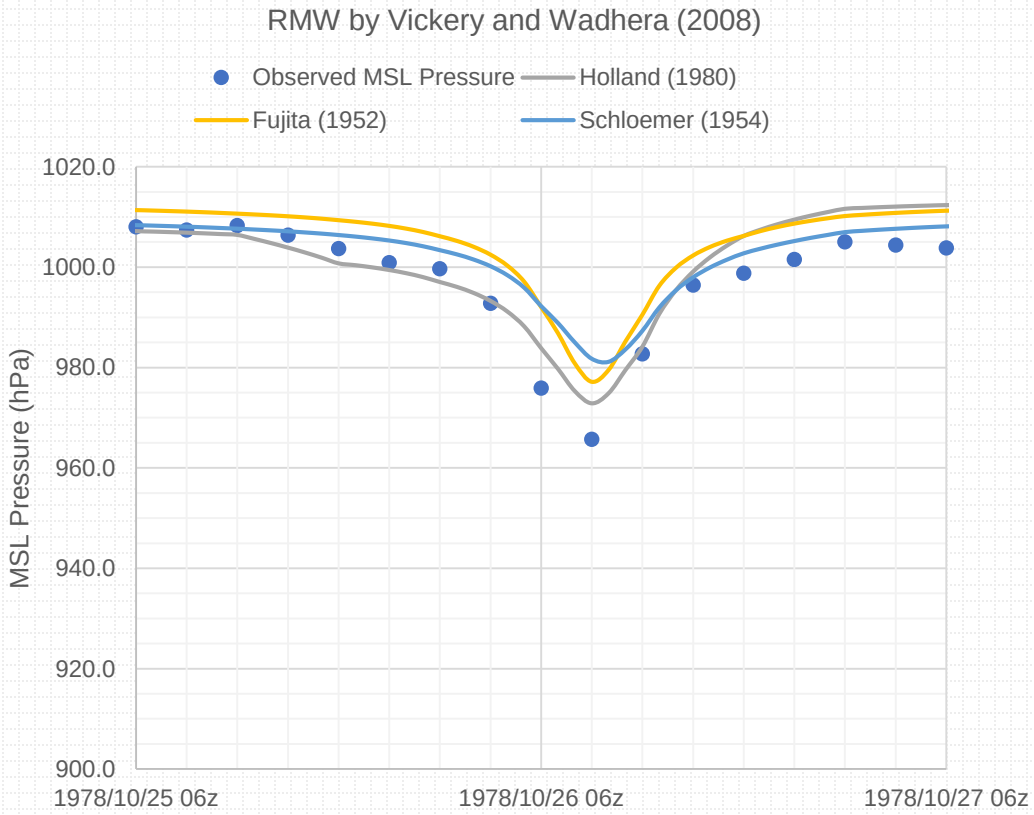


Typhoon Rita (1978)

Sea Level Pressure

Daet Station

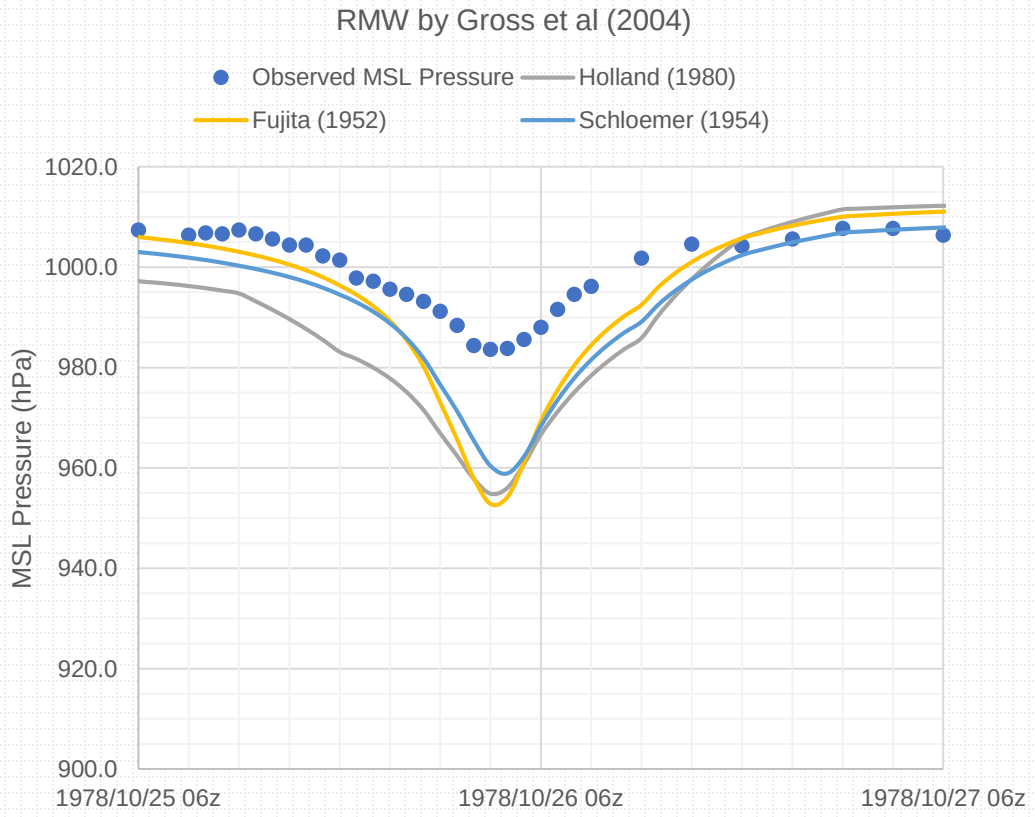


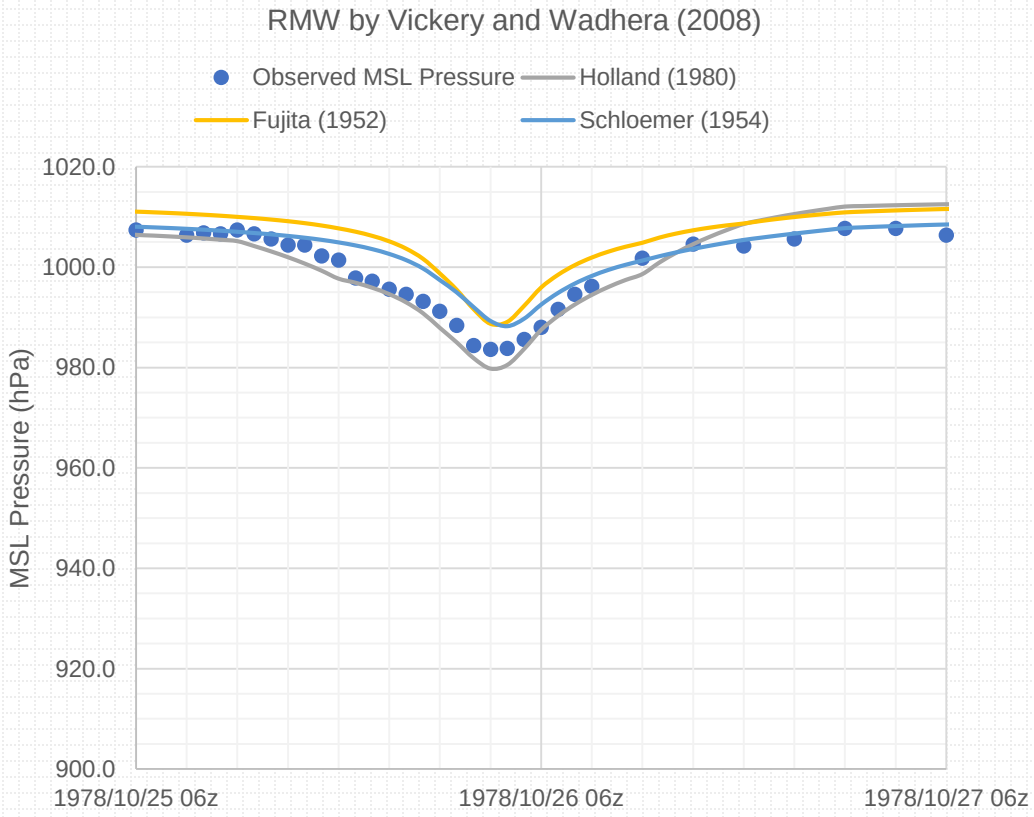


Typhoon Rita (1978)

