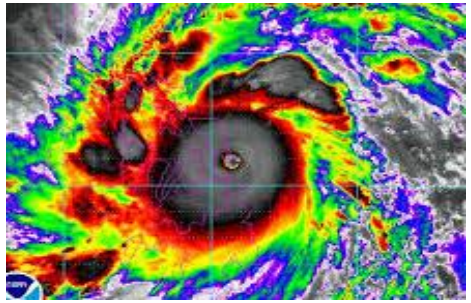
# Development of a Storm Surge Forecasting and Warning System for the Philippines



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**Cynthia P. Celebre, Ph.D. , Ma. Cecilia A. Monteverde**

## 2nd International Workshop on Waves, Storm Surges and Coastal Hazards

**Sheraton Hotel, Melbourne, Australia**
**November 10 – 15, 2019**



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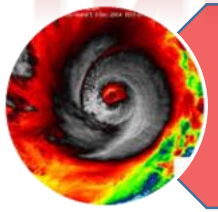
# OUTLINE



Introduction

Some Historical Records of Notable Storm Surge Events

Storm Surge Forecasts and Warnings

Summary


**PHILIPPINE ATMOSPHERIC, GEOPHYSICAL & ASTRONOMICAL SERVICES ADMINISTRATION**

**PAGASA** as the National Meteorological and Hydrological Services (NMHS) of the Philippines is the **"authoritative"** voice in providing the warning for public safety

The Philippines, through the **PAGASA**, is a Member of the **World Meteorological Organization (WMO)**, a specialized body of the United Nations

WMO

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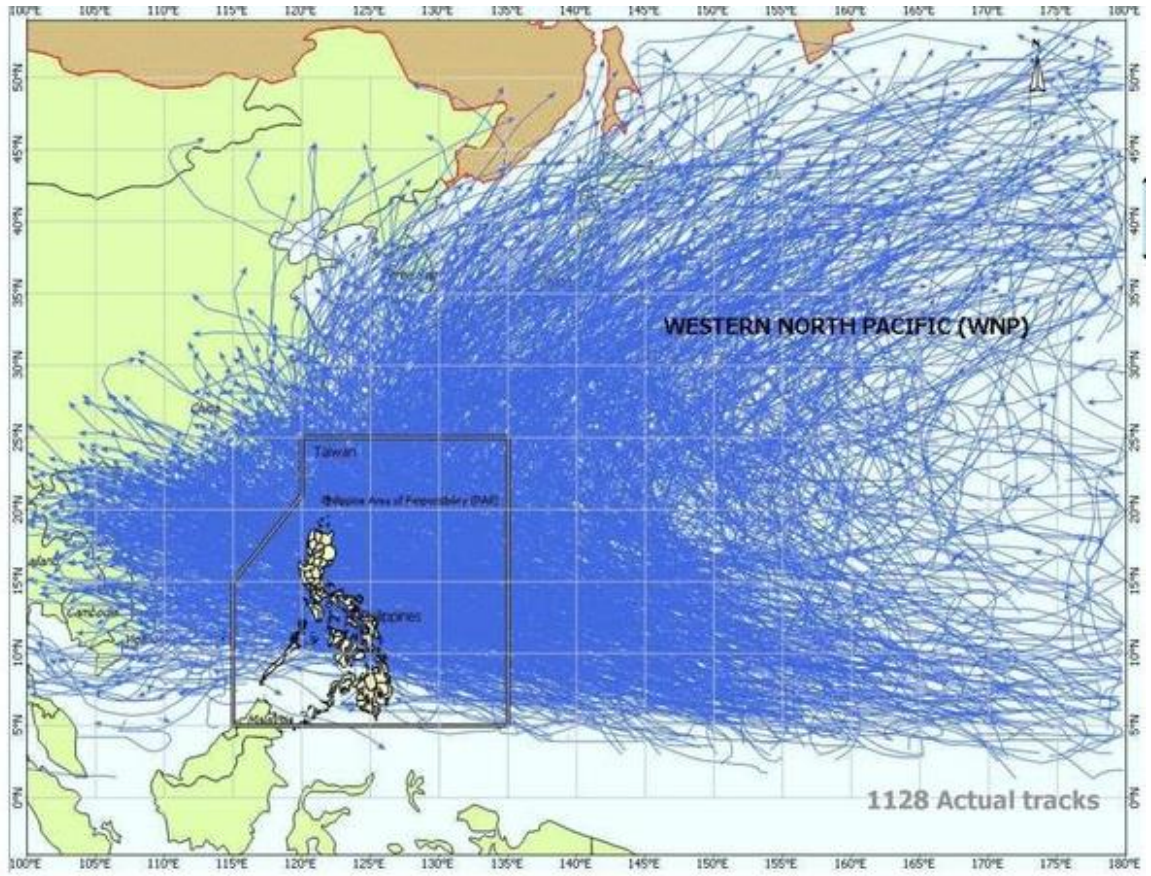
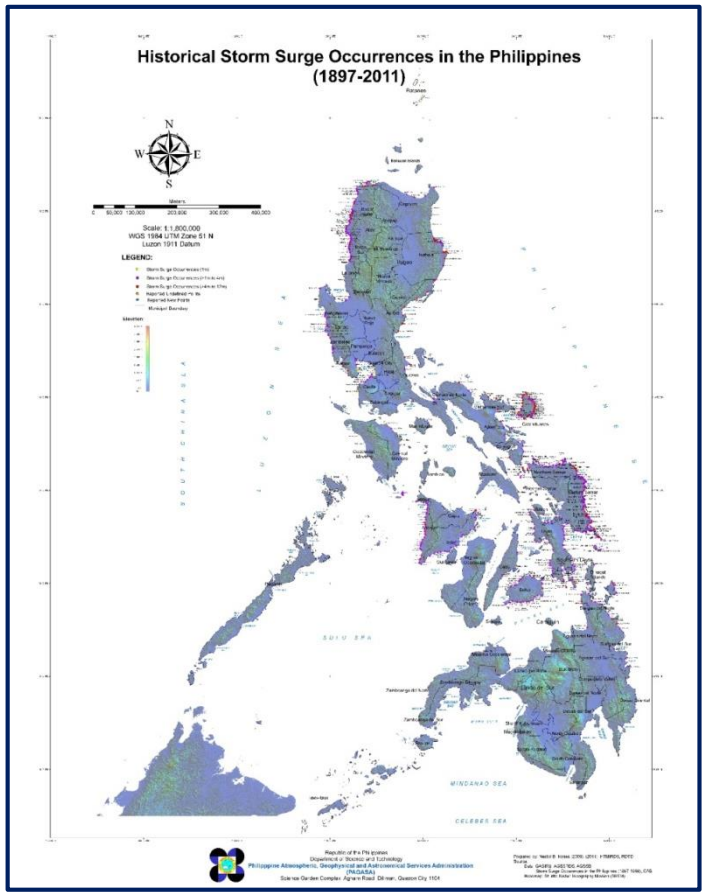
# OUR MISSION

**Protect lives and properties through timely, accurate and reliable weather-related information and services**

# Background

**HIGHLY SUSCEPTIBLE TO TYPHOONS –**
**LOCATED WITHIN PACIFIC TYPHOON BELT AREA**



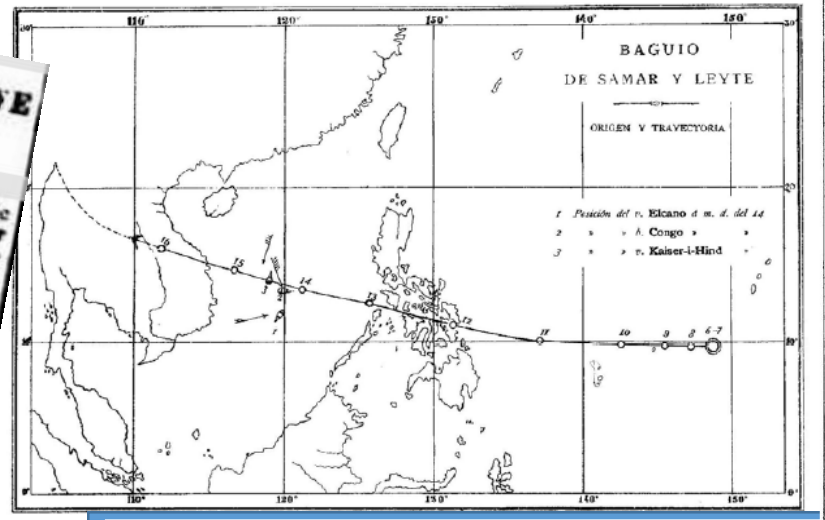

# Typhoon of Samar and Leyte, October 12, 1897

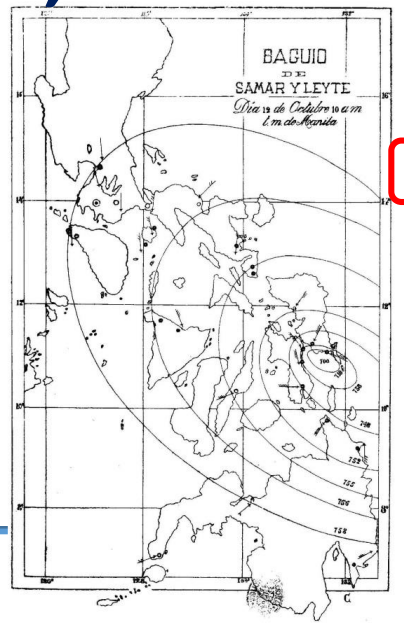
TYPHOON AND TIDAL WAVE IN THE PHILLIPINES.

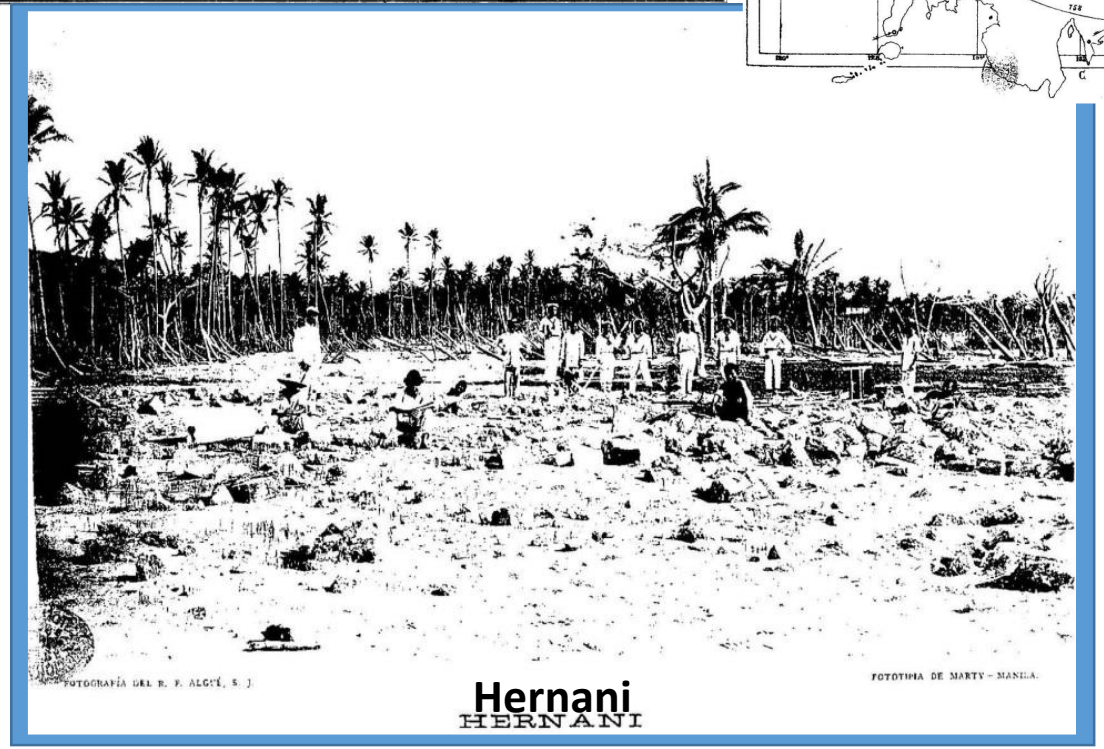
7000 Lives Lost.

MAIL advices, brought by the steamer Gaelic from Chinese and other ports in the Far East, contain details of the fearful destruction wrought in the Phillipine Islands by the typhoon and tidal wave during October. It is estimated that 400 Europeans and 6000 natives lost their lives, many being drowned by the rush of water, while others were killed by the violence of the wind. Several towns have been swept or blown away. The hurricane first struck the Bay of Santa Paula, and devastated the district lying to the south of it. No communication with the neighborhood was possible for two days. The hurricane reached Leyte on October 12, and striking Tacloban, the capital, with terrific force, reduced it to ruins in less than half an hour. The bodies of 128 Europeans have been recovered from the fallen buildings. Four hundred natives were buried in the ruins. A score of small trading vessels and two Sydney traders were wrecked on the southern coast, and their crews drowned. At Gamoa the sea swept inland for a mile, destroying property worth seven million dollars, and many natives lost their lives. The Government prison at Tacloban was wrecked, and of the 200 rebels therein half succeeded in making their escape. The town of Herain was swept away by flood, and its 5000 inhabitants are missing. The small station of Weera, near Loog, is also gone, while in Loog itself only three houses are left standing. Thousands of natives are roaming about the devastated province seeking food and medical attendance. In many cases the corpses were mutilated as though they had fallen in battle, and the expressions of their faces were most agonising.

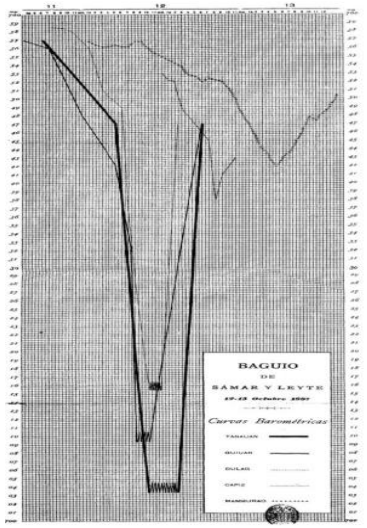
*Source: rove.nla.gov.au/newspaper/article/44204307?searchTerm=typhoon+phillippines&searchLimits*




| Location | Total Storm Tide (Observed) |
|---|---|
| **Samar:** | |
| Hernani, | 7.3 meters |
| Tnglad | 1.5 meters |
| Pambujan | 0.7 meters |
| Giuian | 4.9 meters |
| Basey | |
| **Leyte:** | |
| Tacloban | 0.9 meters |