Sea Level Pressure

Virac Station

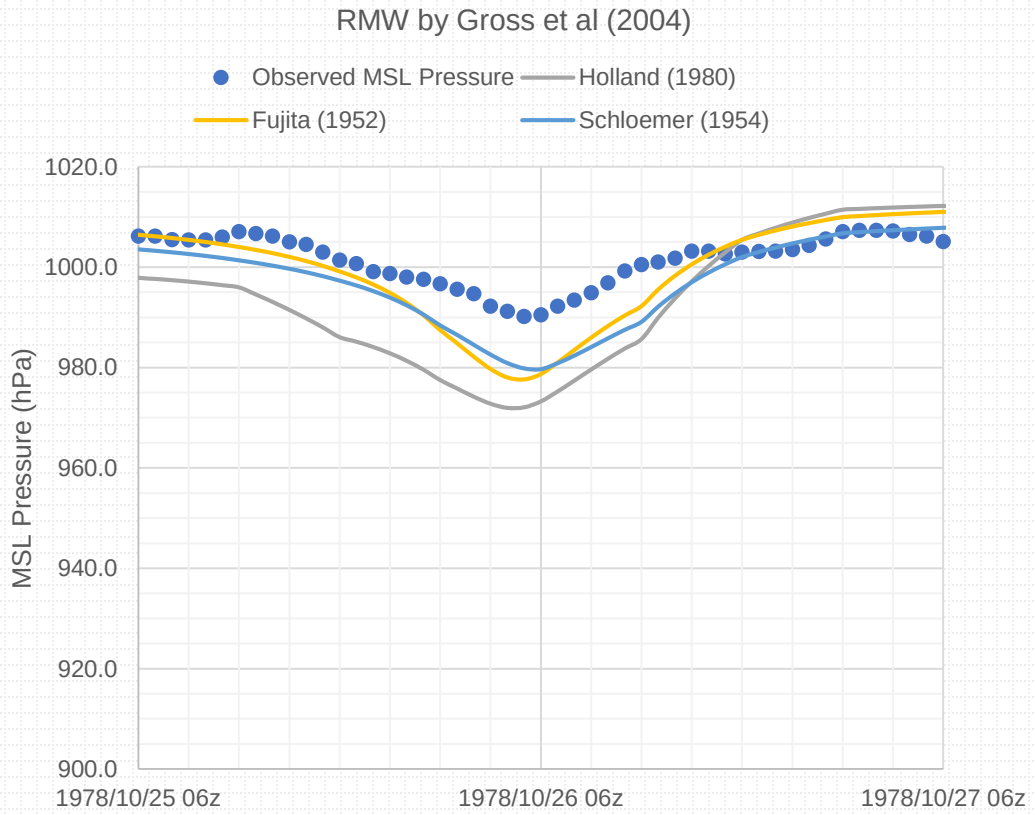


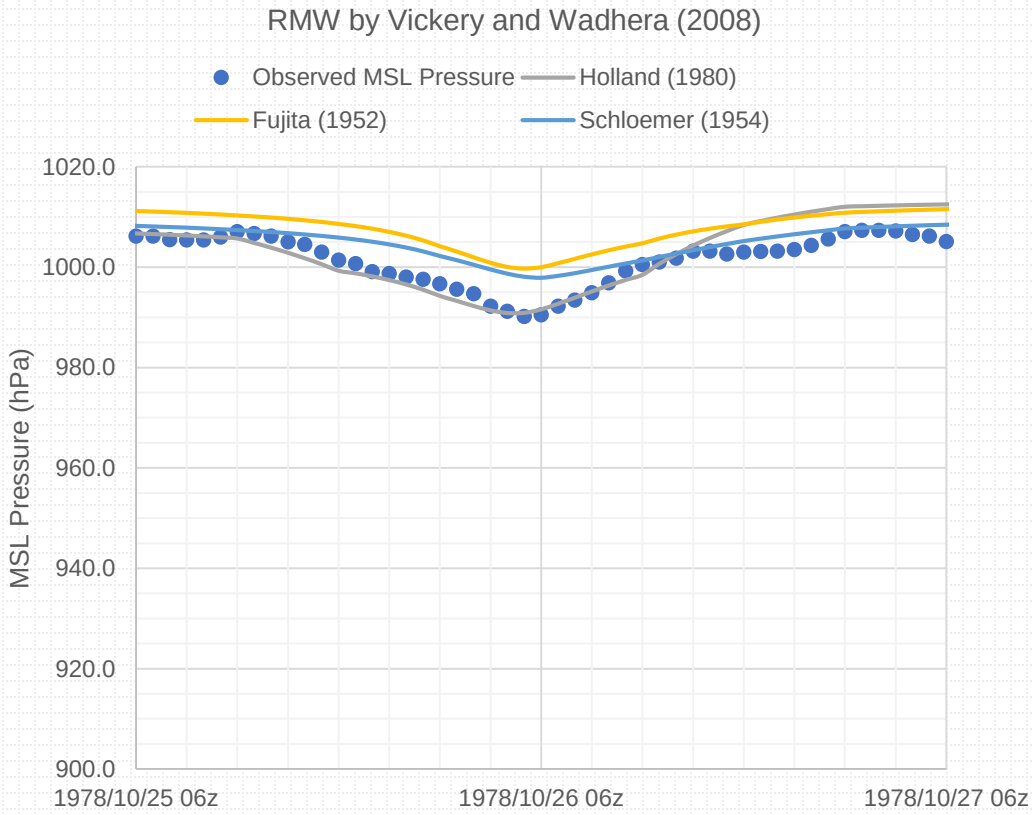


Typhoon Rita (1978)

Sea Level Pressure

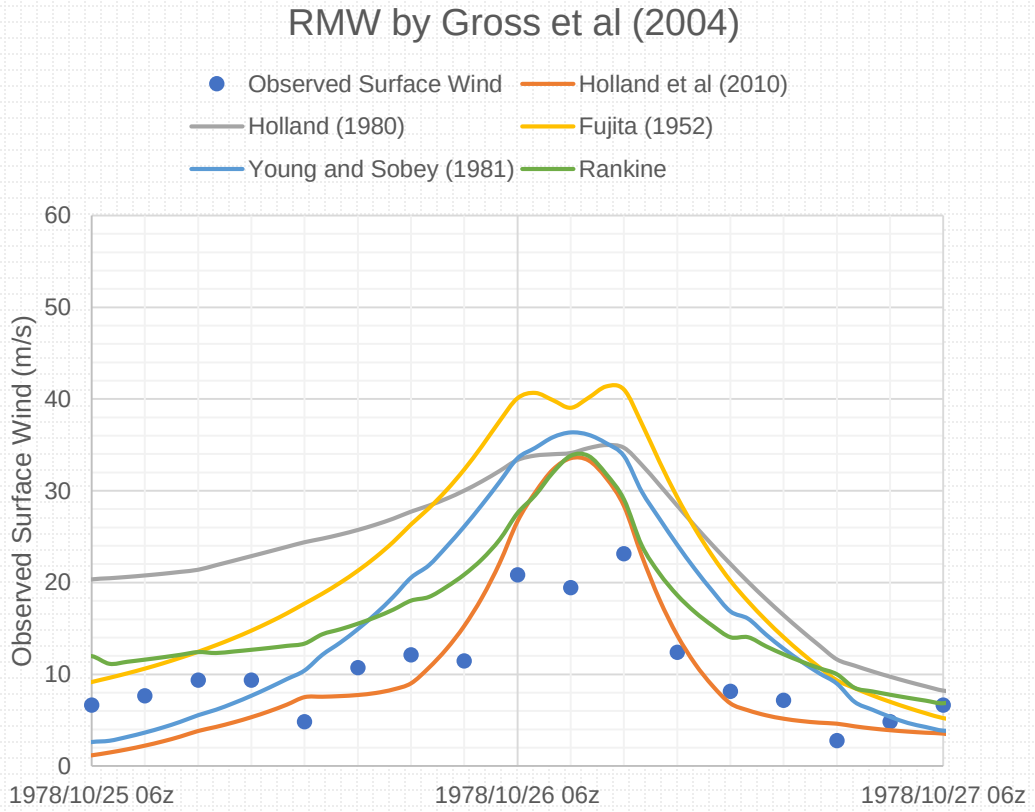
Legazpi Station

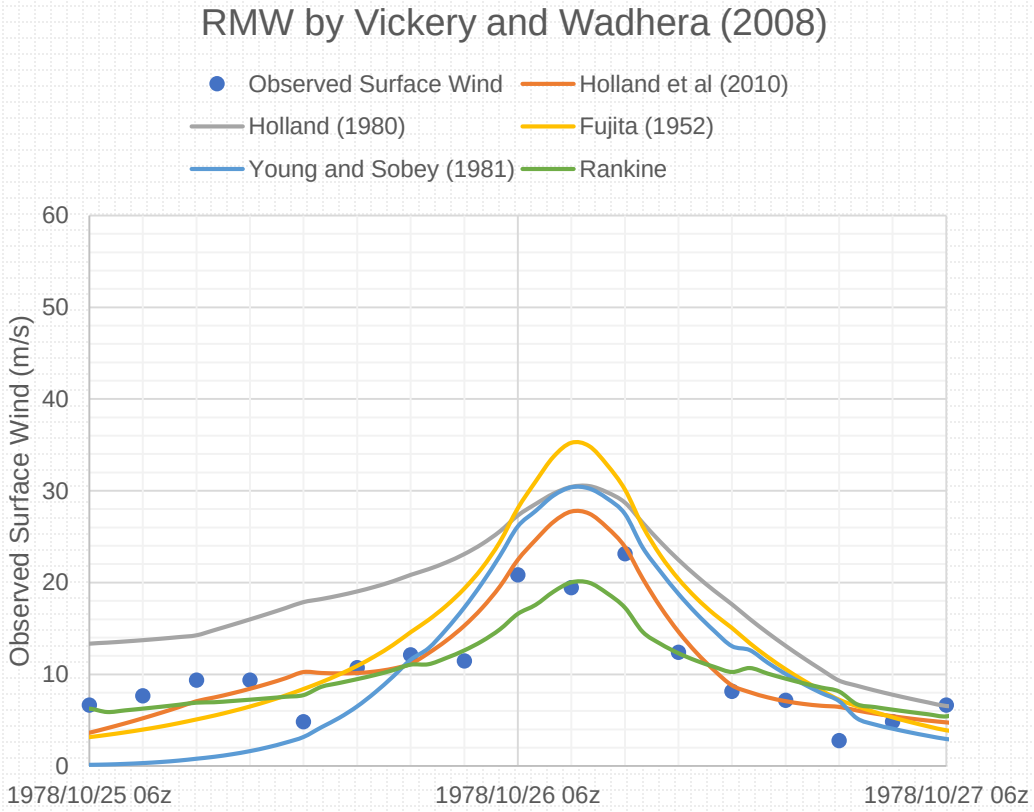




Typhoon Rita (1978)

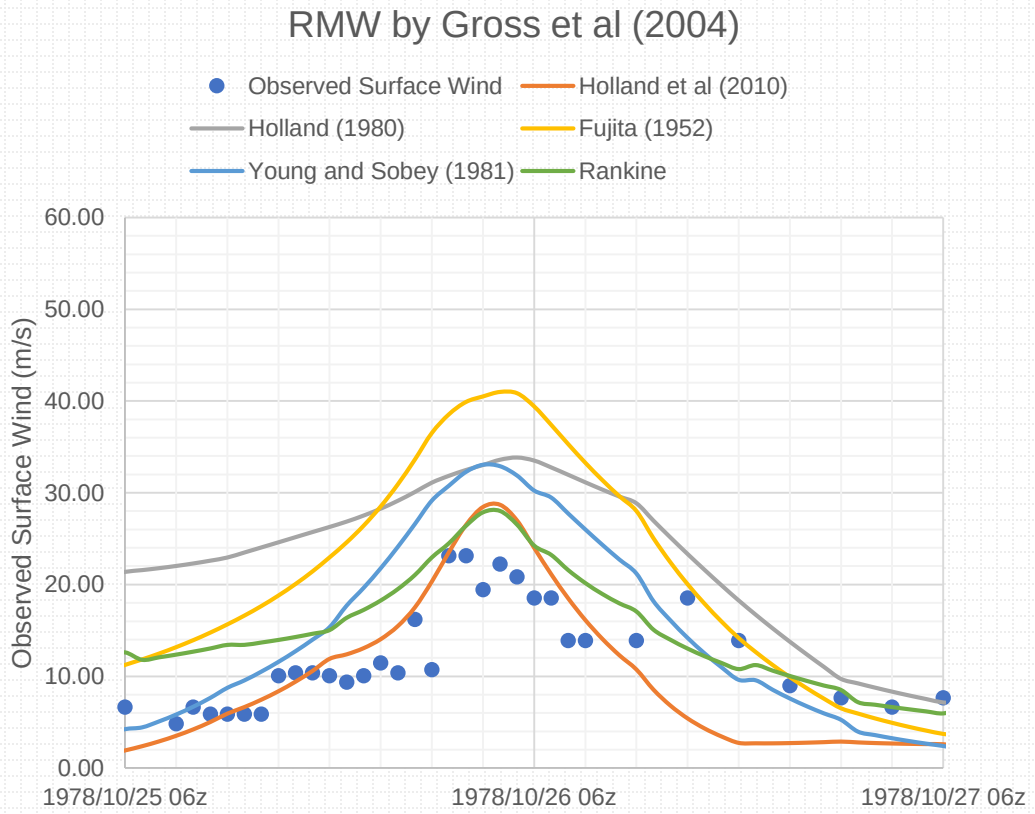
Surface Wind
Daet Station

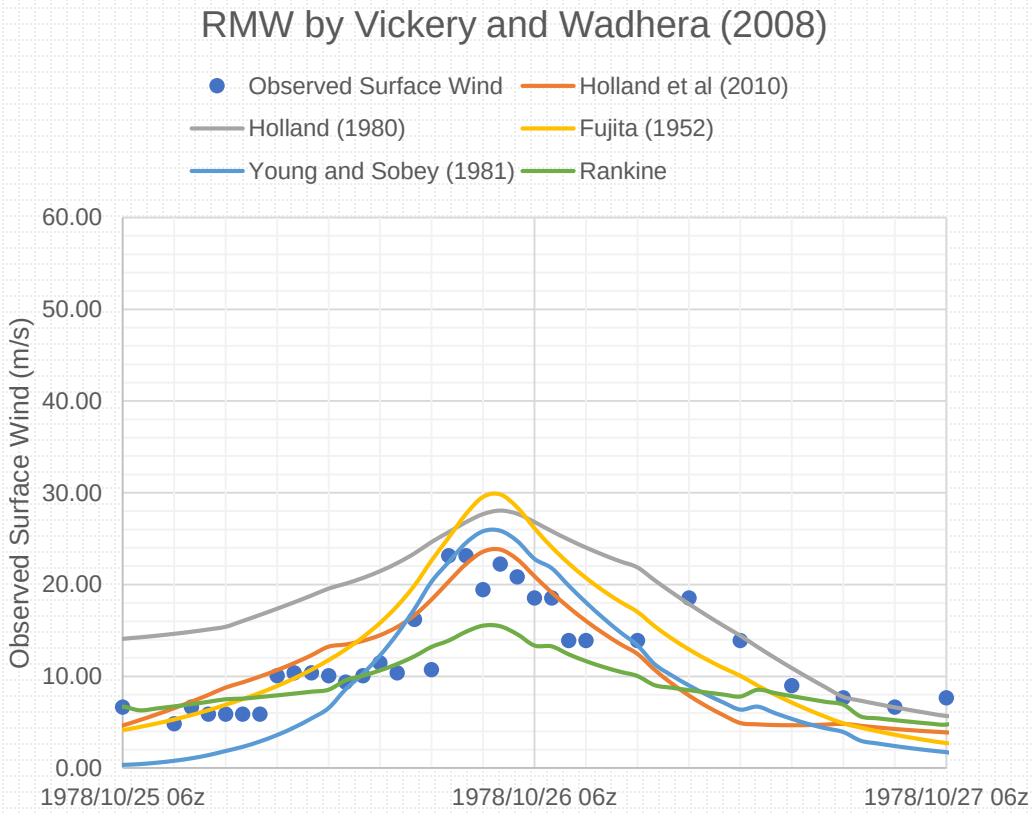




Typhoon Rita (1978)

Surface Wind
Virac Station

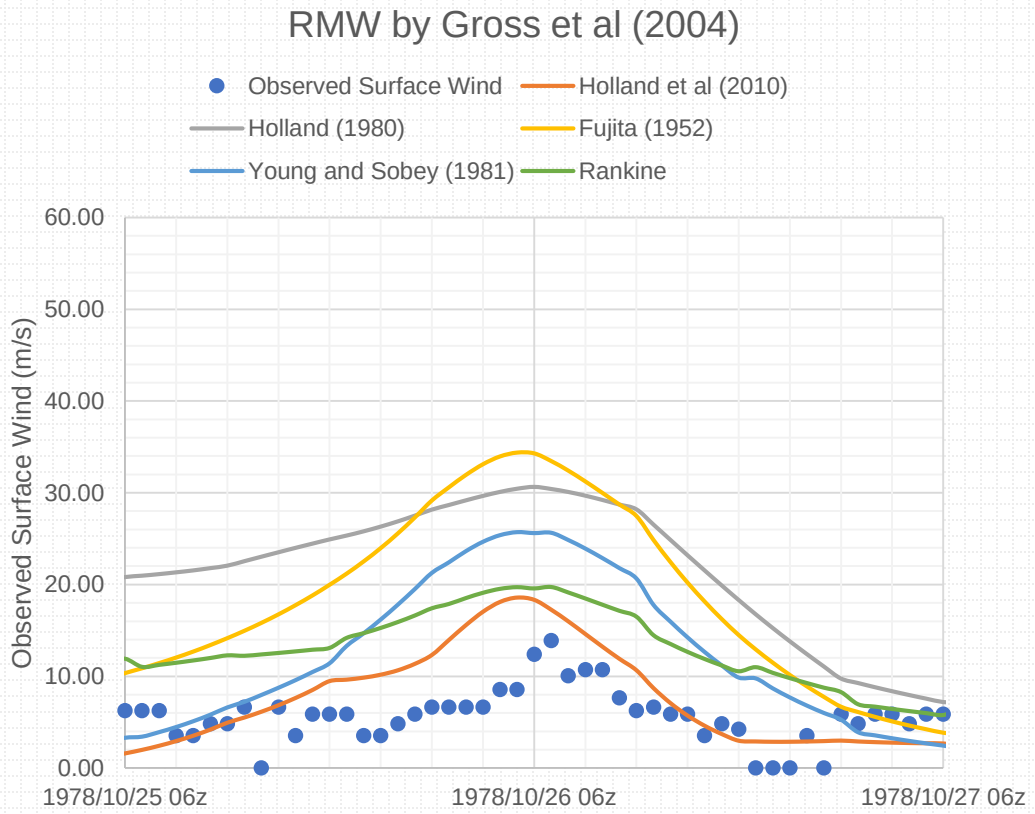


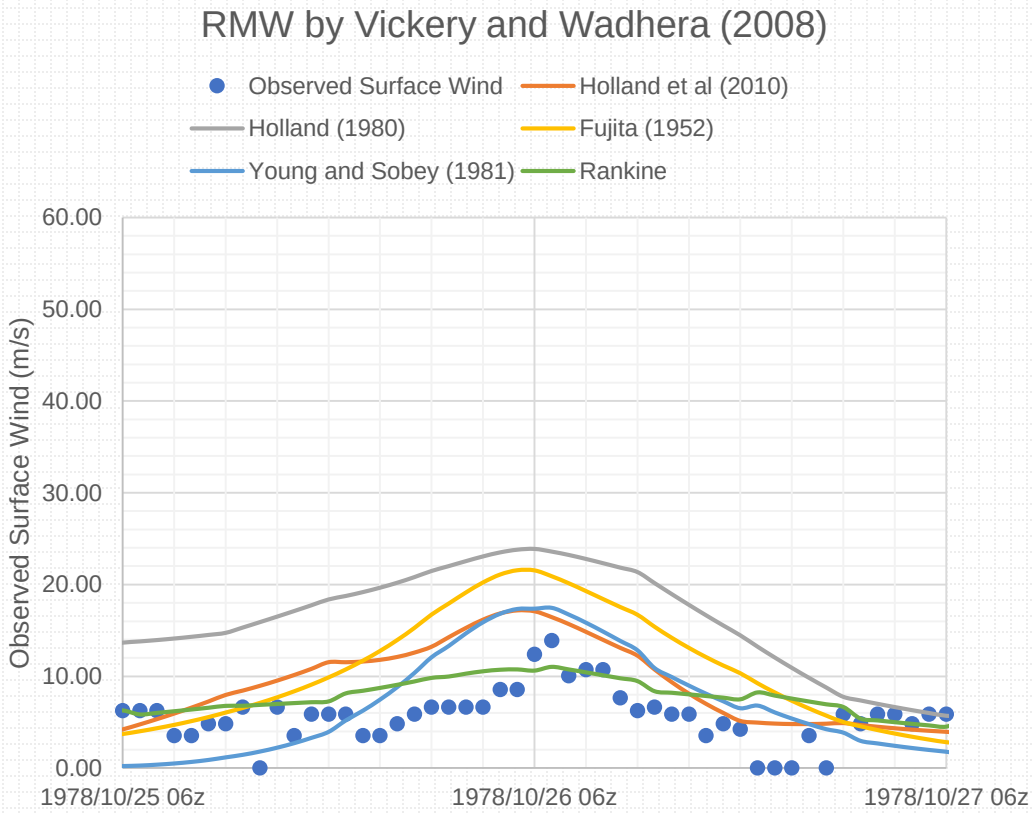


Typhoon Rita (1978)