**Barometer measurement**

*Source: Fr. Jose Algue, S.J. of the Observatorio de Manila, 1897*

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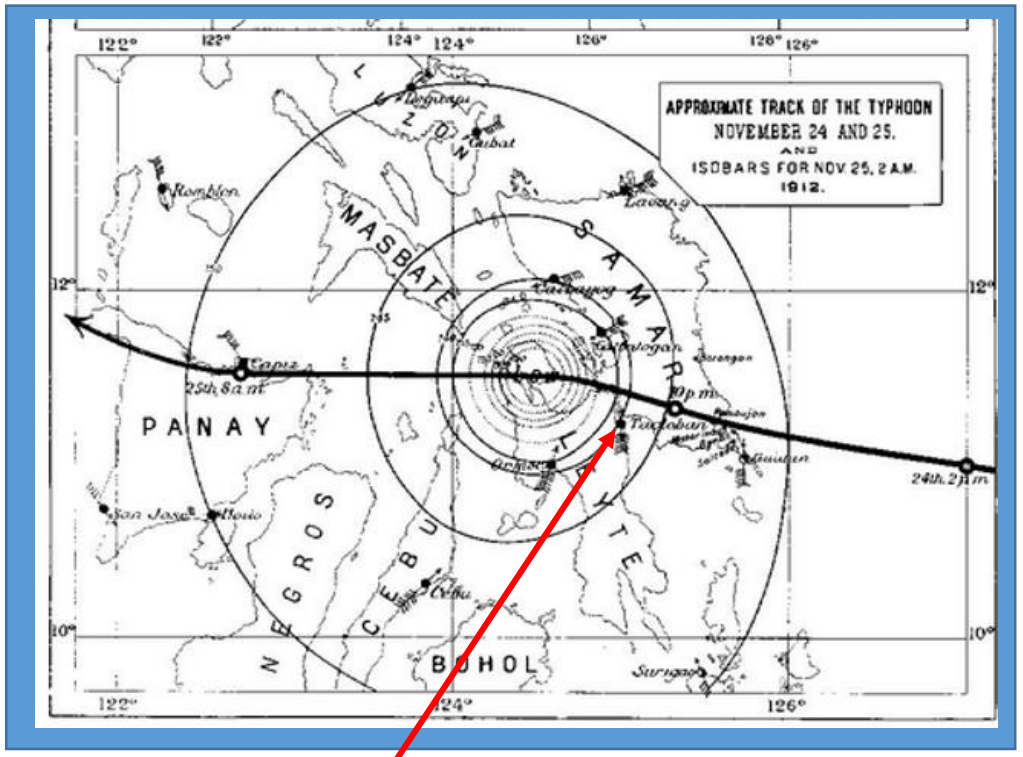
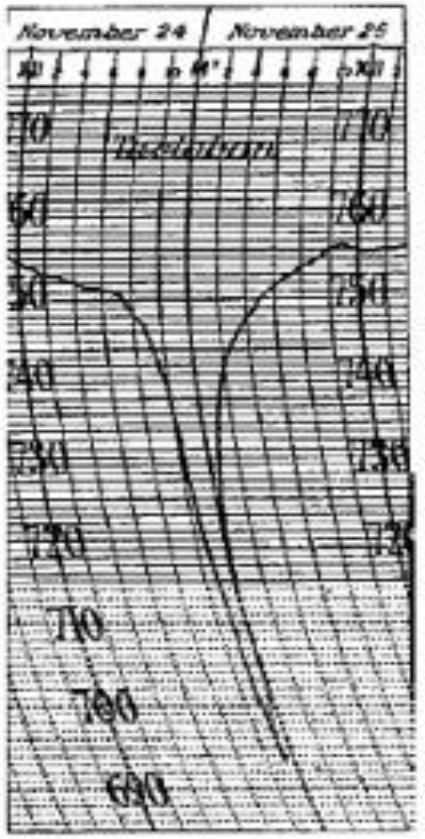
# Typhoon Track in Nov 24, 1912




Tacloban

*Source: Fr. Jose Algue, S.J. of the Observatorio de Manila, 1912*




**Pressure in Tacloban Leyte**
**Nov. 24 – 25, 1912**

| Location | Total Storm Tide (Observed) |
|---|---|
| Santa Rita | 7.0 meters |
| Bobon Tababao | 6.1 meters |
| Tacloban | 2.0 meters |
| Capiz | 1.0 meters |

**Typhoon in Tacloban Leyte, Nov. 24 – 25, 1912**

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# Notable Storm Surge Occurrences in the Philippines

**Typhoon Nitang in 1984 in Nonok Island in Surigao**


Typhoon Undang, Basey, Samar, Nov 5, 1984, follows the same track as Yolanda, two meter wave height
Undang strength , 230 kph
Casualties – 895, P1.9B in damages

Typhoon Yoning, in Eastern Samar, 1988

*Source : PAGASA (STRIDE Team)*

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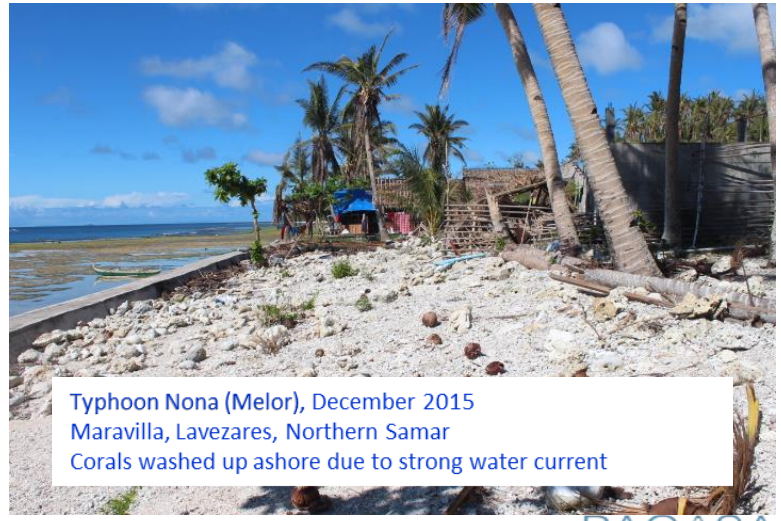
# Other Notable Storm Surge Occurrences in the Philippines

The school compound at Caroan, Gonzaga, Cagayan and the more than 2 hectare land area were carried away by storm surge during the occurrence of TY Igme (2004). The height of watermark at the wall was about 2.25 m.

The heavily damaged resort in Bgy. Laoag, Cabangan,Zambales by storm surge during T. Ondoy (2009).

Typhoon Nona (Melor), December 2015
Bani, Lavezares, Northern Samar
Damaged sea wall due to storm surge

Typhoon Nona (Melor), December 2015
Barcelona, Sorsogon
Damaged fishing boat dock due to storm surge



Typhoon Nona (Melor), December 2015
Maravilla, Lavezares, Northern Samar
Corals washed up ashore due to strong water current

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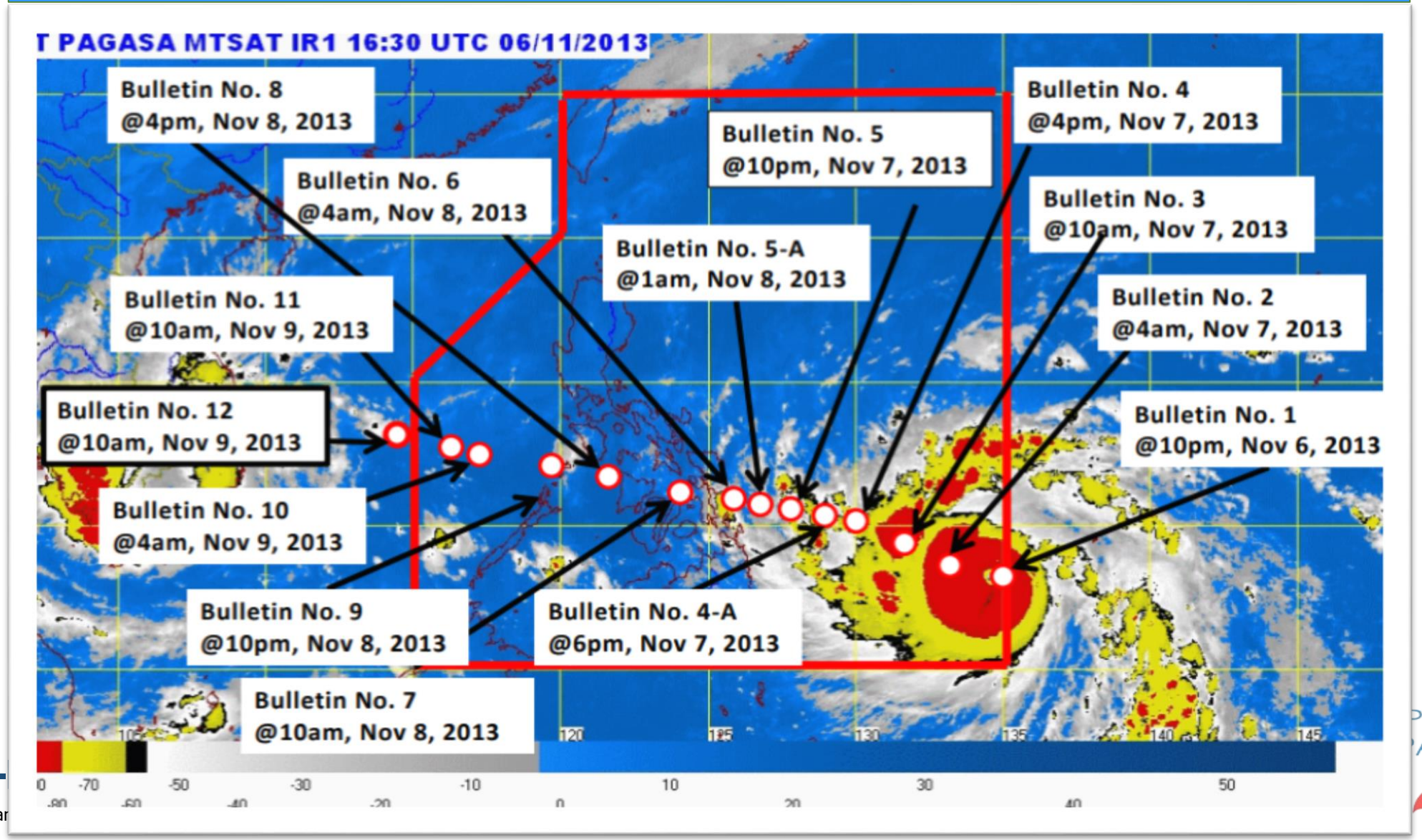
# TYPHOON YOLANDA (HAIYAN)
# November 6 – 10, 2013

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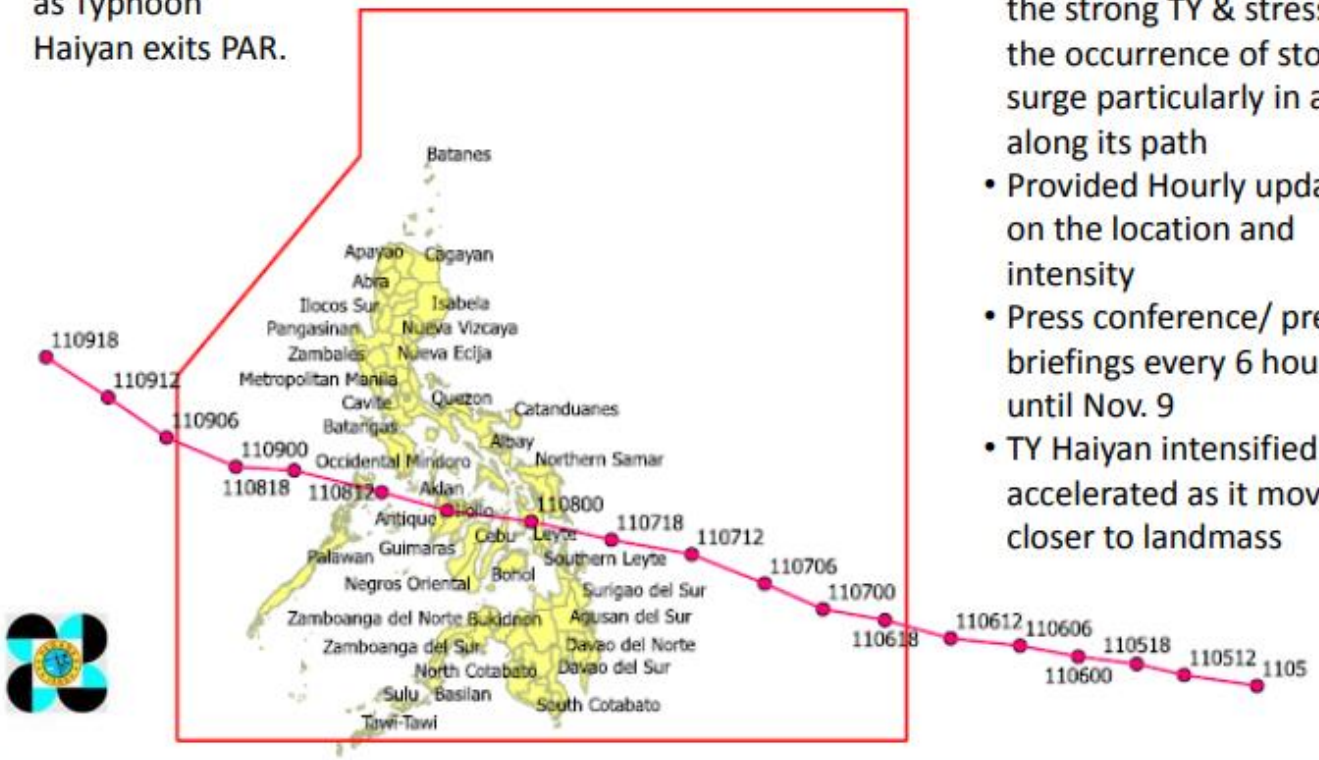
# Chronology of PAGASA Activities

## 09 Nov 2013:

- PSWS #3 and #4 were lowered after Haiyan crossed Visayas islands and continued to move away from the country
- Final bulletin was issued at 3:30PM as Typhoon Haiyan exits PAR.

## 08 Nov 2013:

- Auxilliary bulletin was issued at 2AM to include other areas in Central Visayas and Southern Luzon under PSWS#4 due to acceleration of Haiyan
- 4:40AM, Haiyan made landfall over Guiuan, Eastern Samar
- 11PM, Haiyan exits the landmass of N. Palawan after crossing Central Visayas and Southern Luzon area




## 07 Nov 2013:

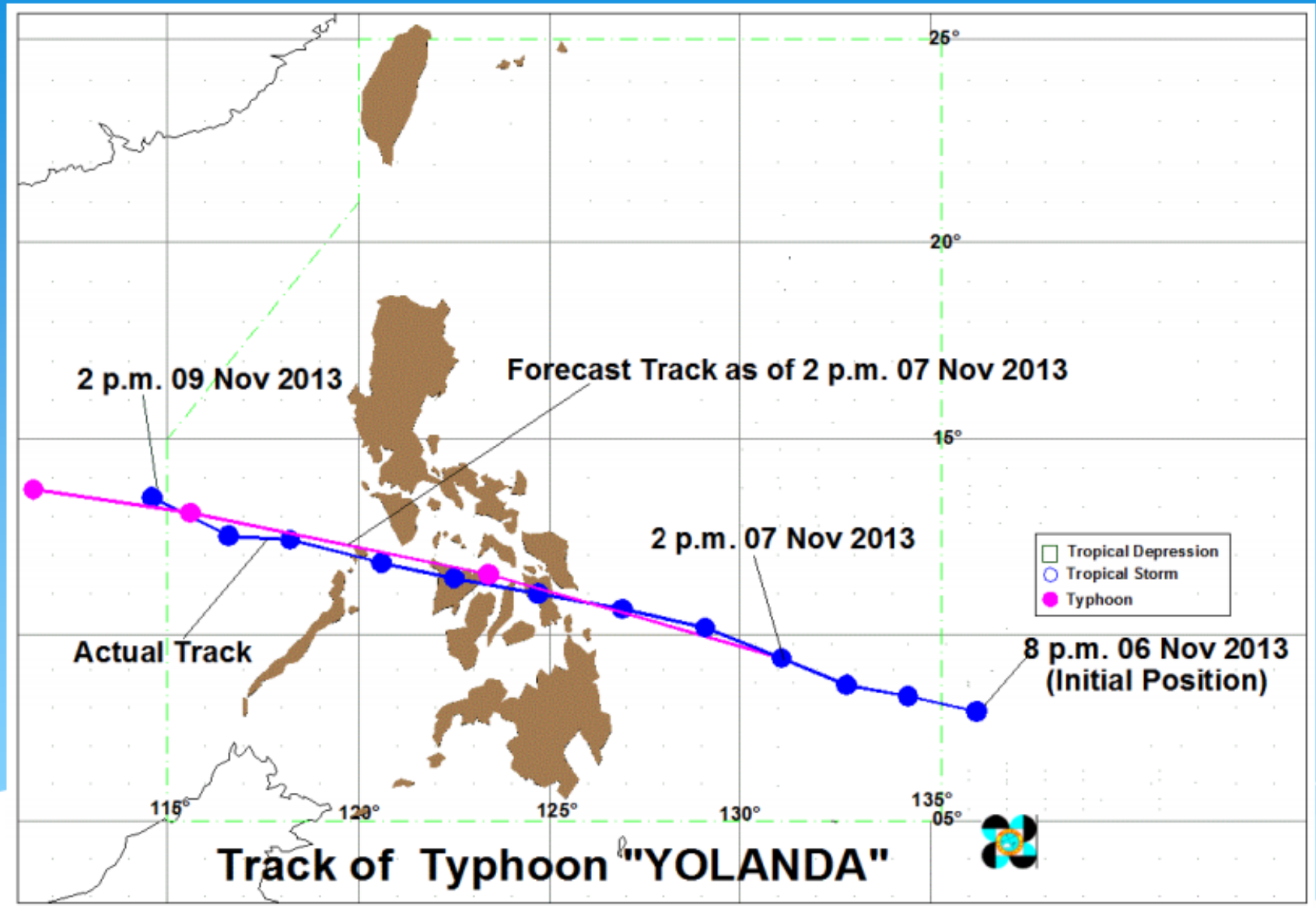
- Deployed STRIDE Team to Sorsogon
- Emphasized that a storm surge of **5-7 meters** is expected over the coastal areas in provinces of Surigao, Dinagat , **Samar and Leyte**, Sorsogon, Masbate, Northern Cebu and Bohol
- Conferred w/ the President who called for a nationwide preparation for the strong TY & stressed the occurrence of storm surge particularly in areas along its path
- Provided Hourly updates on the location and intensity
- Press conference/ press briefings every 6 hours until Nov. 9
- TY Haiyan intensified & accelerated as it moved closer to landmass

## 06 Nov 2013:

- Issued Regular Severe Wx. Bulletin although the TY was still outside PAR
- Presented in the NDRRMC meeting the forecast track of TY Haiyan and possible impacts
- Press conference - PAGASA emphasized that PSWS No. 4 will be issued and storm surge is expected.
- Assigned a meteorologist at the NDRRMC Operation Center
- Dispatched 2 meteorologists to Iloilo
- Dispatched 2 radar technicians to Hinatuan Radar operation.