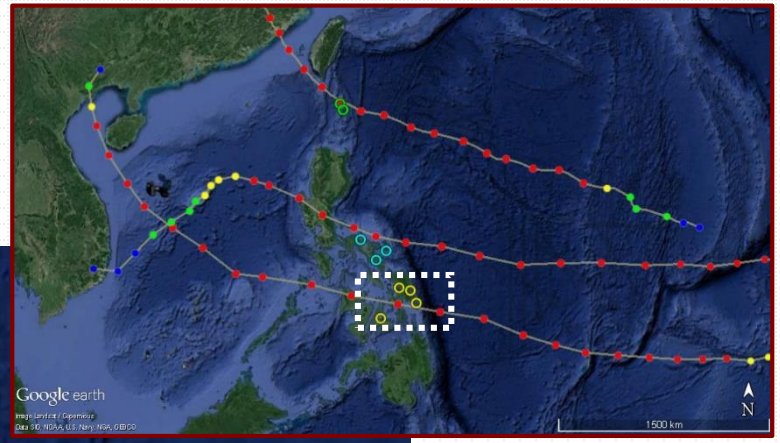
Surface Wind

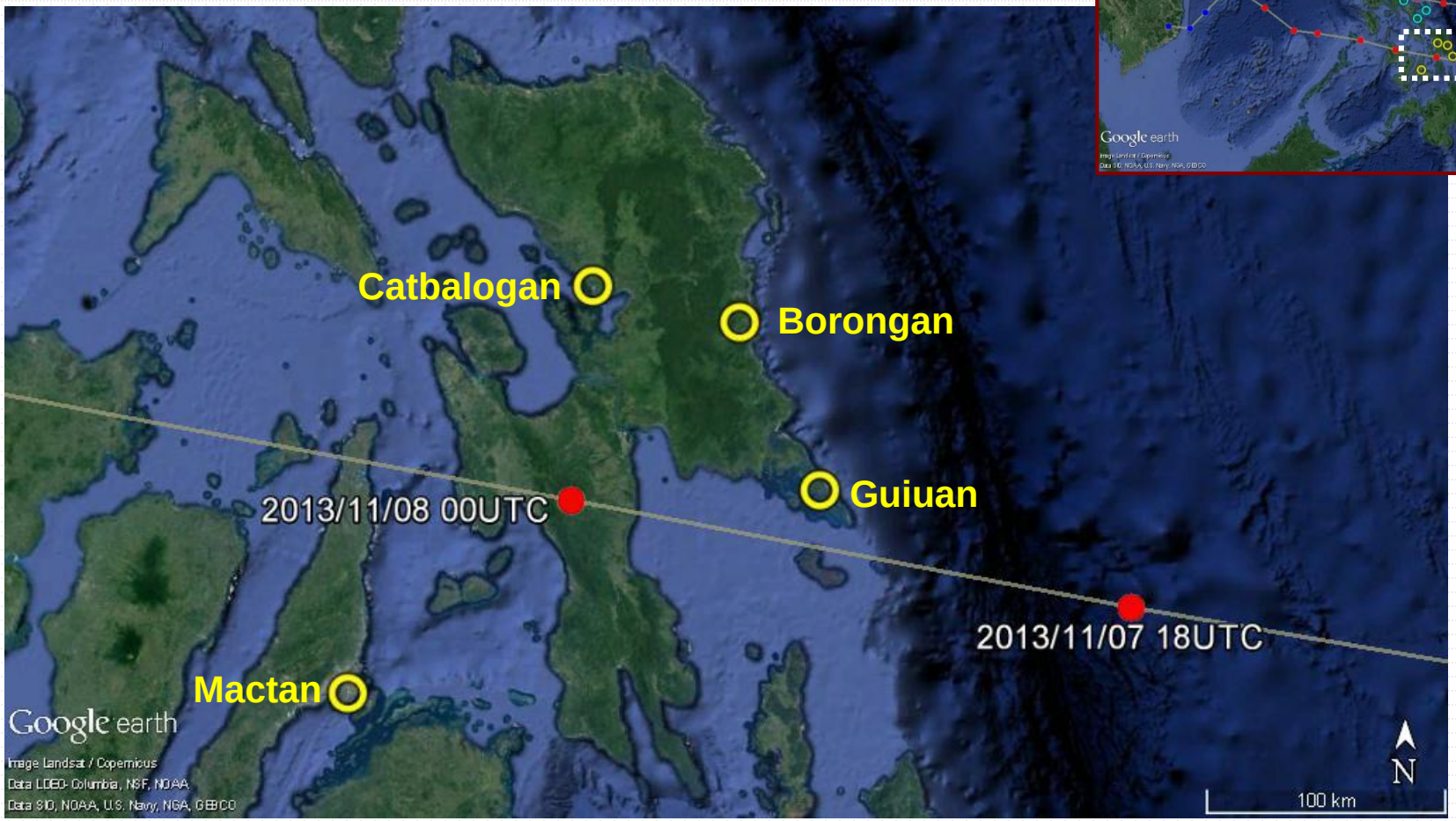
Legazpi Station





Typhoon Haiyan (2013)





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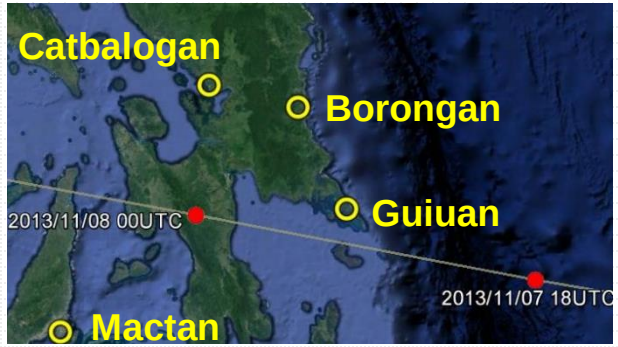
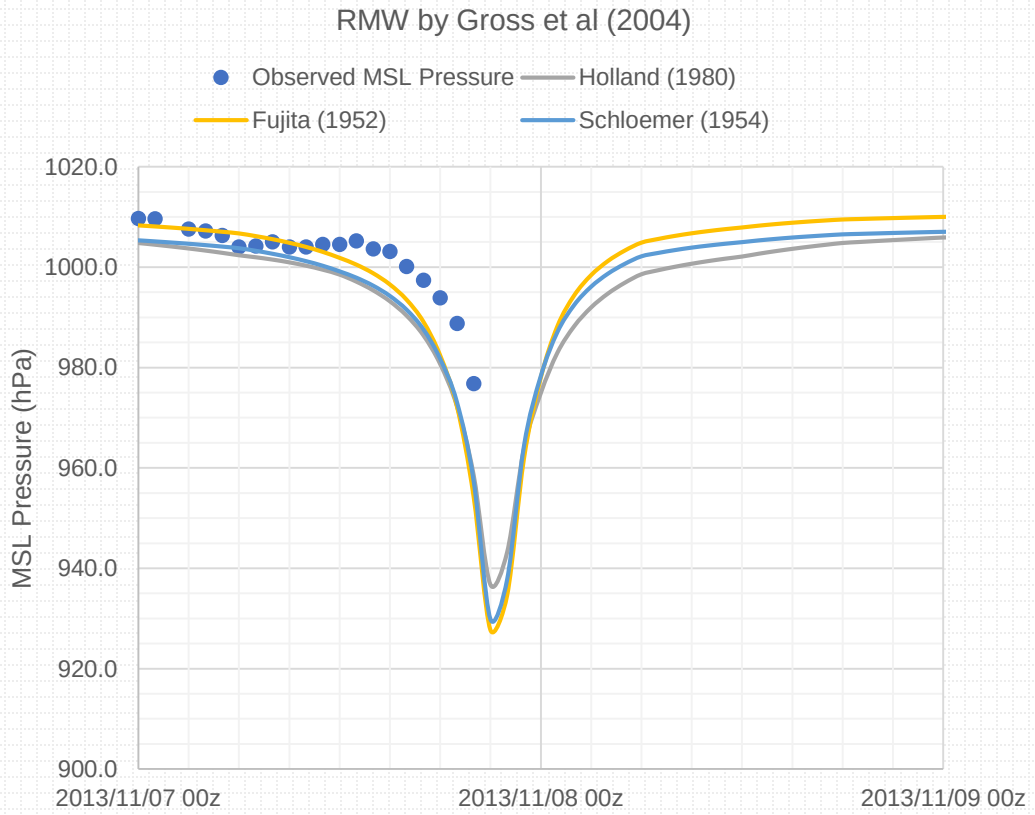
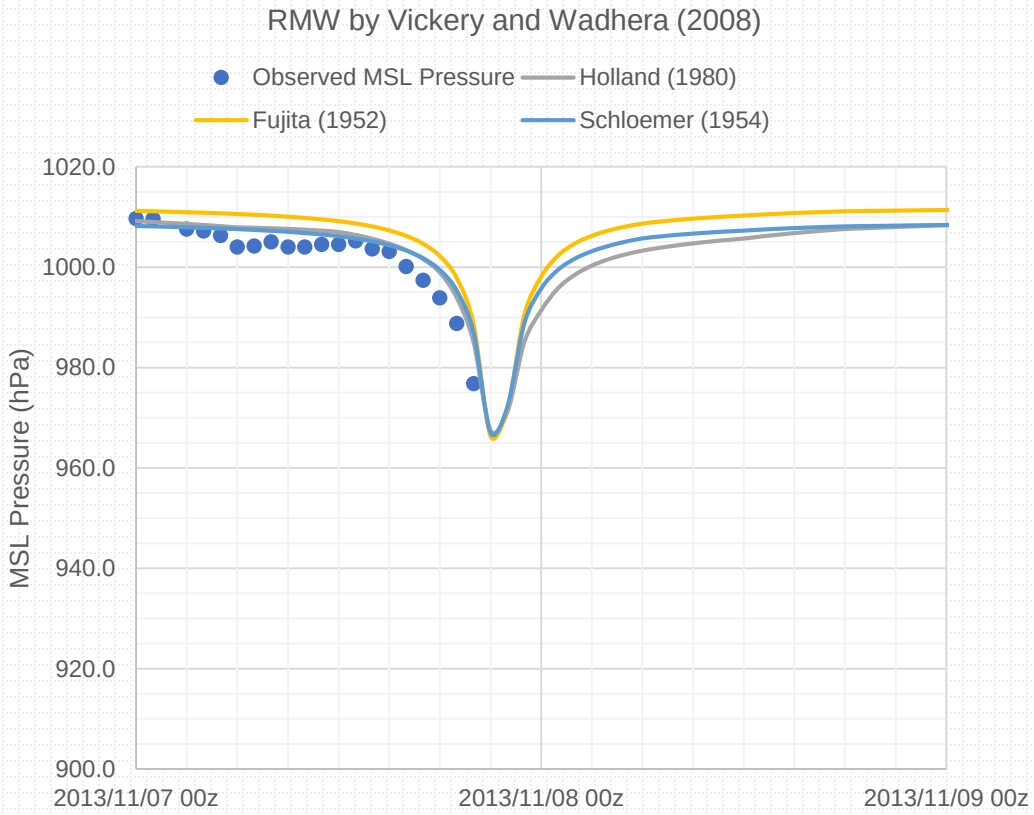


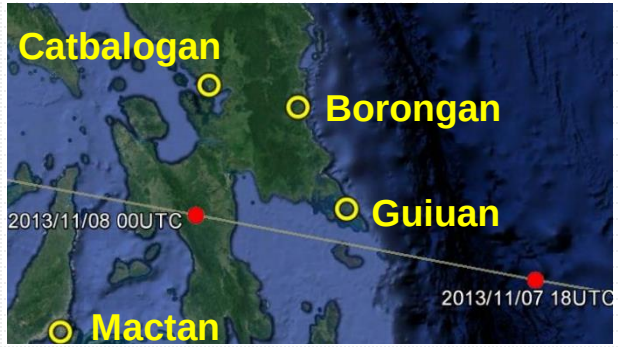
Sea Level Pressure

Guiuan Station



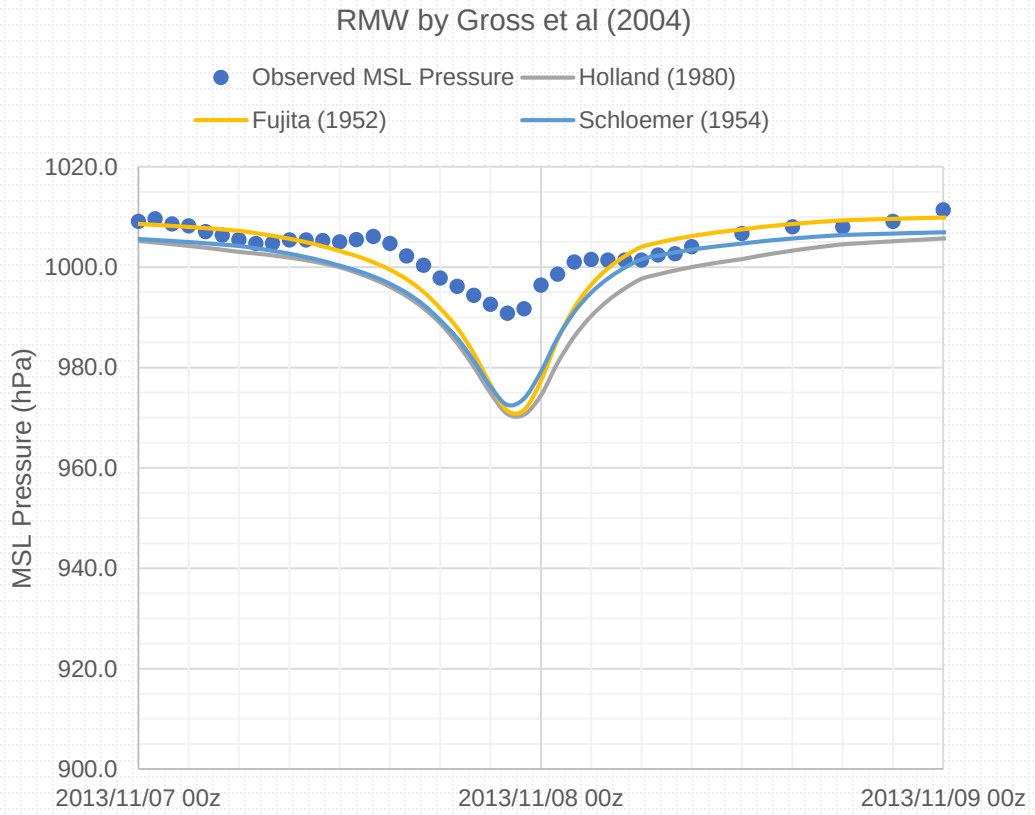


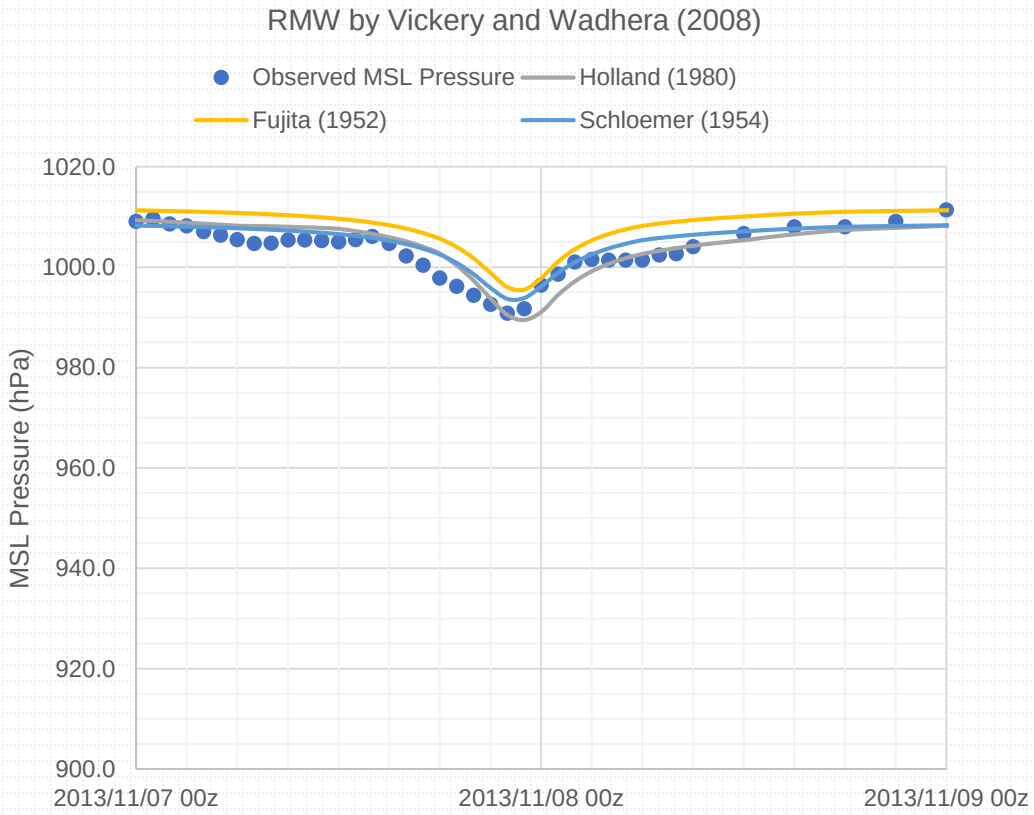
Typhoon Haiyan (2013)



Sea Level Pressure

Borongan Station





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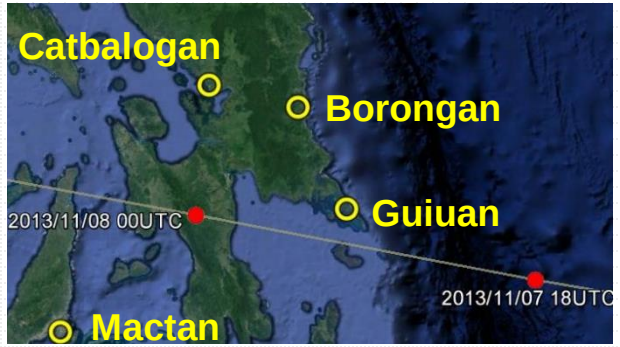
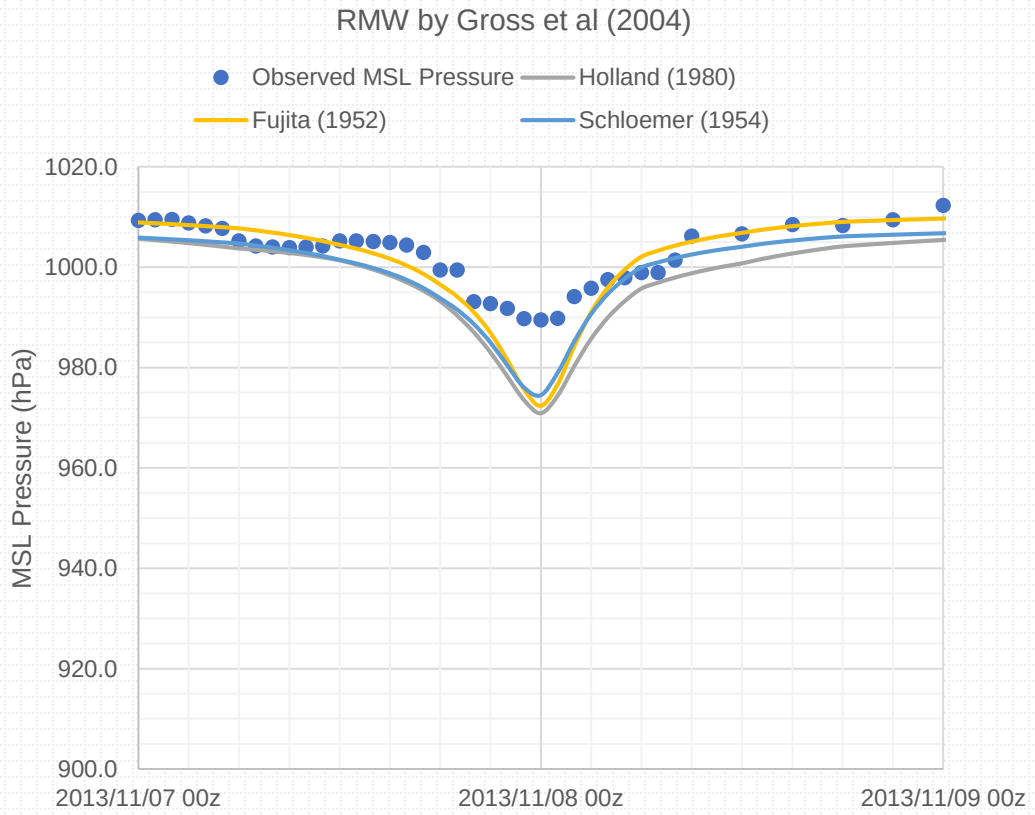
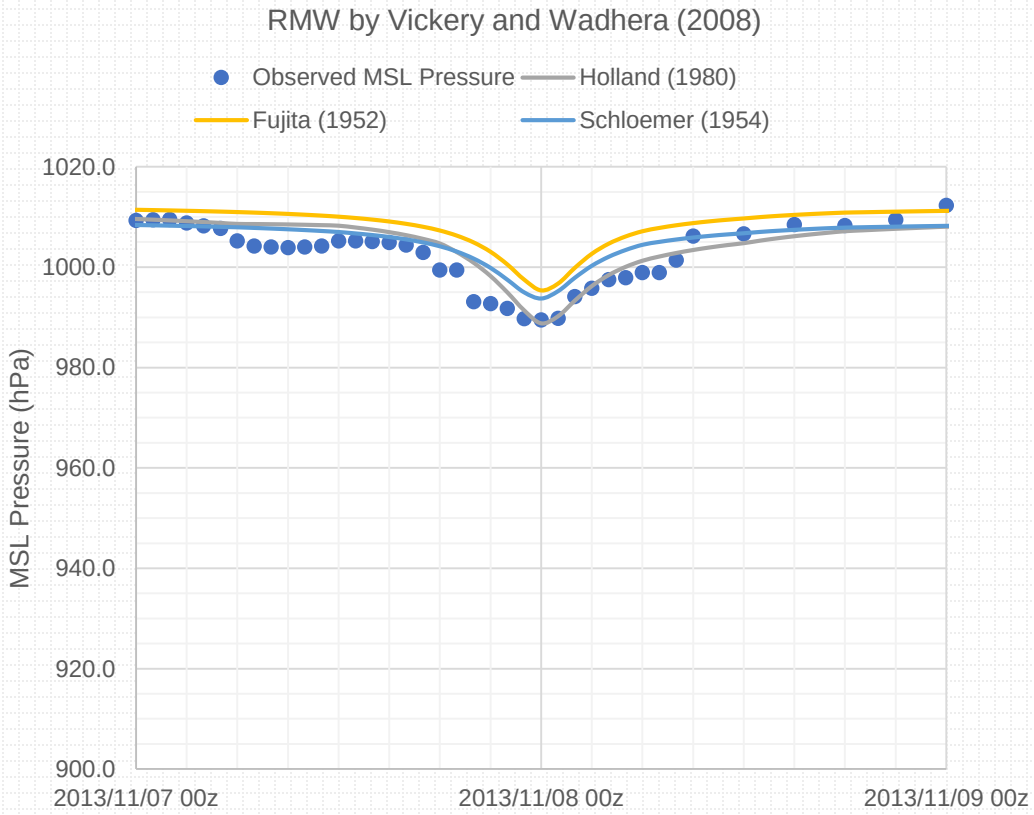
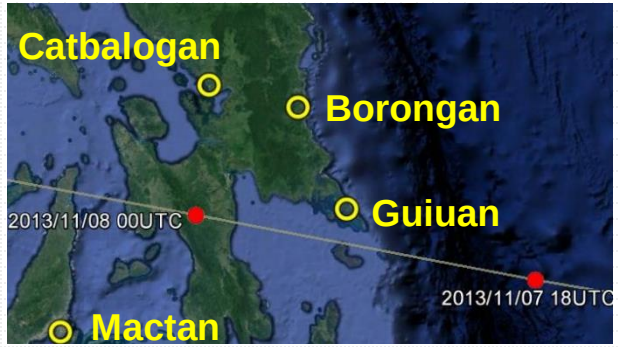