**05 Nov** - Issued initial Weather Advisory
- Visayas PRSD alerted the media & Prov. Gov. of Cebu & Bohol approaching TY

# Forecast Track vs. Actual Track




Actual track  Forecast track

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# Background

PAGASA: Bagyong Yolanda, pinakamalakas na bagyo sa buong mundo ngayong 2013


'Super' typhoon heads for Philippines

# Background

**(PTV) Speech of President Benigno S. Aquino III on Super Typhoon Yolanda (November 7, 2013)**


# Background

## Impacts of Typhoon Yolanda (Haiyan)

**II. EFFECTS**

**A. Pre-emptive Evacuation (Tab A)**

- A total of **161,973 families / 792,018 persons** were pre-emptively evacuated to **812 evacuation centers** in **37 provinces**, **38 cities**, and **215 municipalities**, in **Regions IV-A, IV-B, V, VI, VII, VIII, X, XI, and CARAGA**

**B. Affected Population (Tab B)**

- A total of **3,424,593 families / 16,078,181 persons** were affected in **12,139 barangays** in **44 provinces**, **591 municipalities** and **57 cities** of **Regions IV-A, IV-B, V, VI, VII, VIII, X, XI, and CARAGA**
- 92.04% of 16M affected persons came from Regions VI (24.09%), VII (36.76%) and VIII (31.19%)

Breakdown per region:

| Region | Province | Barangays | Families | Persons |
|---|---|---|---|---|
| IV-A | 5 | 168 | 5,935 | 27,076 |
| IV-B | 5 | 793 | 101,006 | 466,120 |
| V | 6 | 1,229 | 150,889 | 692,020 |
| VI | 6 | 3,176 | 840,557 | 3,873,028 |
| VII | 4 | 2,136 | 1,299,436 | 5,909,955 |
| VIII | 6 | 4,387 | 1,006,718 | 5,015,434 |
| X | 4 | 26 | 4,253 | 19,592 |
| XI | 3 | 19 | 1,000 | 5,000 |
| XIII | 5 | 205 | 14,799 | 69,956 |
| TOTAL | 44 | 12,139 | 3,424,593 | 16,078,181 |

- At the height of the typhoon, a total of 1,093,023 families / 5,130,580 persons were served inside and outside the evacuation centers:

Inside 1,687 Evacuation Centers : 90,972 families / 430,041 persons
Outside Evacuation Centers : 1,002,051 families / 4,700,539 persons

**C. Casualties (Tab C)**

- A total of **6,300** individuals were reported dead, **28,688** injured and **1,062** are still missing
- 93.68% of the total number of deaths, 94.72% of missing and 91.28 of injured came from Region VIII

**Source:**

FINAL REPORT re EFFECTS of Typhoon "YOLANDA" (HAIYAN)

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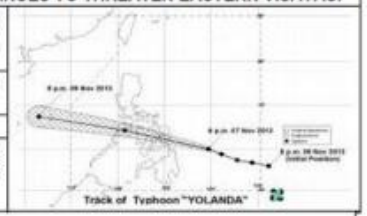
# Background
## Lessons learned

**The storm surge information was shown as a minor line item yet this event was the most damaging component of the typhoon**

**TROPICAL CYCLONE WARNING: TYPHOON "YOLANDA" (HAIYAN)**
**ISSUED AT 8:00 PM, 07 NOVEMBER 2013**
(Valid for broadcast until the next bulletin to be issued at 11 PM today)

**TYPHOON "YOLANDA HAS ACCELERATED AND INTENSIFIED SLIGHTLY AS IT CONTINUES TO THREATEN EASTERN VISAYAS.**

| | |
|---|---|
| **Location of eye/center:** | At **6:00 PM** today, the eye of Typhoon **"YOLANDA"** was located based on all available data at **453 km Southeast of Guiuan, Eastern Samar (9.9°N, 129.7°E).** |
| **Strength:** | Maximum sustained winds of **225 kph** near the center and gustiness of up to **260 kph.]** |
| **Movement:** | Forecast to move **West Northwest** at **39 kph.** |
| **Forecast Position:** | Typhoon **"YOLANDA"** is expected to be at **55 km East of Coron, Palawan** by tomorrow evening. By Saturday evening, it will be at **1032 km West of Manila or outside the Philippine Area of Responsibility.** |




**PUBLIC STORM WARNING SIGNAL**

| PSWS | LUZON | VISAYAS | MINDANAO | POTENTIAL IMPACTS OF THE WINDS |
|---|---|---|---|---|
| #4 (Winds of more than 185 kph is expected in at least 12 hrs) | | Eastern Samar, Samar, Leyte, Southern Leyte Biliran Province, extreme Northern Cebu including Bantayan Island, Capiz, Aklan, Northern Antique. | | • Coconut plantation may suffer extensive damage<br>• Many large trees maybe uprooted<br>• Rice and corn plantation may suffer severe losses<br>• Most residential and institutional buildings of mixed construction material maybe severely damaged<br>• Electrical power distribution and communication services maybe severely disrupted<br>• In the overall, damage to affected communities can be very heavy<br>• The situation is potentially very destructive to communities<br>• All travel and outdoor activities should be cancelled<br>• Evacuation to much safer shelters should have been completed earlier since it maybe too late under this situation |

- Yolanda, after hitting Guiuan or Abuyog, Leyte, is expected to traverse the provinces of Biliran, the Northern tip of Cebu, Iloilo, Capiz, Aklan, Romblon, Semirara Island, the Southern part of Mindoro then Busuanga and will exit the Philippine landmass (on Saturday early morning) towards the West Philippine Sea.
- Estimated rainfall amount is from 10.0 - 30.0 mm per hour (Heavy - Intense) within the **600 km** diameter of the Typhoon.
- Sea travel is risky over the seaboards of Northern Luzon and over the eastern seaboard of Central Luzon.
- Residents in low lying and mountainous areas under signal #4, #3,#2 & #1 are alerted against possible flashfloods and landslides. Likewise, those living in coastal areas under signal #4, #3 and #2 are alerted against storm surges which may reach up to 7-meter wave height.
- The public and the disaster risk reduction and management council concerned are advised to take appropriate actions and watch for the next bulletin to be issued at 11 PM today.

7-meter wave height

- People didn't understand what a storm surge was, were caught unaware by the severity of the surge and struggled to protect themselves against the impact
- Communication and dissemination systems, networks and processes failed in place during and after Haiyan
- Lack of scientific and technical capacity to translate hazard information into impacts – therefore impacts underestimated

**Forecasting impact is more important than pure meteorological forecast, they are more readily understood by those at risk and those responsible for mitigating those risks**

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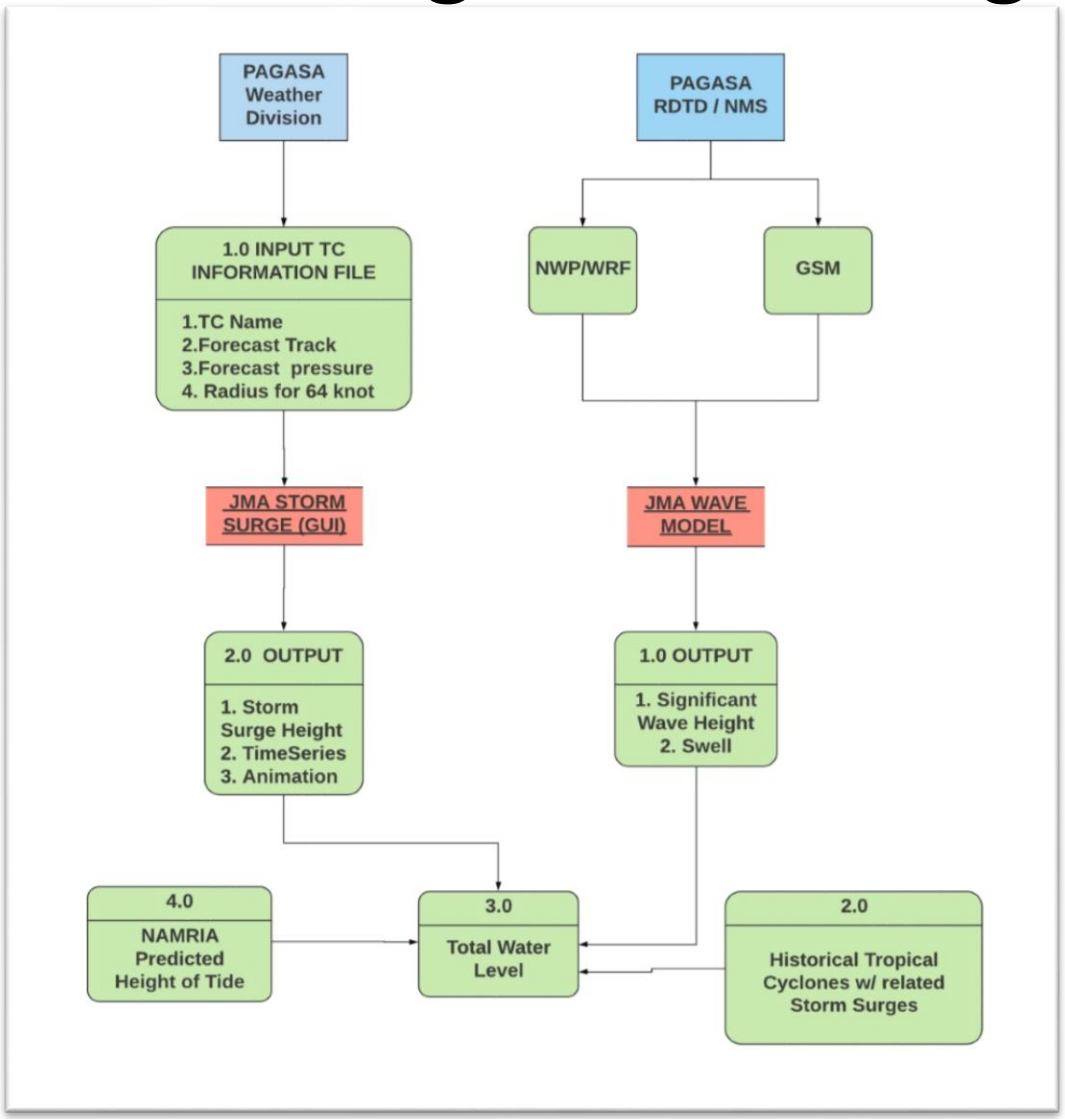
# Forecasting and warning system objectives

- Storm Surge Forecasting  and Warning System ( SSFWS) was developed to provide coastal flood early warning for communities located along the shorelines of the Philippines
- It aims to provide easy-to-interpret information for decision-makers and encourage the public to take necessary actions to ensure their safety and protect their properties and livelihood.