Sea Level Pressure
Catbalogan Station



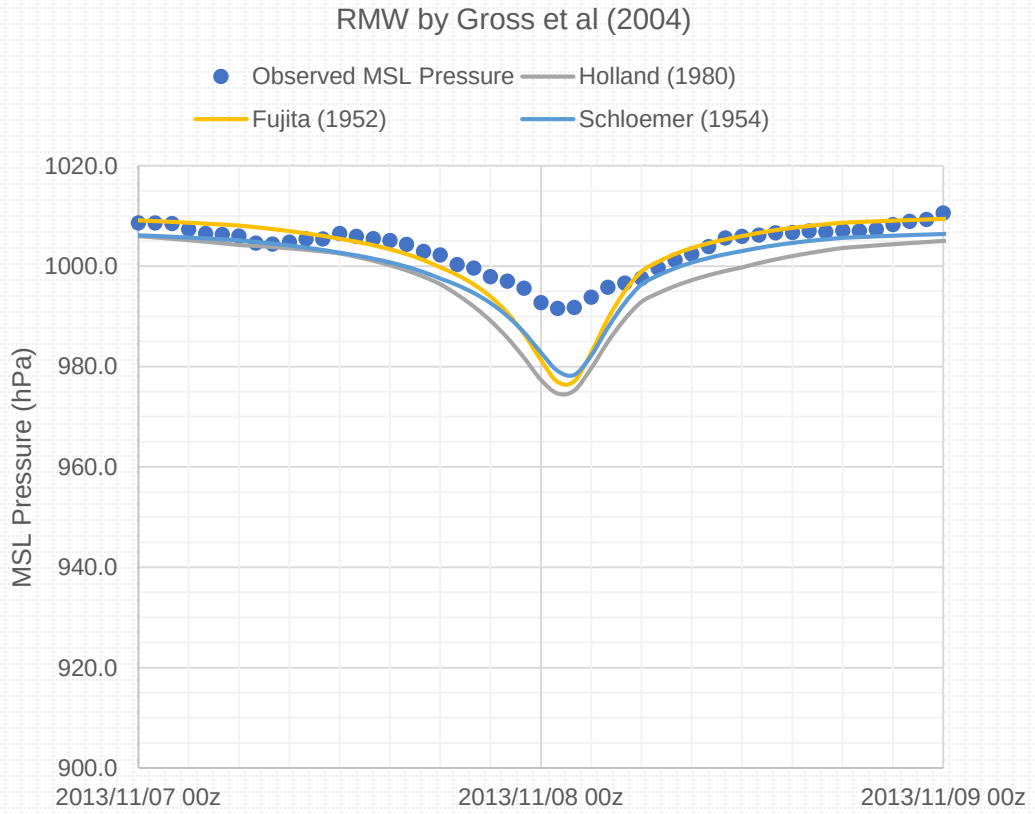


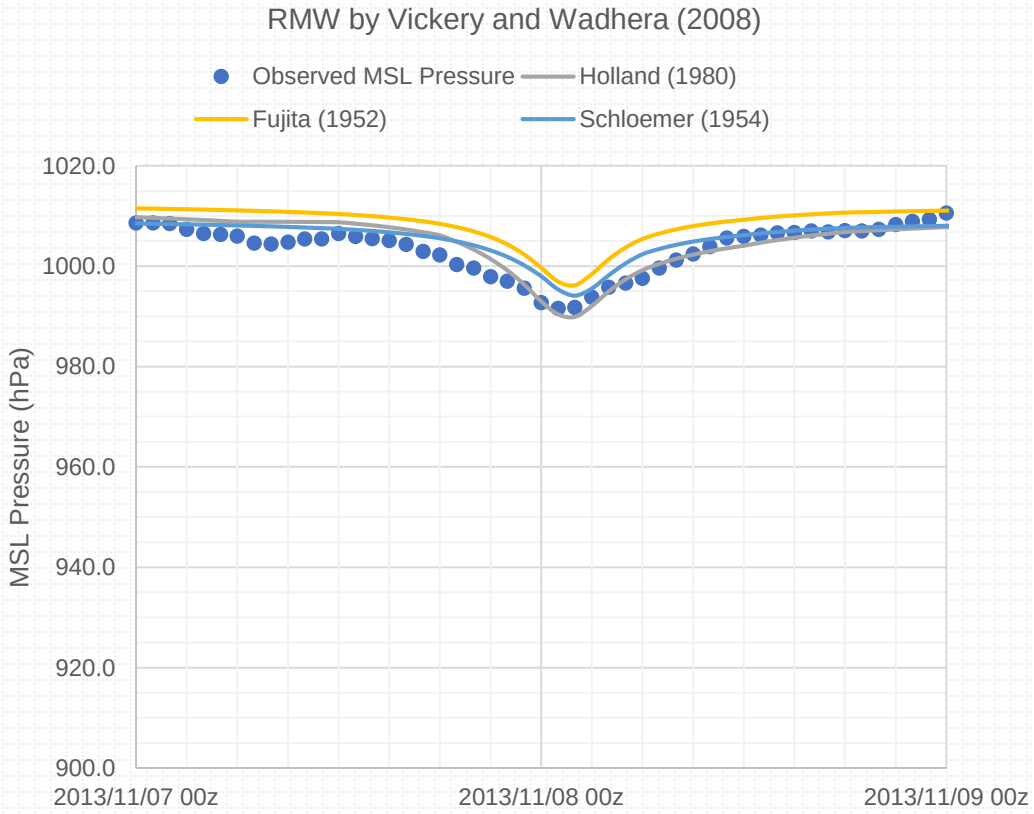
Typhoon Haiyan (2013)



Sea Level Pressure

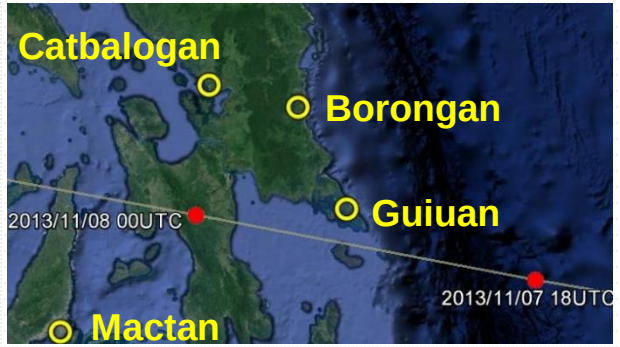
Mactan Station



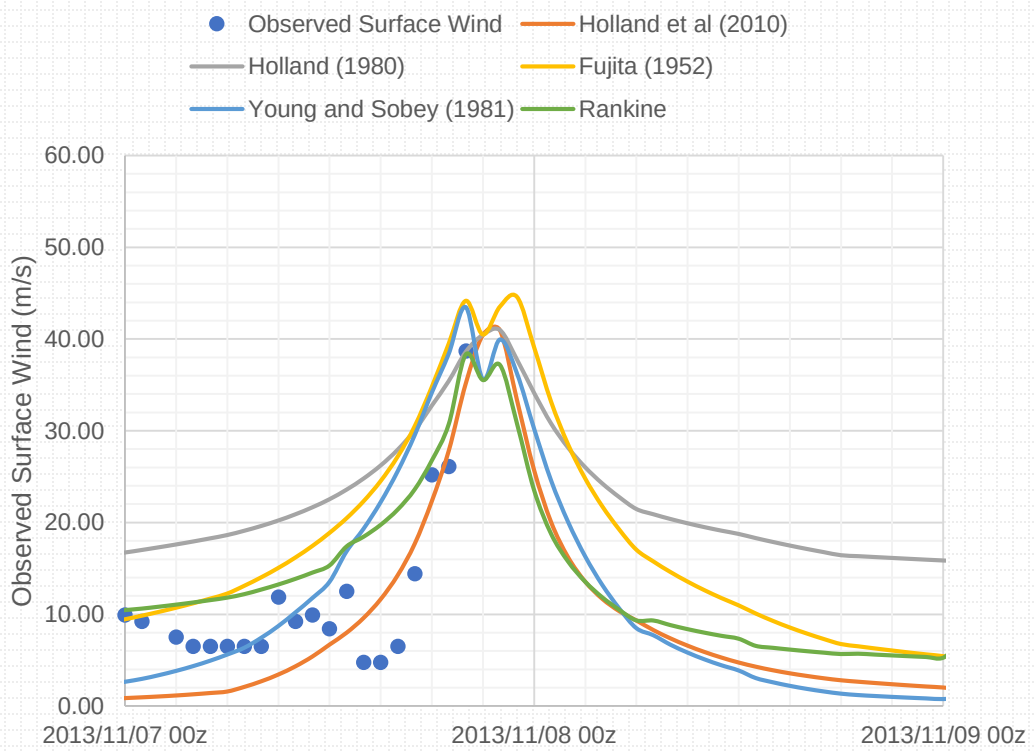


Typhoon Haiyan (2013)

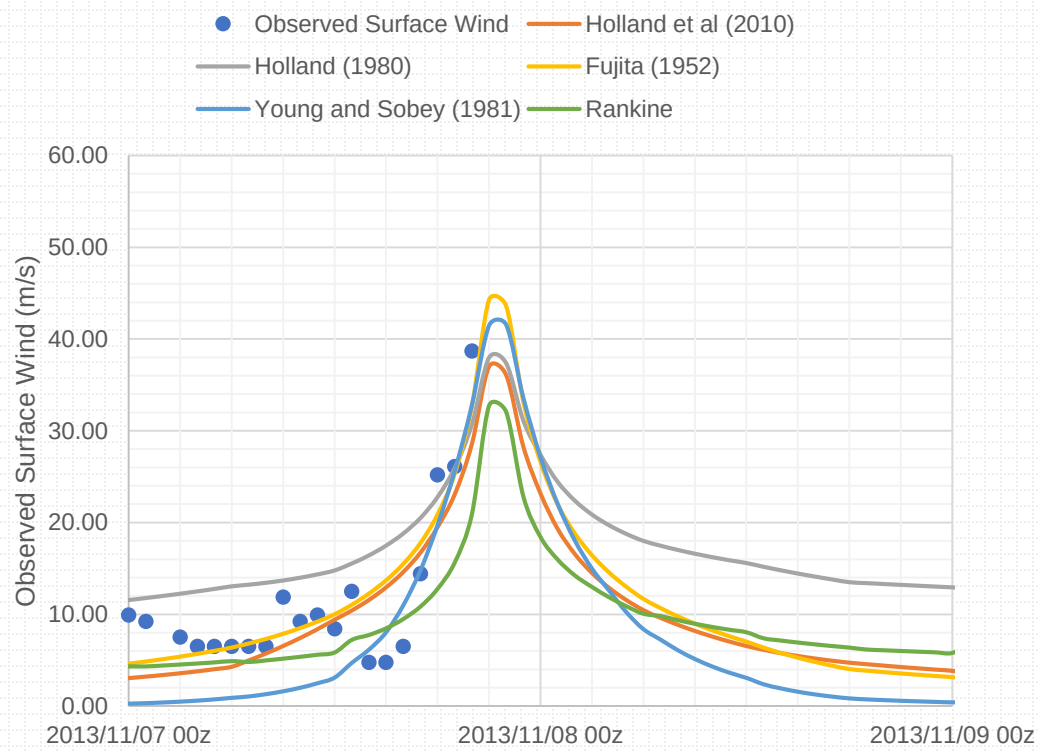
Surface Wind
Guiuan Station



RMW by Gross et al (2004)



RMW by Vickery and Wadhera (2008)



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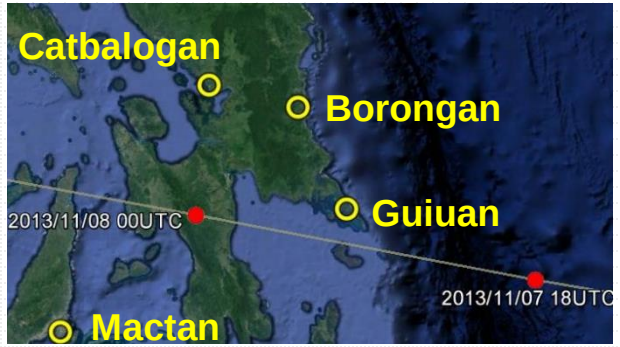
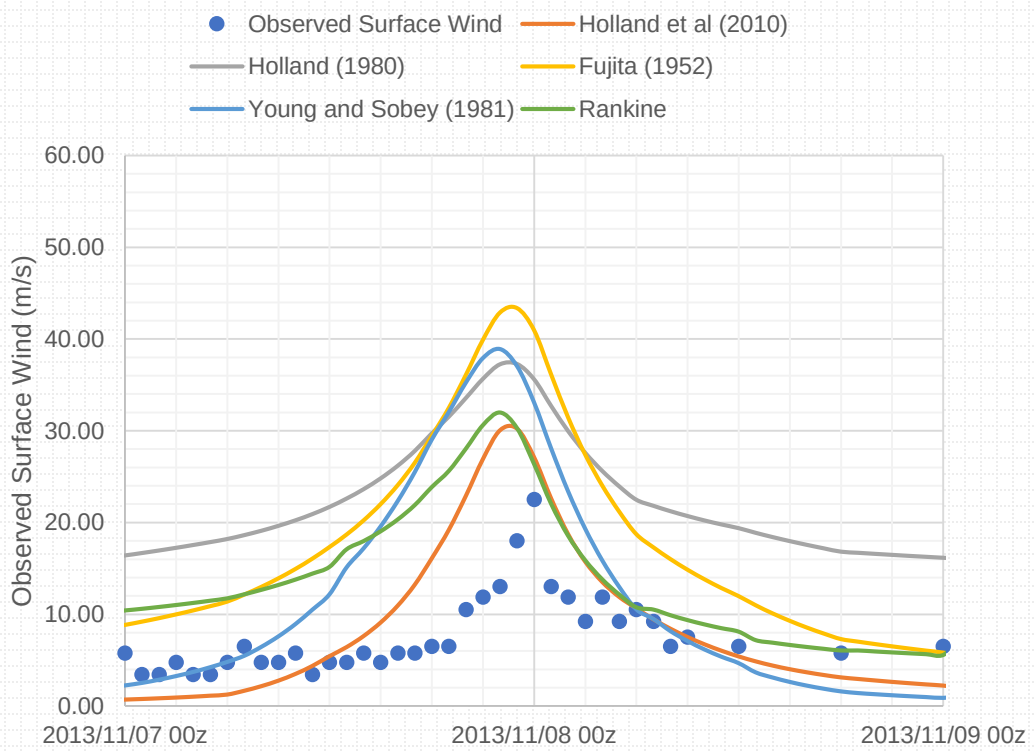


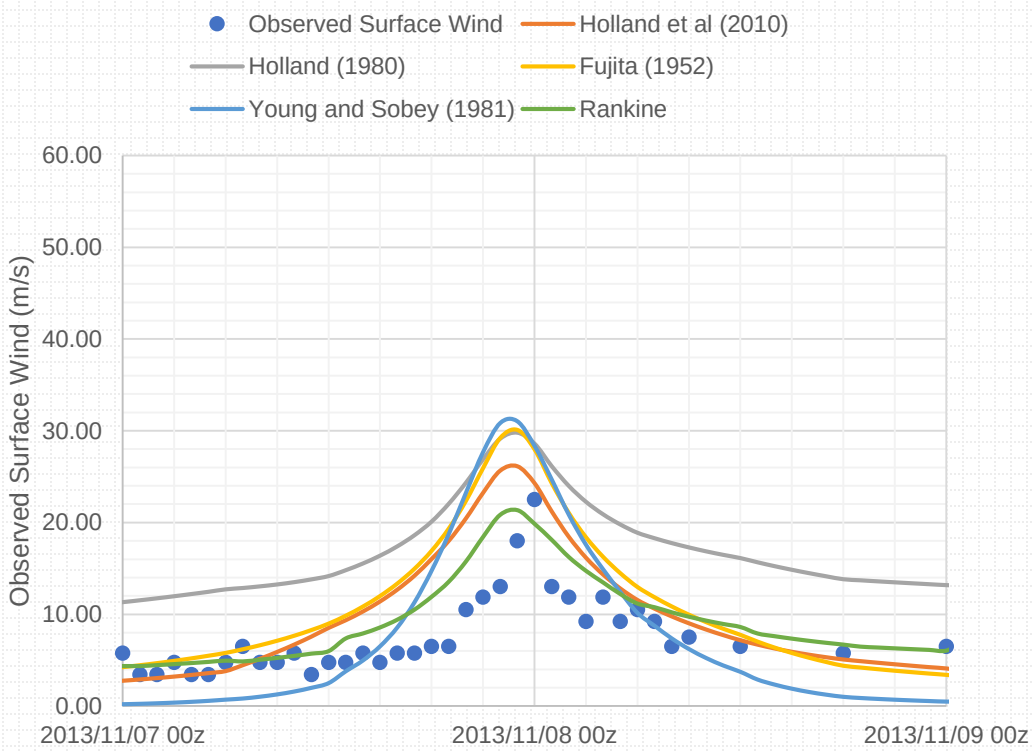
Surface Wind

Borongan Station

RMW by Gross et al (2004)



RMW by Vickery and Wadhera (2008)



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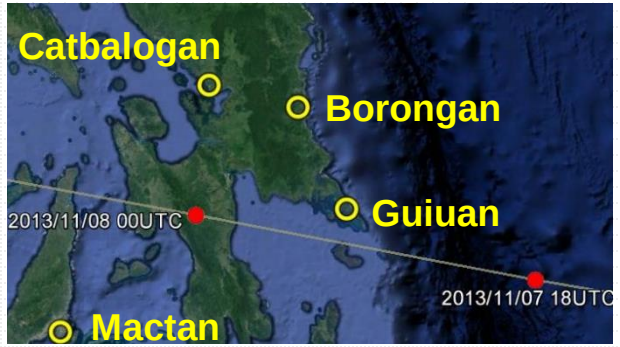
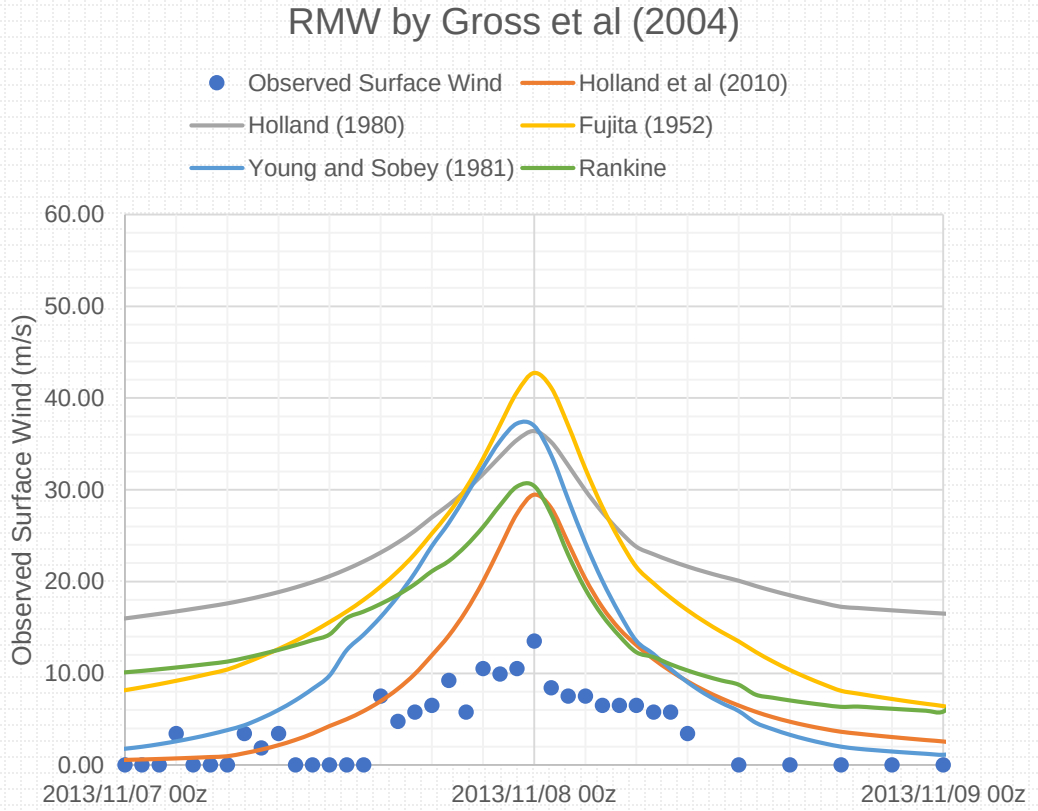
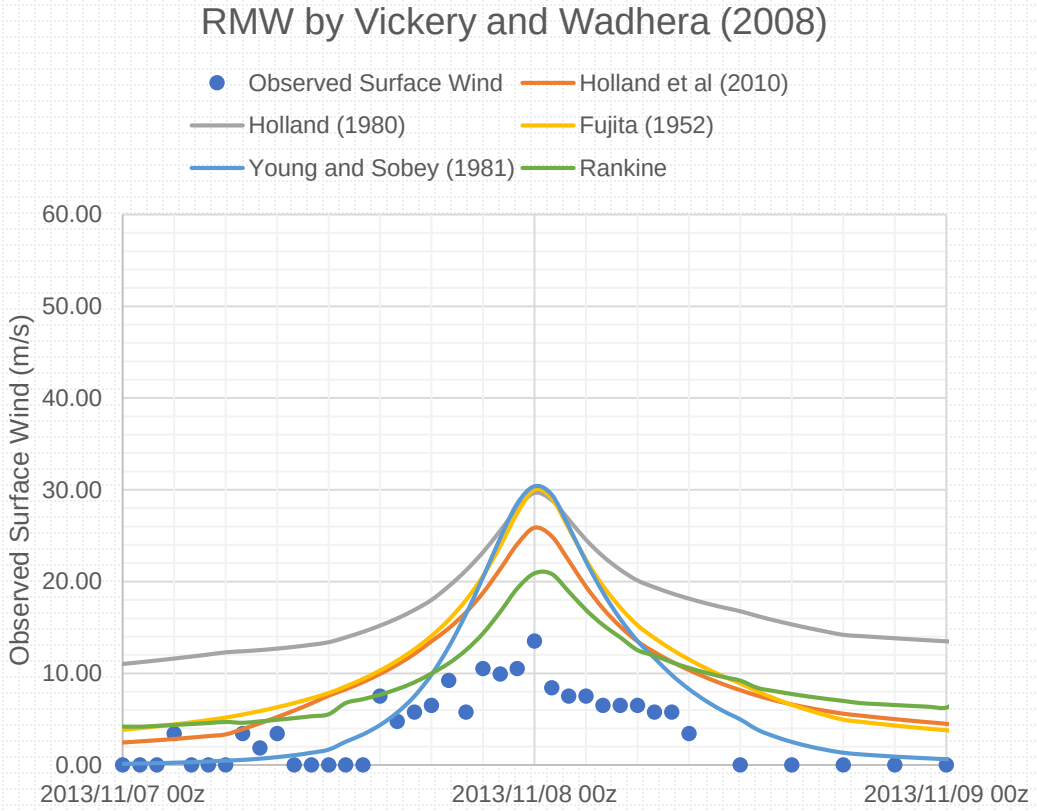