# Storm Surge Forecasting System




## Components of the storm surge modelling system

- **Tropical cyclone conditions for storm surge prediction inputs**

  Forecast positions, pressure and radius of maximum winds

- **Storm Surge Model**

  JMA Storm Surge Model

- **Wave Model**

  JMA Wave Model

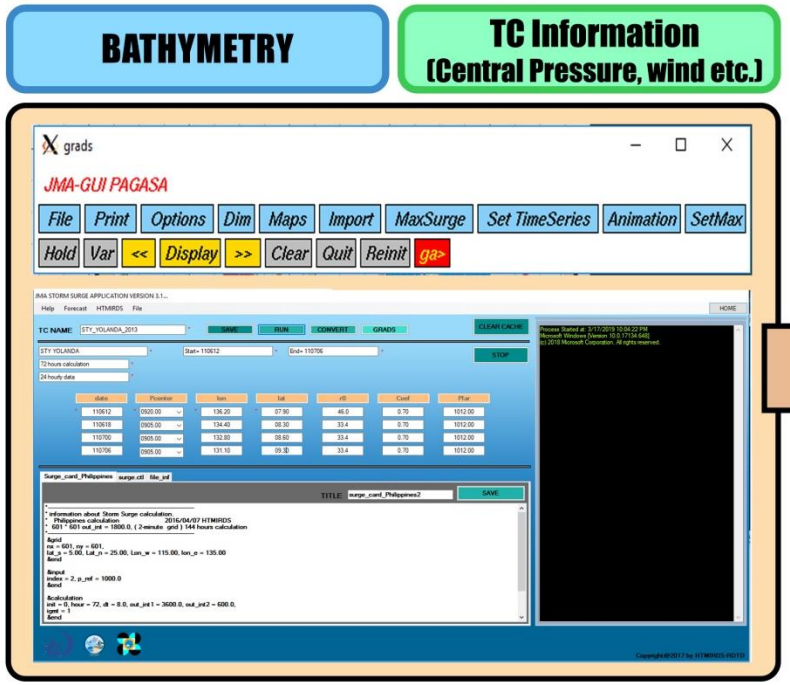
- **Tides**

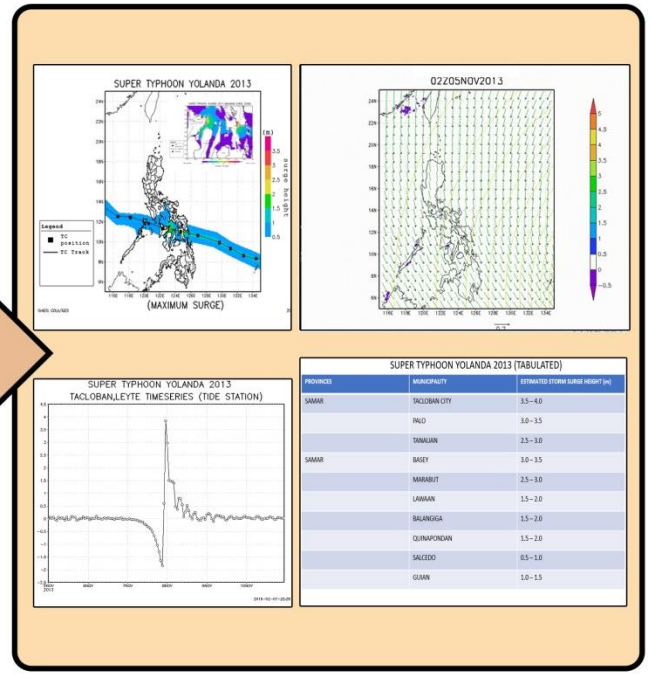
  NAMRIA predicted tide heights

- **Historical tropical cyclones with related storm surge occurrences**

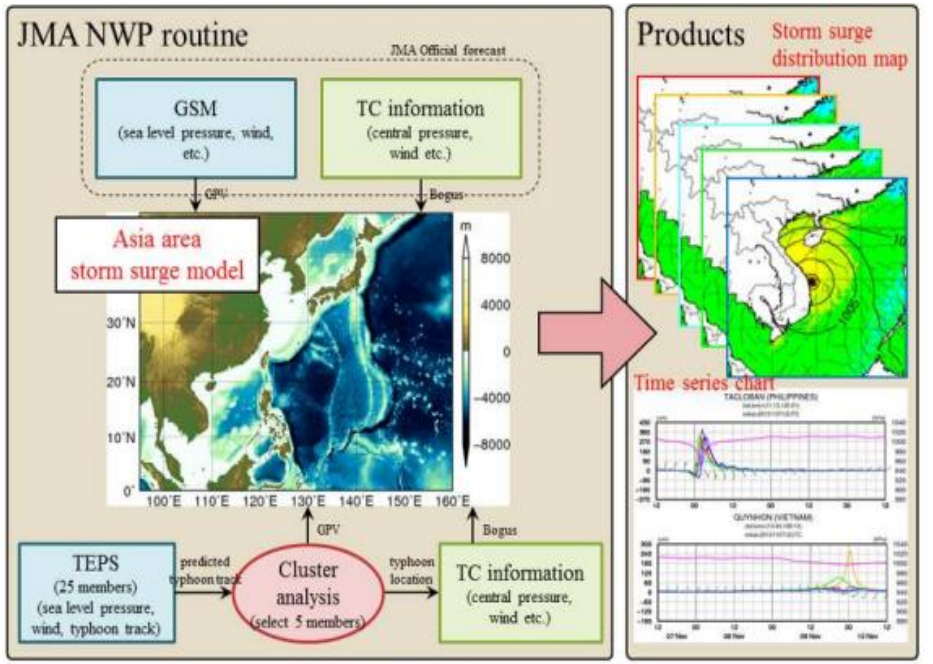
# Storm Surge Forecasting System

- **JMA Storm Surge Model**




- **Regional Storm Surge Watch Scheme (SSWS) of WMO**




**Grid**: Arakawa C grid

**Resolution**: approximately 1km mesh

**Bathymetry**: GEBCO Data

A multi-scenario prediction method is incorporated into the model

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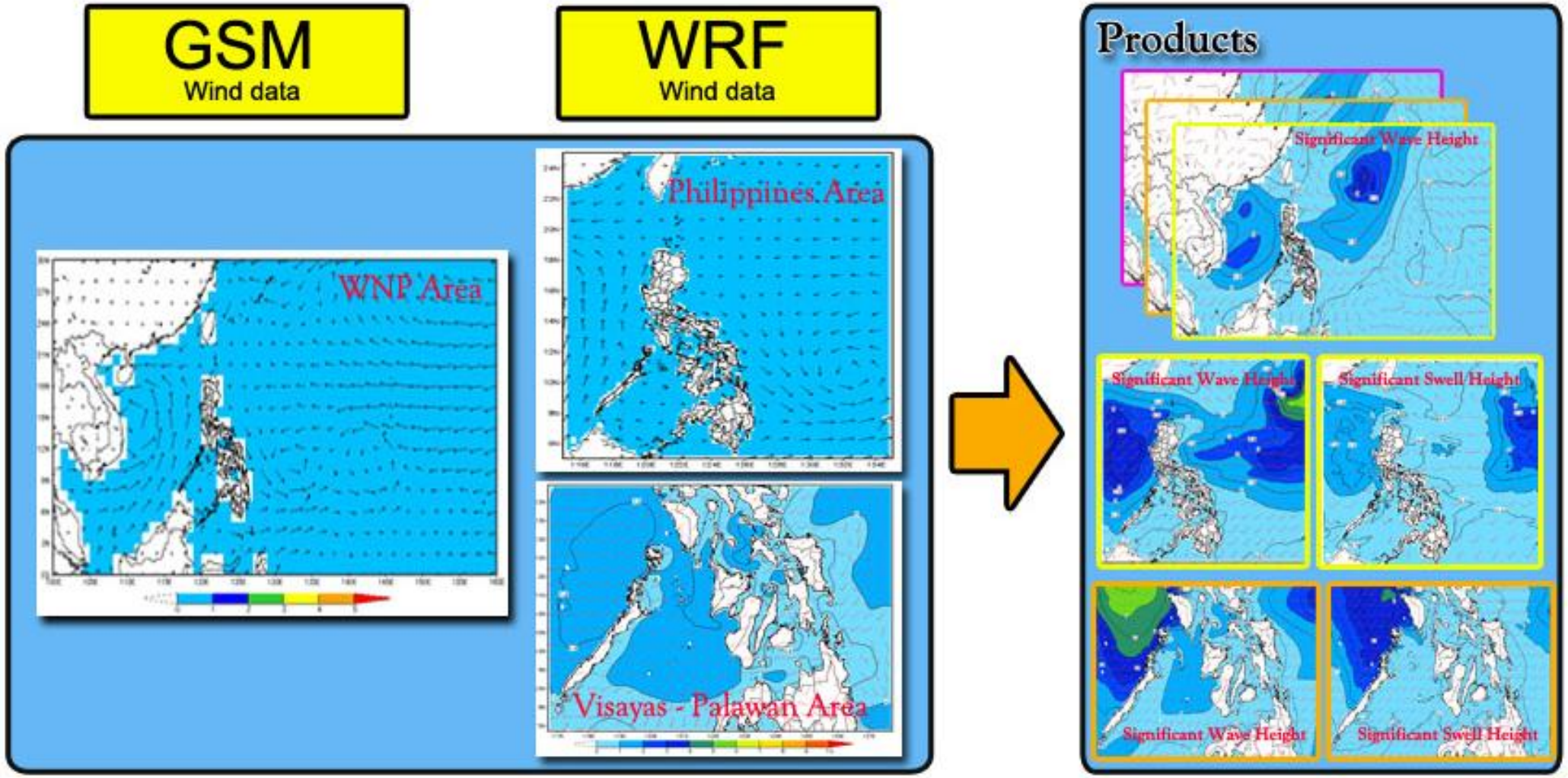
# Storm Surge Forecasting System

- **JMA Wave Model**



# Storm Surge Forecasting System

- **NAMRIA Predicted Height of Tide**

## PREDICTED HOURLY HEIGHT OF TIDE

2019 - MARCH - 18

### METRO MANILA

**Manila South Harbor**

| HOUR | HEIGHT | HOUR | HEIGHT |
|---|---|---|---|
| 0000 | 0.17 | 1200 | 0.41 |
| 0100 | 0 | 1300 | 0.46 |
| 0200 | 0.12 | 1400 | 0.53 |
| 0300 | 0.18 | 1500 | 0.63 |
| 0400 | 0.17 | 1600 | 0.75 |
| 0500 | 0.1 | 1700 | 0.87 |
| 0600 | 0.01 | 1800 | 0.98 |
| 0700 | 0.12 | 1900 | 1.04 |
| 0800 | 0.22 | 2000 | 1.05 |
| 0900 | 0.3 | 2100 | 0.98 |
| 1000 | 0.35 | 2200 | 0.83 |
| 1100 | 0.38 | 2300 | 0.63 |

### LUZON TIDE STATIONS

**Puerto Princesa, Palawan**

| HOUR | HEIGHT | HOUR | HEIGHT |
|---|---|---|---|
| 0000 | 0.48 | 1200 | 0.62 |
| 0100 | 0.23 | 1300 | 0.61 |
| 0200 | 0.01 | 1400 | 0.62 |
| 0300 | -0.12 | 1500 | 0.67 |
| 0400 | -0.16 | 1600 | 0.78 |
| 0500 | -0.1 | 1700 | 0.95 |
| 0600 | 0.03 | 1800 | 1.14 |
| 0700 | 0.21 | 1900 | 1.31 |
| 0800 | 0.38 | 2000 | 1.4 |
| 0900 | 0.52 | 2100 | 1.4 |
| 1000 | 0.6 | 2200 | 1.28 |
| 1100 | 0.63 | 2300 | 1.07 |

### VISAYAS TIDE STATIONS

**Cebu Port, Cebu**

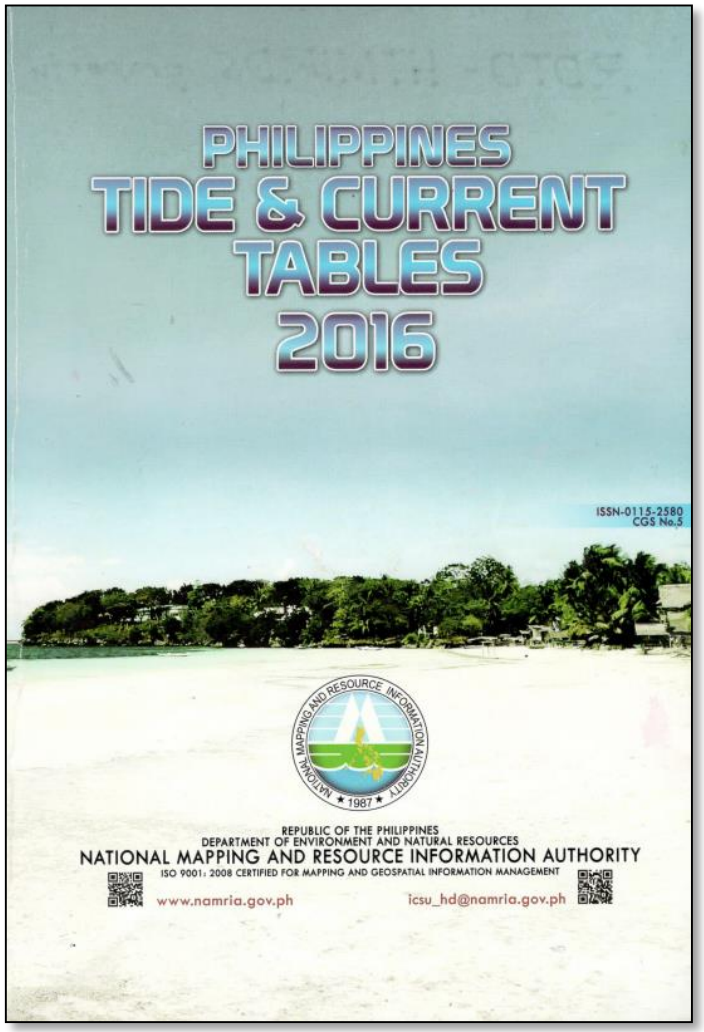
| HOUR | HEIGHT | HOUR | HEIGHT |
|---|---|---|---|
| 0000 | 0.55 | 1200 | 0.77 |
| 0100 | 0.28 | 1300 | 0.71 |
| 0200 | 0.06 | 1400 | 0.64 |
| 0300 | -0.09 | 1500 | 0.62 |
| 0400 | -0.12 | 1600 | 0.68 |
| 0500 | -0.05 | 1700 | 0.82 |
| 0600 | 0.09 | 1800 | 1.02 |
| 0700 | 0.27 | 1900 | 1.2 |
| 0800 | 0.46 | 2000 | 1.35 |
| 0900 | 0.64 | 2100 | 1.41 |
| 1000 | 0.76 | 2200 | 1.37 |
| 1100 | 0.8 | 2300 | 1.2 |

### MINDANAO TIDE STATIONS

**Davao City, Davao Del Sur**

| HOUR | HEIGHT | HOUR | HEIGHT |
|---|---|---|---|
| 0000 | 0.33 | 1200 | 0.58 |
| 0100 | 0.58 | 1300 | 0.88 |
| 0200 | 0.85 | 1400 | 1.2 |
| 0300 | 1.06 | 1500 | 1.47 |
| 0400 | 1.16 | 1600 | 1.6 |
| 0500 | 1.13 | 1700 | 1.56 |
| 0600 | 0.98 | 1800 | 1.34 |
| 0700 | 0.76 | 1900 | 0.99 |
| 0800 | 0.54 | 2000 | 0.59 |
| 0900 | 0.37 | 2100 | 0.23 |
| 1000 | 0.3 | 2200 | -0.02 |
| 1100 | 0.37 | 2300 | -0.09 |

TIME MERIDIAN 120 DEG EAST. 0000 IS MIDNIGHT. 1200 IS NOON. HEIGHT IS IN METERS AND RECKONED FROM THE DATUM OF SOUNDING ON CHARTS OF THE LOCALITY WHICH IS MEAN LOWER LOW WATER.

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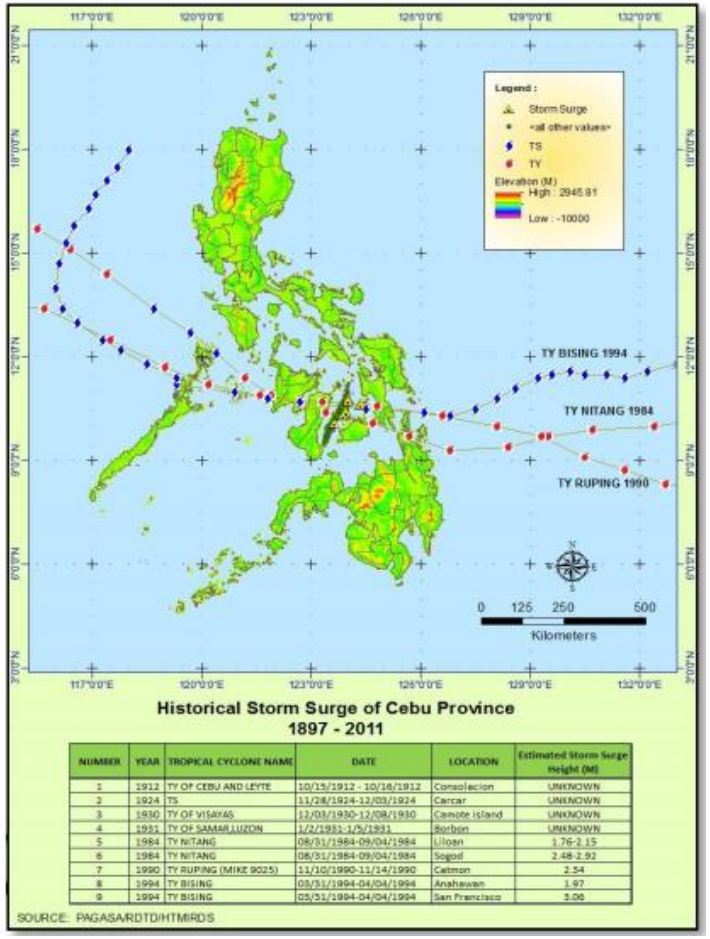
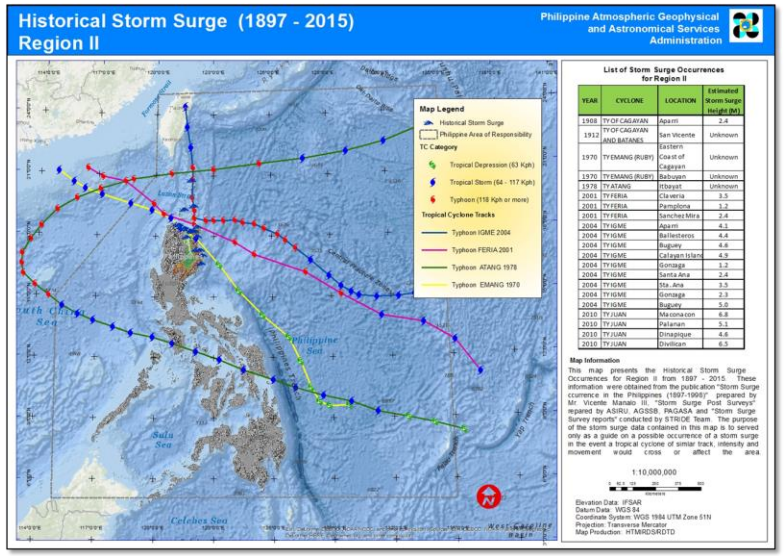
# Storm Surge Forecasting System