Surface Wind

Catbalogan Station





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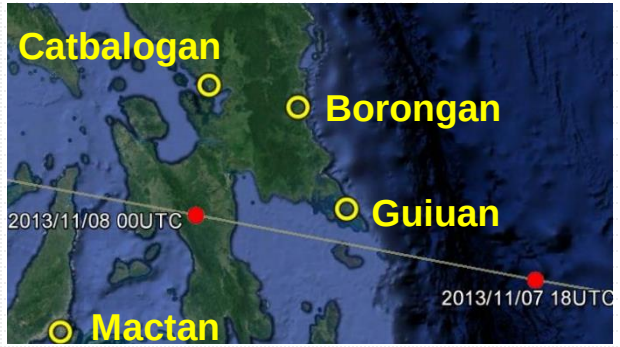
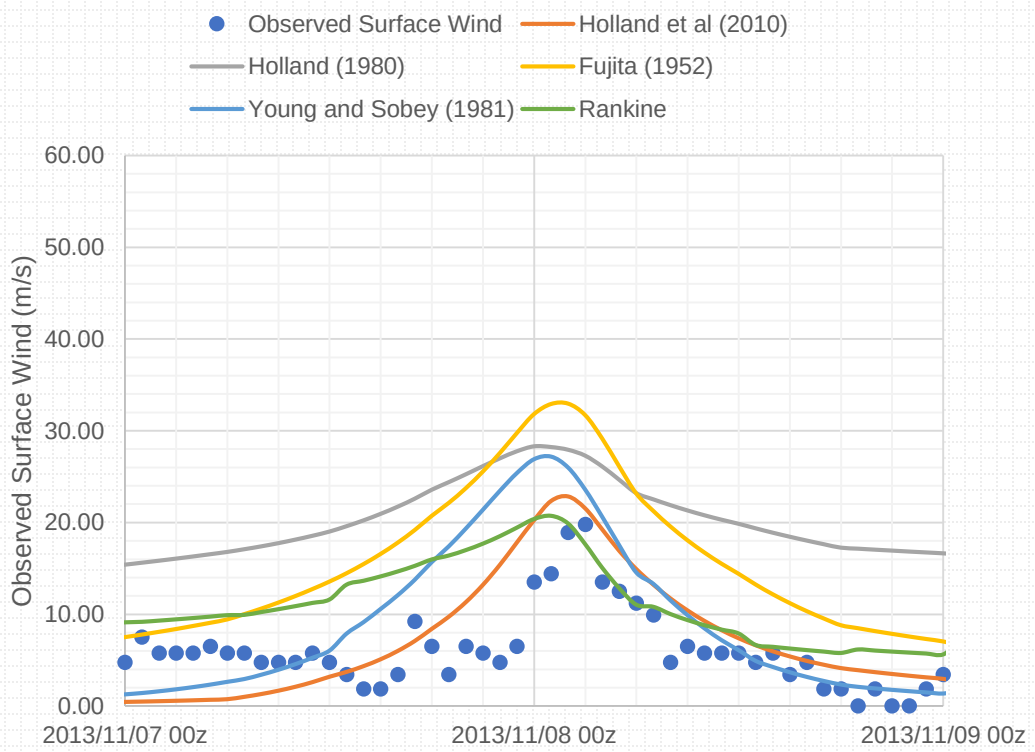
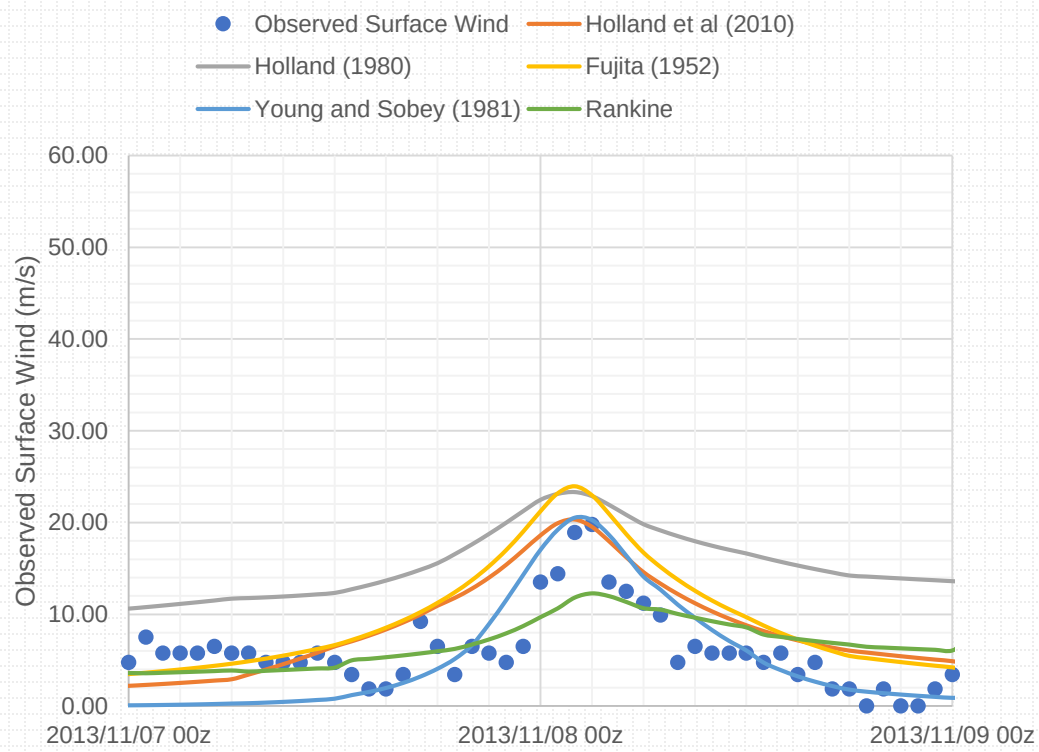


Surface Wind
Mactan Station

RMW by Gross et al (2004)



RMW by Vickery and Wadhera (2008)



Surface Winds

Station	Holland et al. (2010)		Holland (1980)		Fujita (1952)		Young and Sobey (1981)		Modified Rankine Model	
	R^2	*RMSE (m/s)*	R^2	*RMSE (m/s)*	R^2	*RMSE (m/s)*	R^2	*RMSE (m/s)*	R^2	*RMSE (m/s)*
Itbayat, Batanes	0.73	*4.60*	-0.91	*12.25*	0.07	*6.71*	0.07	*8.55*	0.65	*5.21*
Basco, Batanes	0.96	*1.72*	-0.44	*10.12*	0.67	*4.87*	0.89	*2.85*	0.79	*3.85*
Daet, Camarines Norte	0.70	*3.08*	-1.00	*7.94*	-0.19	*6.11*	-0.04	*5.73*	0.78	*2.66*
Virac, Catanduanes	0.52	*3.84*	-1.17	*8.15*	0.18	*5.00*	0.25	*4.78*	0.47	*4.03*
Legazpi, Albay	-1.95	*4.98*	-15.13	*11.64*	-5.24	*7.24*	-1.73	*4.79*	-0.37	*3.39*
Guiuan, Samar	0.66	*4.94*	0.37	*6.69*	0.75	*4.24*	0.46	*6.23*	0.43	*6.38*
Borongan, Samar	-0.78	*5.55*	-5.34	*10.47*	-1.75	*6.89*	-1.74	6.89	0.34	*3.38*
Catbalogan, Samar	-2.96	*7.75*	-11.23	*13.63*	-4.71	*9.32*	-3.37	*8.05*	-1.58	*6.26*
Mactan, Cebu	-0.19	*4.66*	-4.50	*10.03*	-0.56	*5.34*	0.21	*3.81*	0.36	*3.41*

Sea Level Pressure

Station	Holland (1980)		Fujita (1952)		Schloemer (1954)	
	R^2	*RMSE (hPa)*	R^2	*RMSE (hPa)*	R^2	*RMSE (hPa)*
Itbayat, Batanes	0.91	*5.69*	0.98	*2.86*	0.95	*4.20*
Basco, Batanes	0.83	*6.33*	0.79	*7.16*	0.80	*6.90*
Daet, Camarines Norte	0.81	*5.13*	0.58	*7.62*	0.70	*6.46*
Virac, Catanduanes	0.87	*2.87*	0.44	*5.97*	0.76	*3.95*
Legazpi, Albay	0.55	*3.41*	-0.52	*6.26*	0.44	*3.81*
Guiuan, Samar	0.79	*3.45*	0.38	*5.47*	0.77	*3.66*
Borongan, Samar	0.77	*2.46*	0.11	*4.79*	0.79	*2.34*
Catbalogan, Samar	0.77	*3.02*	0.07	*6.03*	0.64	*3.76*
Mactan, Cebu	0.78	*2.32*	-0.06	*5.11*	0.71	*2.65*

Conclusions

Conclusions

- Surface winds and sea level pressure are the primary drivers in the generation of a storm surge. The accuracy of these parameters are necessary for reliable modeling of the storm surge height.
- Outputs of several parametric cyclone models were compared for three typhoon cases that made landfall in the Philippines. Observations from nine monitoring stations were considered in the study.

Conclusions

- The parametric cyclone models provided very different surface wind profiles, but the wind field given by **Holland et al. (2010)** best described the observed surface winds.
- All models provided similar pressure profiles, but the observations were generally best matched by the **Holland (1980)** radial pressure distribution.
- The empirical relation derived by **Vickery and Wadhera (2008)** provided a better correlation between modeled and observed surface winds and sea level pressures, compared to the relation given by Gross et al. (2004).

Conclusions

- The storm surge height can be either highly affected by the wind speeds or be highly dependent on the sea level pressure.
- For coastlines with shallow and wide continental shelves, the storm surge height is highly attributed to the surface winds, whereas for small islands located in deep bathymetry, the storm surge height is primarily due to the negative ambient pressure.
- Therefore, it is recommended to select an appropriate parametric cyclone model for use as boundary conditions to a storm surge model for a considering the characteristics of the study area.

Comparative Analysis of Parametric Cyclone Models for Surface Wind and Sea Level Pressure Modeling for Storm Surge Simulations

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