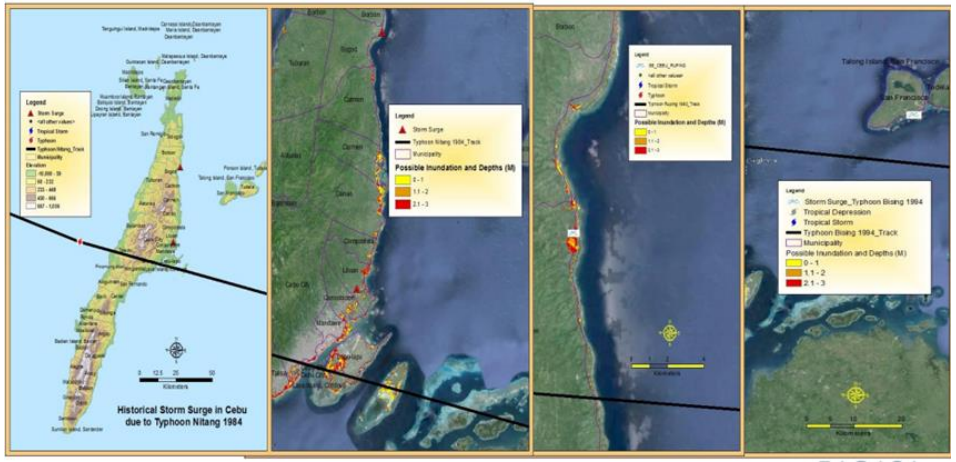
- **Related historical tropical cyclones and storm surges**

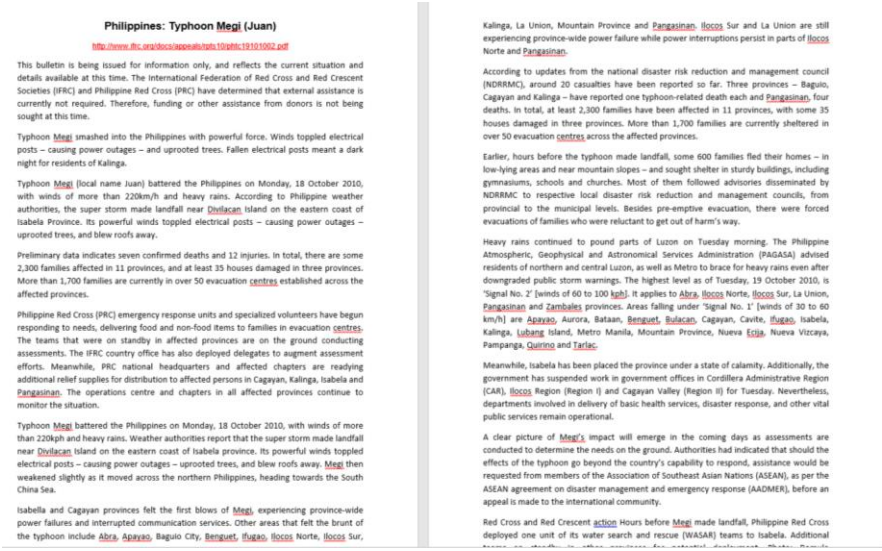



| NUMBER | YEAR | TROPICAL CYCLONE NAME | DATE | LOCATION | Estimated Storm Surge Height (M) |
|---|---|---|---|---|---|
| 1 | 1912 | TY OF CEBU AND LEYTE | 10/15/1912 - 10/16/1912 | Consolacion | UNKNOWN |
| 2 | 1924 | TS | 11/28/1924-12/03/1924 | Carcar | UNKNOWN |
| 3 | 1930 | TY OF VISAYAS | 12/03/1930-12/08/1930 | Camote Island | UNKNOWN |
| 4 | 1931 | TY OF SAMAR LUZON | 1/2/1931-1/5/1931 | Borbon | UNKNOWN |
| 5 | 1984 | TY NITANG | 08/31/1984-09/04/1984 | Liloan | 1.76-2.15 |
| 6 | 1984 | TY NITANG | 08/31/1984-09/04/1984 | Sogod | 2.48-2.92 |
| 7 | 1990 | TY RUPING (MIKE 9025) | 11/10/1990-11/14/1990 | Catmon | 2.54 |
| 8 | 1994 | TY BISING | 03/31/1994-04/04/1994 | Anahawan | 1.97 |
| 9 | 1994 | TY BISING | 03/31/1994-04/04/1994 | San Francisco | 3.06 |




| YEAR | CYCLONE | LOCATION | Estimated Storm Surge Height (M) |
|---|---|---|---|
| 1908 | TY OF CAGAYAN | Aparri | 2.4 |
| 1912 | TY OF CAGAYAN AND BATANES | San Vicente | Unknown |
| 1970 | TY EMANG (RUBY) | Eastern Coast of Cagayan | Unknown |
| 1970 | TY EMANG (RUBY) | Babuyan | Unknown |
| 1978 | TY ATANG | Itbayat | Unknown |
| 2001 | TY FERIA | Claveria | 3.5 |
| 2001 | TY FERIA | Pamplona | 3.2 |
| 2001 | TY FERIA | Sanchez Mira | 2.4 |
| 2004 | TY IGME | Aparri | 4.1 |
| 2004 | TY IGME | Ballesteros | 4.4 |
| 2004 | TY IGME | Buguey | 4.6 |
| 2004 | TY IGME | Calayan Island | 4.9 |
| 2004 | TY IGME | Gonzaga | 1.2 |
| 2004 | TY IGME | Santa Ana | 2.4 |
| 2004 | TY IGME | Sta. Ana | 3.5 |
| 2004 | TY IGME | Gonzaga | 2.3 |
| 2004 | TY IGME | Buguey | 5.0 |
| 2010 | TY JUAN | Maconacon | 6.8 |
| 2010 | TY JUAN | Palanan | 5.1 |
| 2010 | TY JUAN | Dinapigue | 4.6 |
| 2010 | TY JUAN | Divilican | 6.5 |



**Philippines: Typhoon Megi (Juan)**

http://www.ifrc.org/docs/appeals/rpts10/phtc19101002.pdf

This bulletin is being issued for information only, and reflects the current situation and details available at this time. The International Federation of Red Cross and Red Crescent Societies (IFRC) and Philippine Red Cross (PRC) have determined that external assistance is currently not required. Therefore, funding or other assistance from donors is not being sought at this time.

Typhoon Megi smashed into the Philippines with powerful force. Winds toppled electrical posts – causing power outages – and uprooted trees. Fallen electrical posts meant a dark night for residents of Kalinga.

Typhoon Megi (local name Juan) battered the Philippines on Monday, 18 October 2010, with winds of more than 220km/h and heavy rains. According to Philippine weather authorities, the super storm made landfall near Divilacan Island on the eastern coast of Isabela Province. Its powerful winds toppled electrical posts – causing power outages – uprooted trees, and blew roofs away.

Preliminary data indicates seven confirmed deaths and 12 injuries. In total, there are some 2,300 families affected in 11 provinces, and at least 35 houses damaged in three provinces. More than 1,700 families are currently in over 50 evacuation centres established across the affected provinces.

Philippine Red Cross (PRC) emergency response units and specialized volunteers have begun responding to needs, delivering food and non-food items to families in evacuation centres. The teams that were on standby in affected provinces are on the ground conducting assessments. The IFRC country office has also deployed delegates to augment assessment efforts. Meanwhile, PRC national headquarters and affected chapters are readying additional relief supplies for distribution to affected persons in Cagayan, Kalinga, Isabela and Pangasinan. The operations centre and chapters in all affected provinces continue to monitor the situation.

Typhoon Megi battered the Philippines on Monday, 18 October 2010, with winds of more than 220kph and heavy rains. Weather authorities report that the super storm made landfall near Divilacan Island on the eastern coast of Isabela province. Its powerful winds toppled electrical posts – causing power outages – uprooted trees, and blew roofs away. Megi then weakened slightly as it moved across the northern Philippines, heading towards the South China Sea.

Isabella and Cagayan provinces felt the first blows of Megi, experiencing province-wide power failures and interrupted communication services. Other areas that felt the brunt of the typhoon include Abra, Apayao, Baguio City, Benguet, Ifugao, Ilocos Norte, Ilocos Sur, Kalinga, La Union, Mountain Province and Pangasinan. Ilocos Sur and La Union are still experiencing province-wide power failure while power interruptions persist in parts of Ilocos Norte and Pangasinan.

According to updates from the national disaster risk reduction and management council (NDRRMC), around 20 casualties have been reported so far. Three provinces – Baguio, Cagayan and Kalinga – have reported one typhoon-related death each and Pangasinan, four deaths. In total, at least 2,300 families have been affected in 11 provinces, with some 35 houses damaged in three provinces. More than 1,700 families are currently sheltered in over 50 evacuation centres across the affected provinces.

Earlier, hours before the typhoon made landfall, some 600 families fled their homes – in low-lying areas and near mountain slopes – and sought shelter in sturdy buildings, including gymnasiums, schools and churches. Most of them followed advisories disseminated by NDRRMC to respective local disaster risk reduction and management councils, from provincial to the municipal levels. Besides pre-emptive evacuation, there were forced evacuations of families who were reluctant to get out of harm's way.

Heavy rains continued to pound parts of Luzon on Tuesday morning. The Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) advised residents of northern and central Luzon, as well as Metro to brace for heavy rains even after downgraded public storm warnings. The highest level as of Tuesday, 19 October 2010, is 'Signal No. 2' [winds of 60 to 100 kph]. It applies to Abra, Ilocos Norte, Ilocos Sur, La Union, Pangasinan and Zambales provinces. Areas falling under 'Signal No. 1' [winds of 30 to 60 km/h] are Apayao, Aurora, Bataan, Benguet, Bulacan, Cagayan, Cavite, Ifugao, Isabela, Kalinga, Lubang Island, Metro Manila, Mountain Province, Nueva Ecija, Nueva Vizcaya, Pampanga, Quirino and Tarlac.

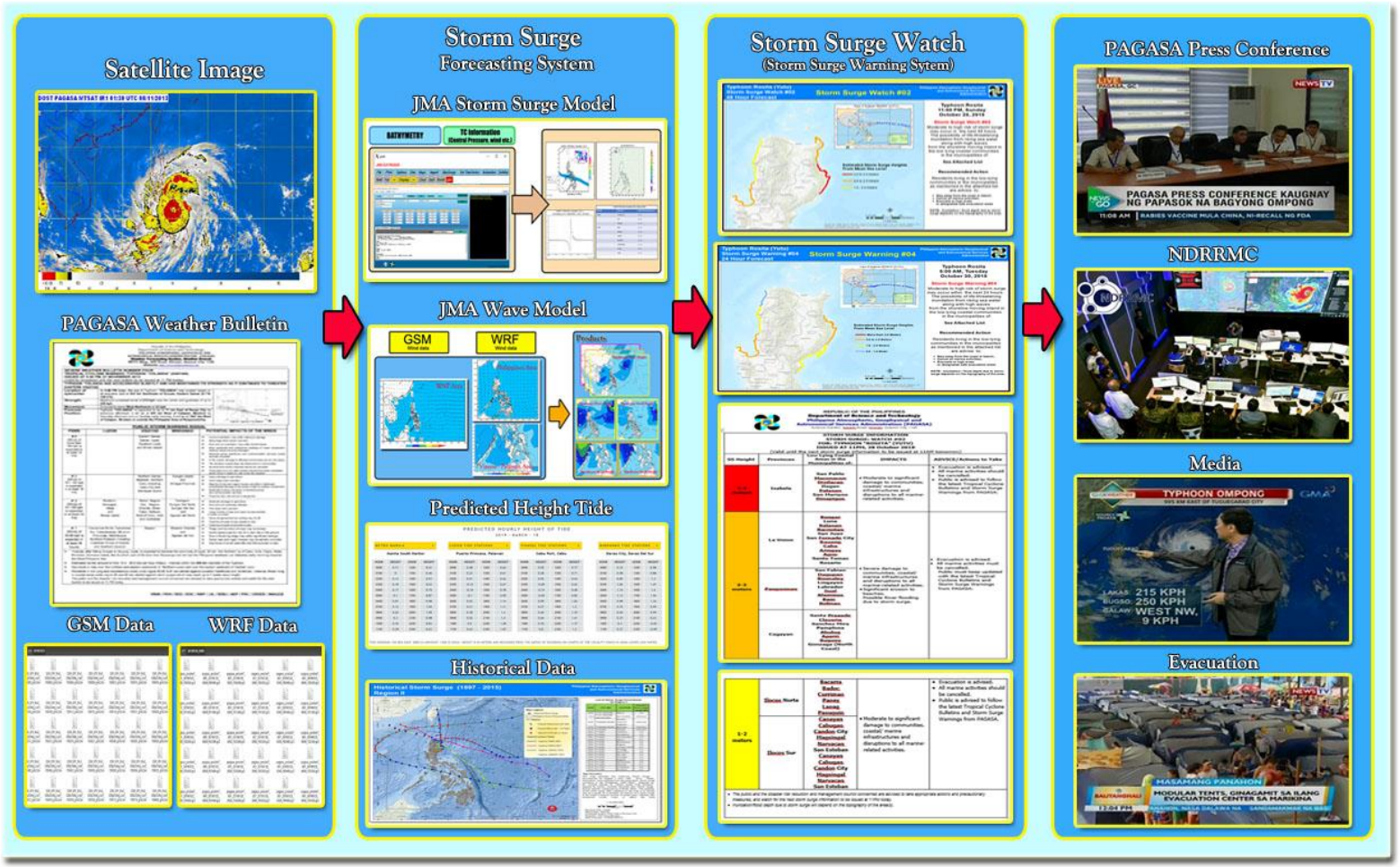
Meanwhile, Isabela has been placed the province under a state of calamity. Additionally, the government has suspended work in government offices in Cordillera Administrative Region (CAR), Ilocos Region (Region I) and Cagayan Valley (Region II) for Tuesday. Nevertheless, departments involved in delivery of basic health services, disaster response, and other vital public services remain operational.

A clear picture of Megi's impact will emerge in the coming days as assessments are conducted to determine the needs on the ground. Authorities had indicated that should the effects of the typhoon go beyond the country's capability to respond, assistance would be requested from members of the Association of Southeast Asian Nations (ASEAN), as per the ASEAN agreement on disaster management and emergency response (AADMER), before an appeal is made to the international community.

Red Cross and Red Crescent action Hours before Megi made landfall, Philippine Red Cross deployed one unit of its water search and rescue (WASAR) teams to Isabela. Additional

# Storm Surge Warning System

- **Overview of the Storm Surge Warning System**




**The early warning system consists of the following functionalities:**

- Data gathering  provided to the system as inputs
- Pre-processing of data (forecasts) before using it in the JMA storm surge and wave models
- Simulation of the storm surge  and wave model
- Generation of GIS based maps for visualization of forecasts
- Dissemination of storm surge forecasts, watch/warning to stakeholders

# How the Storm Surge Warning is generated…

- **Forty-eight (48) hours** before the landfall, **STORM SURGE WATCH** are disseminated every 6 hours. This gives the decision makers more lead time to plan and prepare for possible occurrence of storm surge in the threatened areas.
- **Twenty-four (24) hours** before the landfall, **STORM SURGE WARNINGS** are disseminated every 6 hours simultaneous with Severe Weather Bulletin issuances. This emphasizes a high risk for storm surge and the possibility of life-threatening inundation from rising sea waters.
- **Storm Surge Watch and Warning** comes with GIS generated maps, **showing areas with threat for storm surge**. Storm surge heights are plotted into the map depending on the severity as color coded assigned to each (e.g. **YELLOW**= 1 – 2 meters; **ORANGE**= 2 – 3 meters; **RED** = more than 3 meters).
- Together with **Storm Surge Watch and Warning** is a table of Storm Surge Heights with forecast up to the municipal level. Historical storm surge occurrences and wave height forecasts are also taken into account.
- **Storm Surge Watch and Warnings** are sent thru e-mails and posted at the **PAGASA website**

# Storm Surge Warning Levels

**BE INFORMED.**
Evacuation NOT necessary.

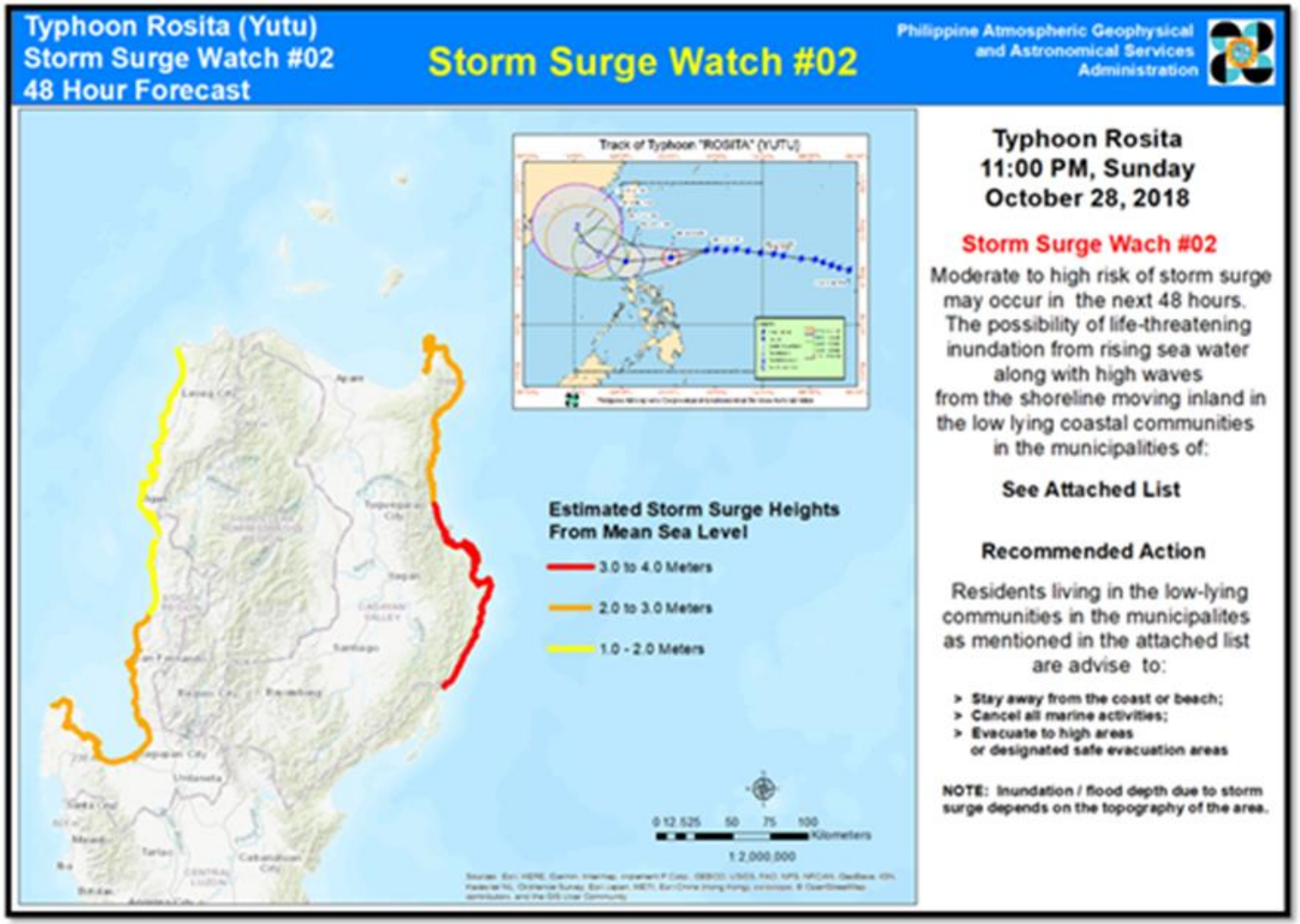
**Storm Surge is POSSIBLE – BE AWARE**
Get READY. Stay away from the coast or beach.

**Storm Surge is EXPECTED – BE PREPARED**
Conditions could be Life Threatening. Follow evacuation guidance from local authorities.

**Storm Surge is CATASTROPHIC – TAKE ACTION**
Catastrophic. MANDATORY EVACUATION is enforced.

| STORM SURGE HEIGHT | IMPACTS |
|---|---|
| **SURGE OF LESS THAN 1 METER** | **BE INFORMED**<br>• Minor damage to communities, coastal/ marine infrastructures and disruptions to all marine-related activities.<br>• Flooding is possible in low-lying areas |
| **SURGE FROM 1 TO 2 METER** | **STORM SURGE IS POSSIBLE**<br>• Moderate to significant damage to communities, coastal/ marine infrastructures and disruptions to all marine-related activities. |
| **SURGE FROM 2 TO 3 METERS** | **STORM SURGE IS EXPECTED**<br>• Severe damage to communities, coastal/ marine infrastructures and disruptions to all marine-related activities.<br>• Significant erosion to beaches.<br>• Possible river flooding due to storm surge. |
| **SURGE ABOVE 3 METERS** | **STORM SURGE IS CATASTROPHIC**<br>• Life-threatening and extensive inundation from rising sea water moving inland from the shoreline.<br>• Extreme damage to communities and coastal/marine infrastructures.<br>• River flooding is aggravated due to storm surge. |

# Storm Surge Watch




***Contents:***

It includes the following details:

- Name of the TC
- Time and Date of Issuance/Validity
- TC Current Information which includes its :
  - > center location
  - > maximum sustained wind
  - > movement
- Storm Surge Watch description
- Recommended actions

DOST-PAGASA
The Weather and Climate Authority

Payong PAGASA

# Storm Surge Watch

REPUBLIC OF THE PHILIPPINES
**Department of Science and Technology**
**Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA)**
Science Garden, Agham Road, Diliman, Quezon City 1100

**STORM SURGE INFORMATION**
**STORM SURGE: WATCH #02**
**FOR: TYPHOON "ROSITA" (YUTU)**
**ISSUED AT 11PM, 28 October 2018**
(Valid until the next storm surge information to be issued at 11AM tomorrow)

| SS Height | Provinces | Low Lying Coastal Areas in the Municipalities of: | IMPACTS | ADVICE/Actions to Take |
|---|---|---|---|---|
| 3-4 meters | Isabela | San Pablo<br>Maconacon<br>Divilacan<br>Ilagan<br>Palanan<br>San Mariano<br>Dinapigue | • Moderate to significant damage to communities, coastal/ marine infrastructures and disruptions to all marine-related activities. | • Evacuation is advised.<br>• All marine activities should be cancelled.<br>• Public is advised to follow the latest Tropical Cyclone Bulletins and Storm Surge Warnings from PAGASA. |
| 2-3 meters | La Union | Bangar<br>Luna<br>Balaoan<br>Bacnotan<br>San Juan<br>San Fernado City<br>Bauang<br>Caba<br>Aringay<br>Agoo<br>Santo Tomas<br>Rosario | • Severe damage to communities, coastal/ marine infrastructures and disruptions to all marine-related activities.<br>• Significant erosion to beaches.<br>Possible River flooding due to storm surge. | • Evacuation is advised.<br>• All marine activities must be cancelled.<br>Public must keep updated with the latest Tropical Cyclone Bulletins and Storm Surge Warnings from PAGASA. |
| | Pangasinan | San Fabian<br>Dagupan<br>Binmaley<br>Lingayen<br>Labrador<br>Sual<br>Alaminos<br>Bani<br>Bolinao | | |
| | Cagayan | Santa Praxede<br>Claveria<br>Sanchez Mira<br>Pamplona<br>Abulug<br>Aparri<br>Buguey<br>Gonzaga (North Coast) | | |
| 1-2 meters | Ilocos Norte | Bacarra<br>Badoc<br>Currimao<br>Paoay<br>Laoag<br>Pasuquin | • Moderate to significant damage to communities, coastal/ marine infrastructures and disruptions to all marine-related activities. | • Evacuation is advised.<br>• All marine activities should be cancelled.<br>• Public is advised to follow the latest Tropical Cyclone Bulletins and Storm Surge Warnings from PAGASA. |
| | Ilocos Sur | Caoayan<br>Cabugao<br>Candon City<br>Magsingal<br>Narvacan<br>San Esteban<br>Caoayan<br>Cabugao<br>Candon City<br>Magsingal<br>Narvacan<br>San Esteban | | |

- *The public and the disaster risk reduction and management council concerned are advised to take appropriate actions and precautionary measures, and watch for the next storm surge information to be issued at 11PM today.*
- *Inundation/flood depth due to storm surge will depend on the topography of the area(s).*

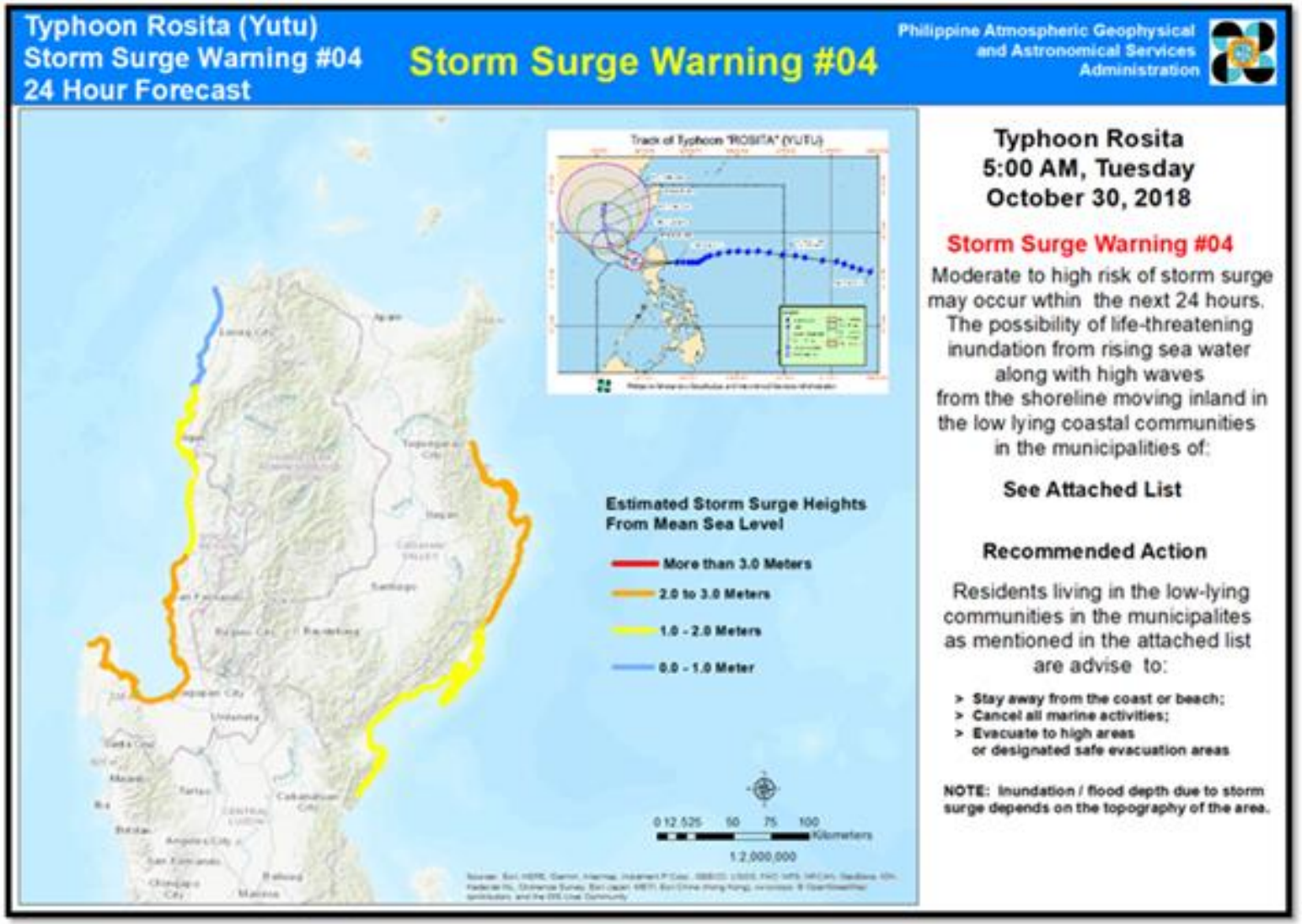
## Contents:

- Predicted storm surge heights, color coded in red, orange or yellow
- In table format, places of provinces/municipalites in low-lying coastal areas with possibility of life-threatening inundation from rising sea water from the shoreline moving inland
- Statements on Recommended Actions/Precautionary Measures

**DOST-PAGASA**
The Weather and Climate Authority

Payong PAGASA

# Storm Surge Warning




- A high risk of storm surge may occur within the next 24 hours. The danger of a life-threatening inundation from rising sea water from the shoreline moving inland in the low-lying coastal communities at the municipal level are identified.

***When to issue:***

The Storm Surge Warning shall be issued when all of the following conditions exist:

1. There is a Tropical Cyclone (TC) inside the PAR;
2. The TC is at least a Tropical Storm (TS)category; and
3. It will affect low lying coastal communities within the next **24 hrs**.

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# Storm Surge Warning

REPUBLIC OF THE PHILIPPINES
**Department of Science and Technology**
**Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA)**
Science Garden, Agham Road, Diliman, Quezon City 1100

**STORM SURGE INFORMATION**
**STORM SURGE: WARNING #04**
**FOR: TYPHOON "ROSITA" (YUTU)**
**ISSUED AT 5 AM, 30 October 2018**
(Valid until the next storm surge information to be issued at 11:00 AM today)

| SS Height | Provinces | Low Lying Coastal Areas in the Municipalities of: | IMPACTS | ADVICE/Actions to Take |
|---|---|---|---|---|
| 2 – 3 meters | Isabela | San Pablo<br>Maconacon<br>Divilacan<br>Ilagan<br>Palanan<br>San Mariano<br>Dinapigue | • Severe damage to communities, coastal/ marine infrastructures and disruptions to all marine-related activities.<br>• Significant erosion to beaches.<br>• Possible River flooding due to storm surge. | • Evacuation is advised.<br>• All marine activities must be cancelled.<br>• Public must keep updated with the latest Tropical Cyclone Bulletins and Storm Surge Warnings from PAGASA. |
| | La Union | Bangar<br>Luna<br>Balaoan<br>Bacnotan<br>San Juan<br>San Fernado City<br>Bauang<br>Caba<br>Aringay<br>Agoo<br>Santo Tomas<br>Rosario | | |
| | Pangasinan | San Fabian<br>Dagupan<br>Binmaley<br>Lingayen<br>Labrador<br>Sual<br>Alaminos<br>Bani<br>Bolinao | | |
| 1-2 meters | Ilocos Sur | Caoayan<br>Cabugao<br>Candon City<br>Magsingal<br>Narvacan<br>San Esteban | • Moderate to significant damage to communities, coastal/ marine infrastructures and disruptions to all marine-related activities. | • Evacuation is advised.<br>• All marine activities should be cancelled.<br>• Public is advised to follow the latest Tropical Cyclone Bulletins and Storm Surge Warnings from PAGASA. |
| | Aurora | Dilasag<br>Casiguran<br>Dipaculao<br>Baler<br>San Luis | | |
| <1 meter | Ilocos Norte | Bacarra<br>Badoc<br>Currimao<br>Paoay<br>Laoag<br>Pasuquin | • Minor damage to communities, coastal/ marine infrastructures and disruptions to all marine-related activities.<br>• Flooding is possible in low-lying areas | • Public is advised to stay away from the coasts or beaches.<br>• Be aware and follow the latest weather updates from PAGASA. |

- *The public and the disaster risk reduction and management council concerned are advised to take appropriate actions and precautionary measures, and watch for the next storm surge information to be issued at 11AM today.*
- *Inundation/flood depth due to storm surge will depend on the topography of the area(s).*

## Contents:

- Predicted storm surge heights, color coded in red, orange or yellow or blue
- In table format, places of provinces/municipalites in low-lying coastal areas with possibility of life-threatening inundation from rising sea water from the shoreline moving inland
- Statements on Recommended Actions/Precautionary Measures

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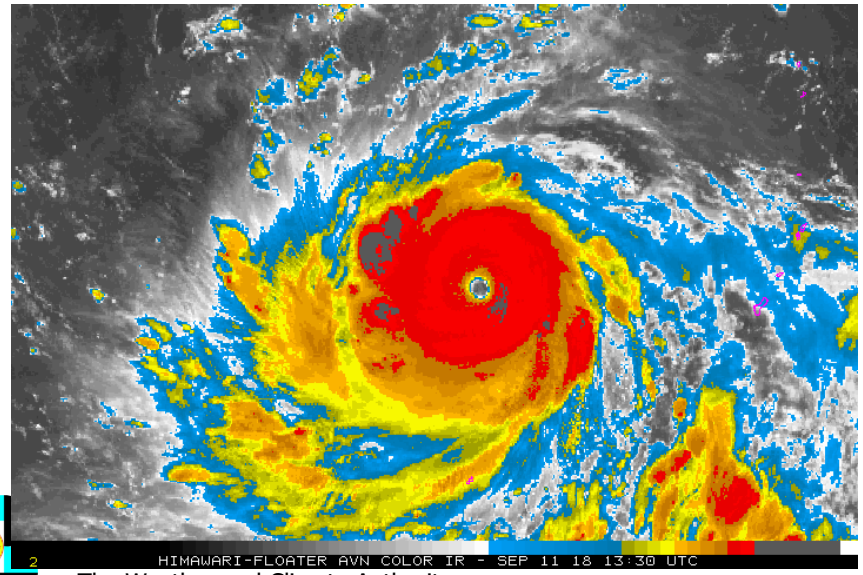
# The Case of Typhoon Mangkhut (2018)


- Typhoon Mangkhut (L.N. “Ompong”) is the 15th tropical cyclone to enter the Philippine Area of Responsibility (PAR) in 2018 and the 3rd for the month of September
- From a low pressure area developed off the Marshall Islands on 07 September, it quickly intensified into Typhoon category in two days. It entered PAR still as a Typhoon on 12 September.
- The typhoon made landfall in Baggao, Cagayan at 2:00 AM on September 15, 2018 with the lowest central minimum pressure of 905 hPa and the 10-minute sustained winds of 205 kph.
- Generated storm surges in northern and western seaboards of Luzon.
- It caused widespread damage across Northern and Central Luzon due to its intense nature and large size.



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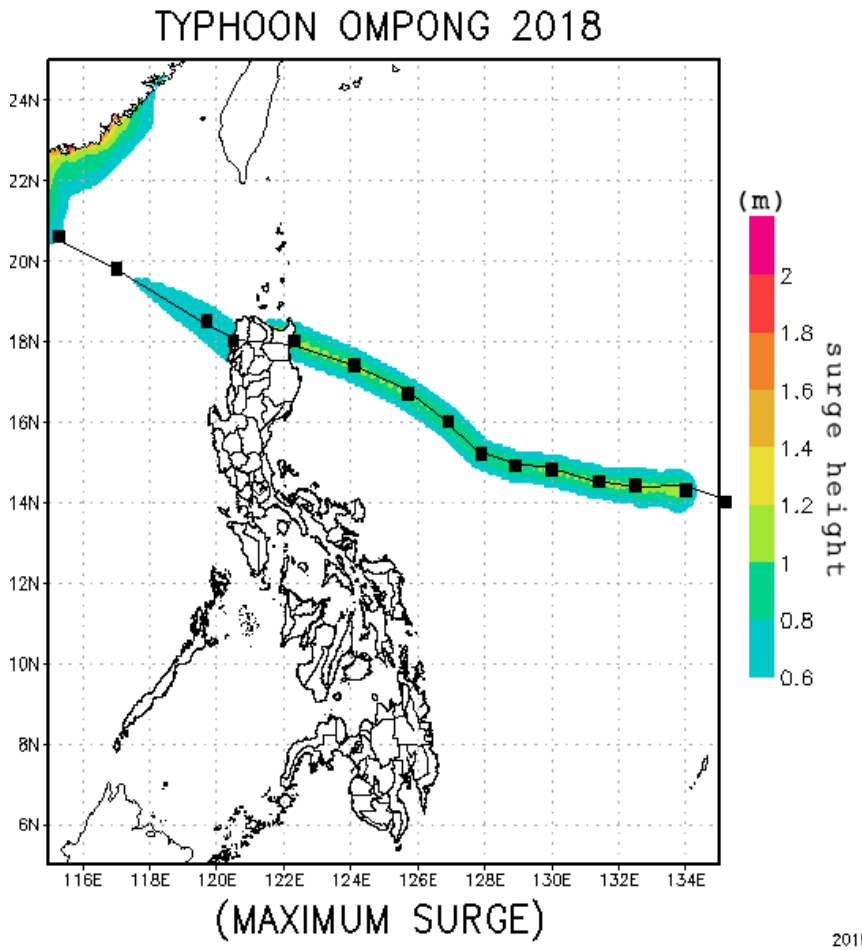
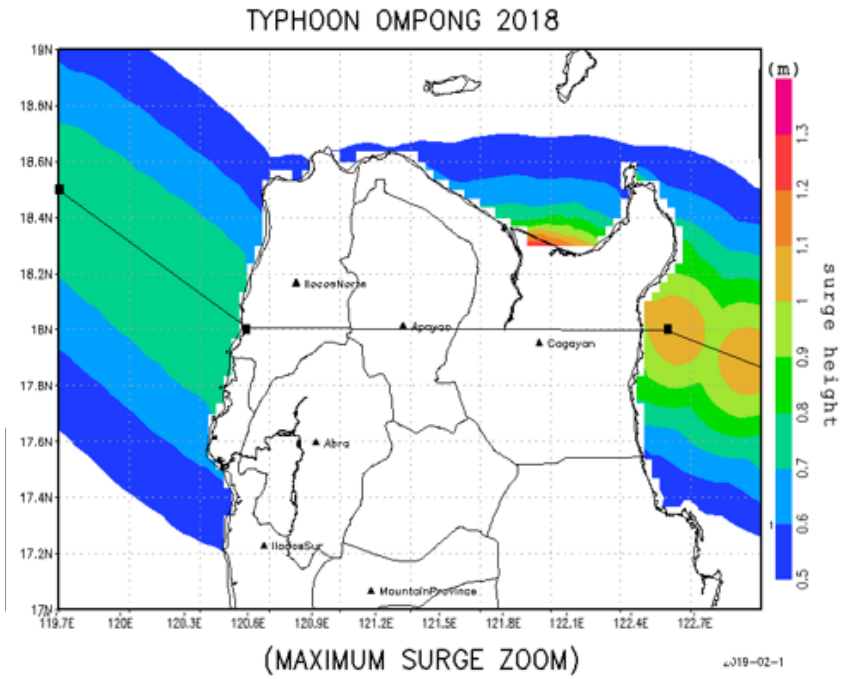
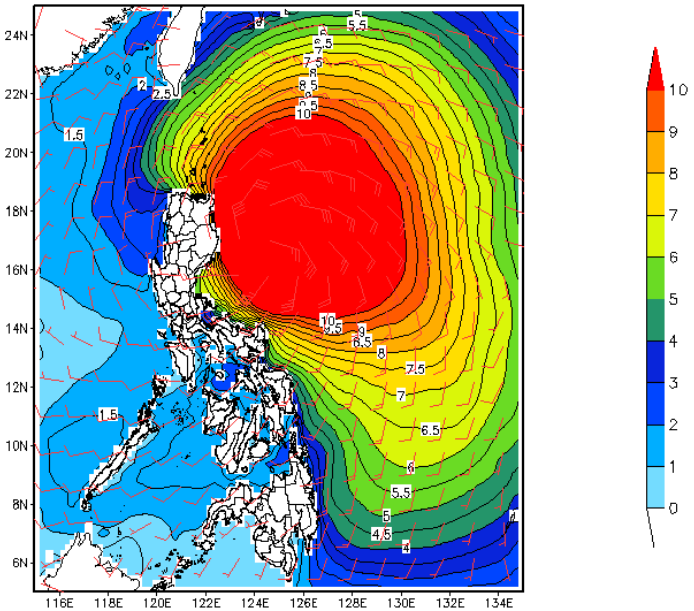
# Case of Typhoon Ompong (Mangkhut) 2018

## JMA Storm Surge Model




## JMA Wave Model



**Total Water Level (TWL):**

TWL = Storm Surge + Wave Set-up + Tide Height

TWL (Cagayan Prov.) = 1.3 + 10 (0.4372) + 0.34 = **6.012**

TWL (Ilocos Prov.) = 0.9 + 4 (0.2374) + 0.85 = **2.8296**

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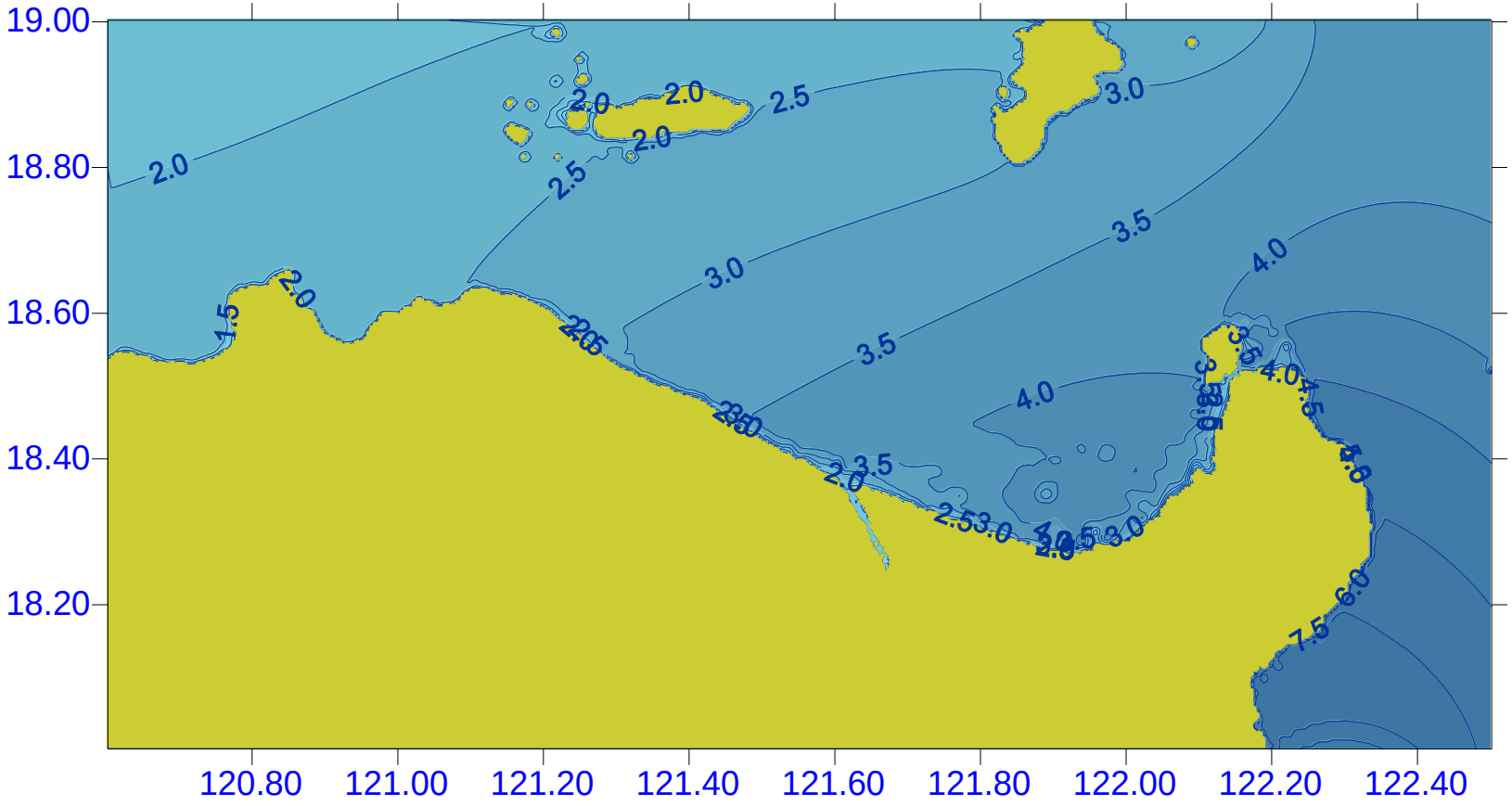
# Case of Typhoon Ompong (Mangkhut) 2018

**Storm Surge Model (Dispersive Model)**




**Simulated storm surge and waves (before storm arrival)**

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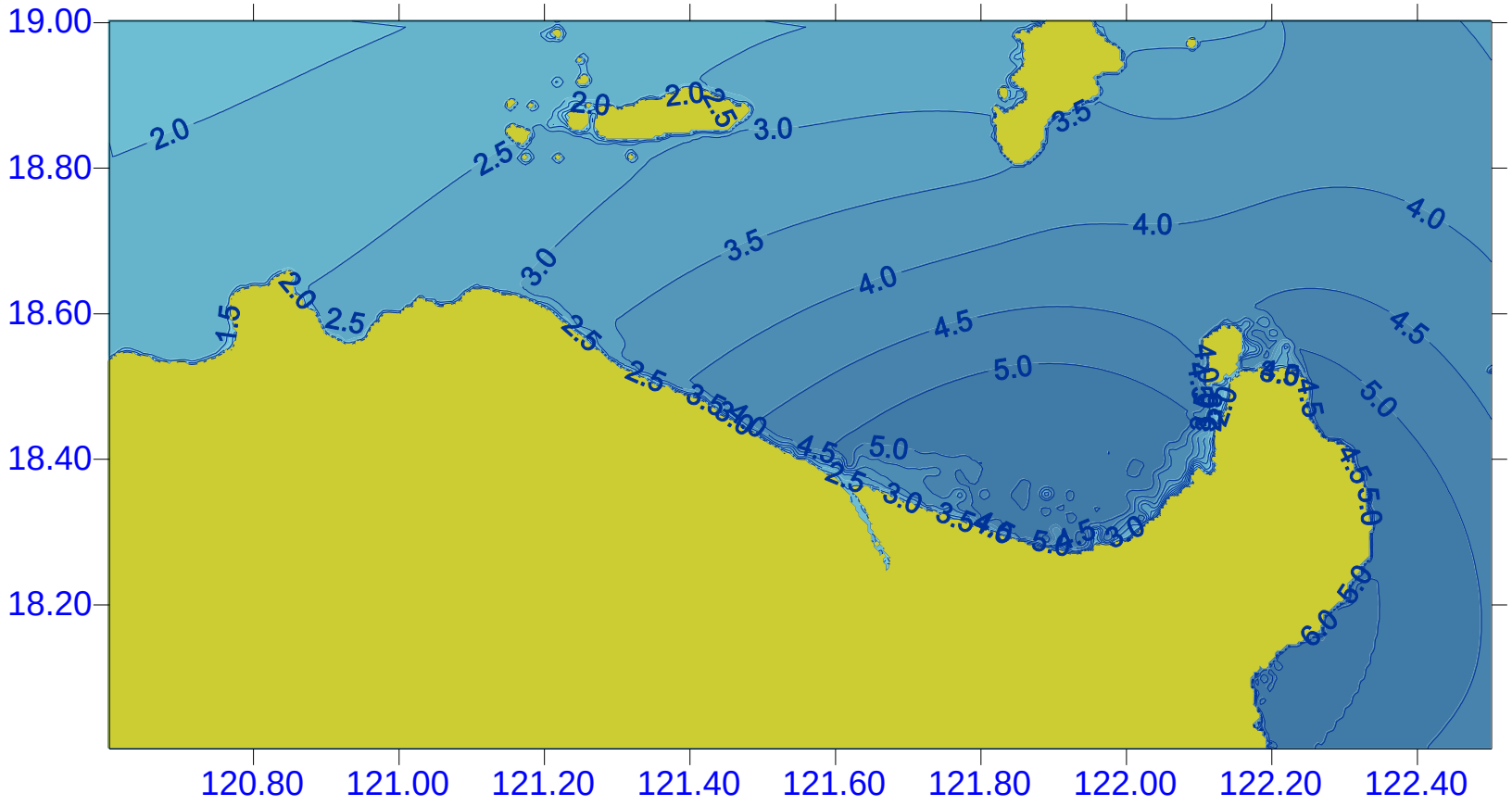
# Case of Typhoon Ompong (Mangkhut) 2018

## Storm Surge Model (Dispersive Model)




**Storm Surge (on storm arrival)**

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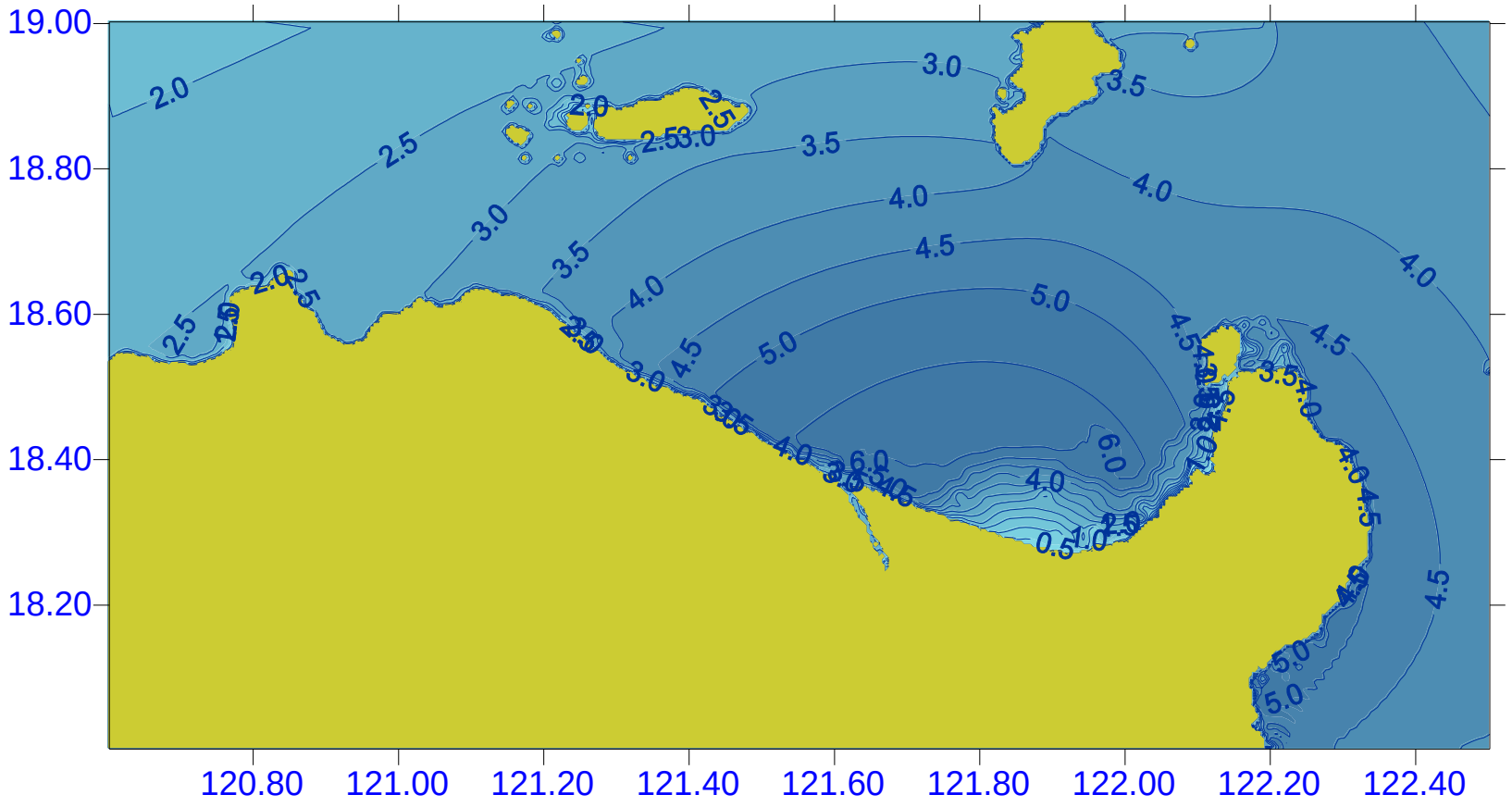
# Case of Typhoon Ompong (Mangkhut) 2018

## Storm Surge Model (Dispersive Model)




Storm surge and waves (just after landfall)

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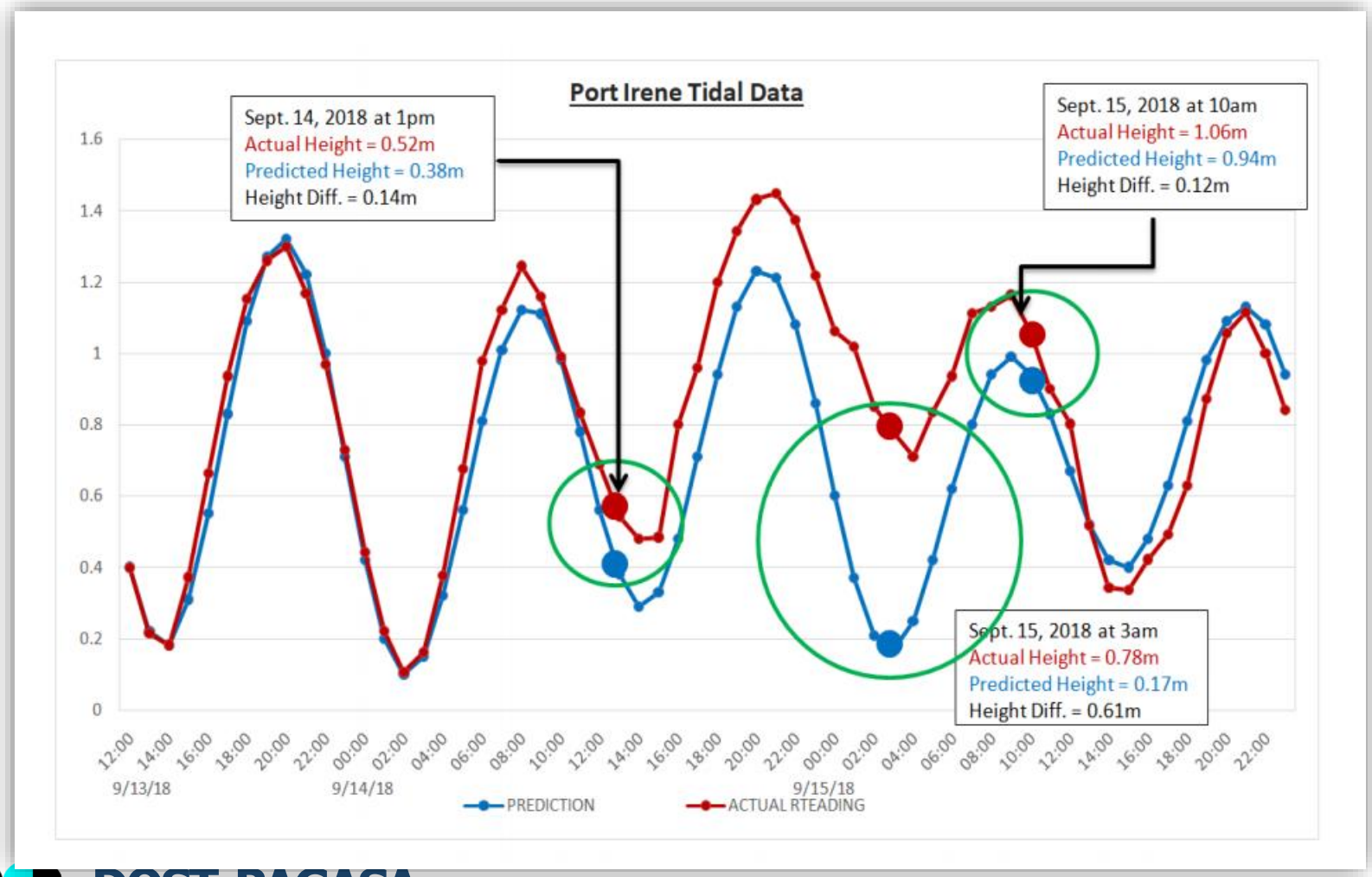
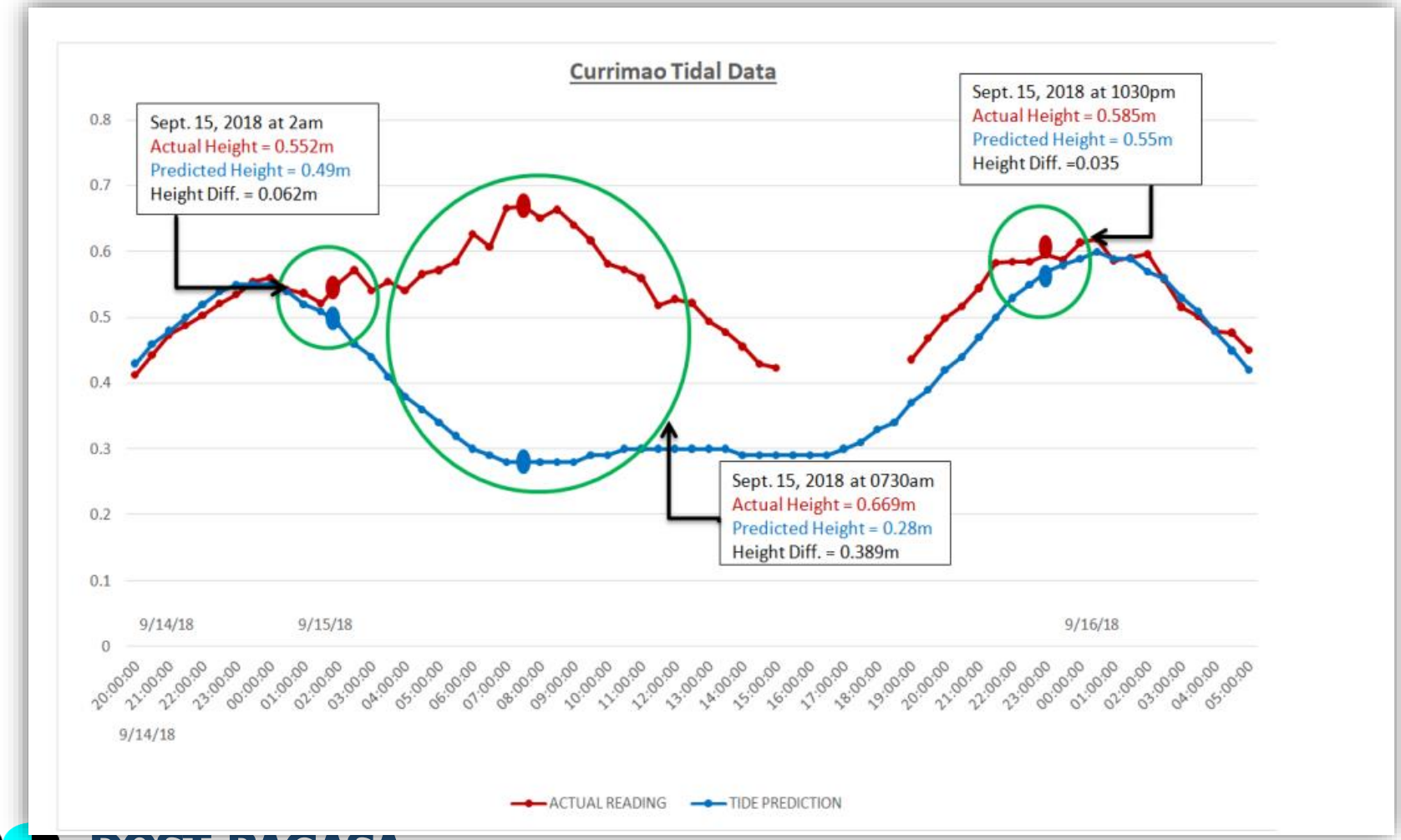
# Validation of Storm Surge Forecasts with Actual Tide Observations from NAMRIA



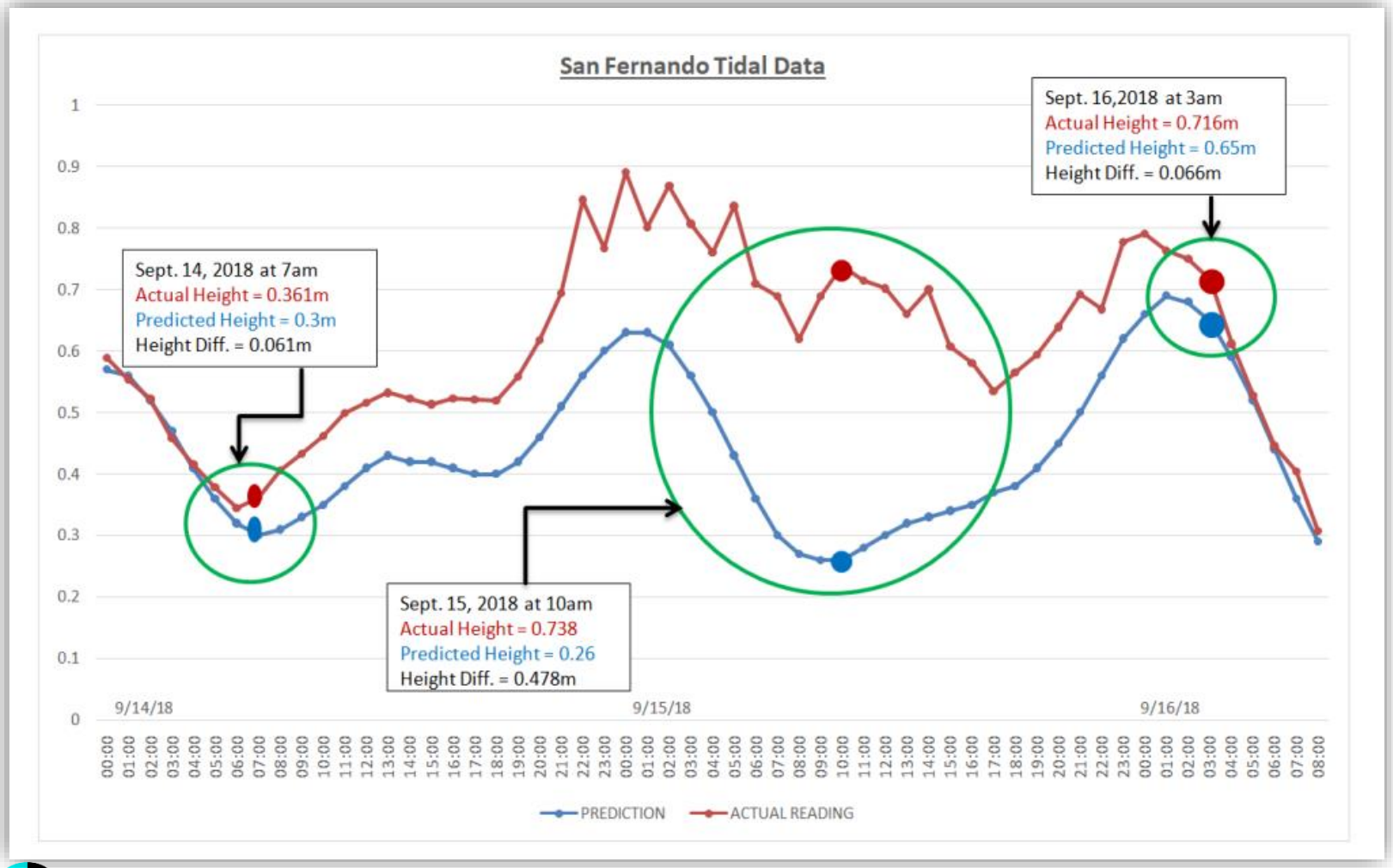

- Based from Port Irene Tidal Station data, deviation of 0.14m from the predicted height started at September 14, 2018 at 1 PM
- On September 15, 2018 at 3AM – the highest deviation from predicted tide was recorded with 0.61
- The highest level of storm tide more than 1.4 meters occurred on September 15, 2018 at 12AM, coinciding with the high tide
- **Highest Storm surge height coincided with the LOW TIDE**

# Validation of Storm Surge Forecasts with Actual Tide Observations from NAMRIA




- Based from Currimao Tidal Station data, deviation of 0.062m from the predicted height started at September 15, 2018 at 2 AM
- On September 15, 2018 at 3AM – the highest deviation from predicted tide was recorded with 0.389
- The last deviation of tide from the predicted happened on September 15, 2018 at 10:30PM
- **Highest storm surge height coincided with the LOW TIDE**

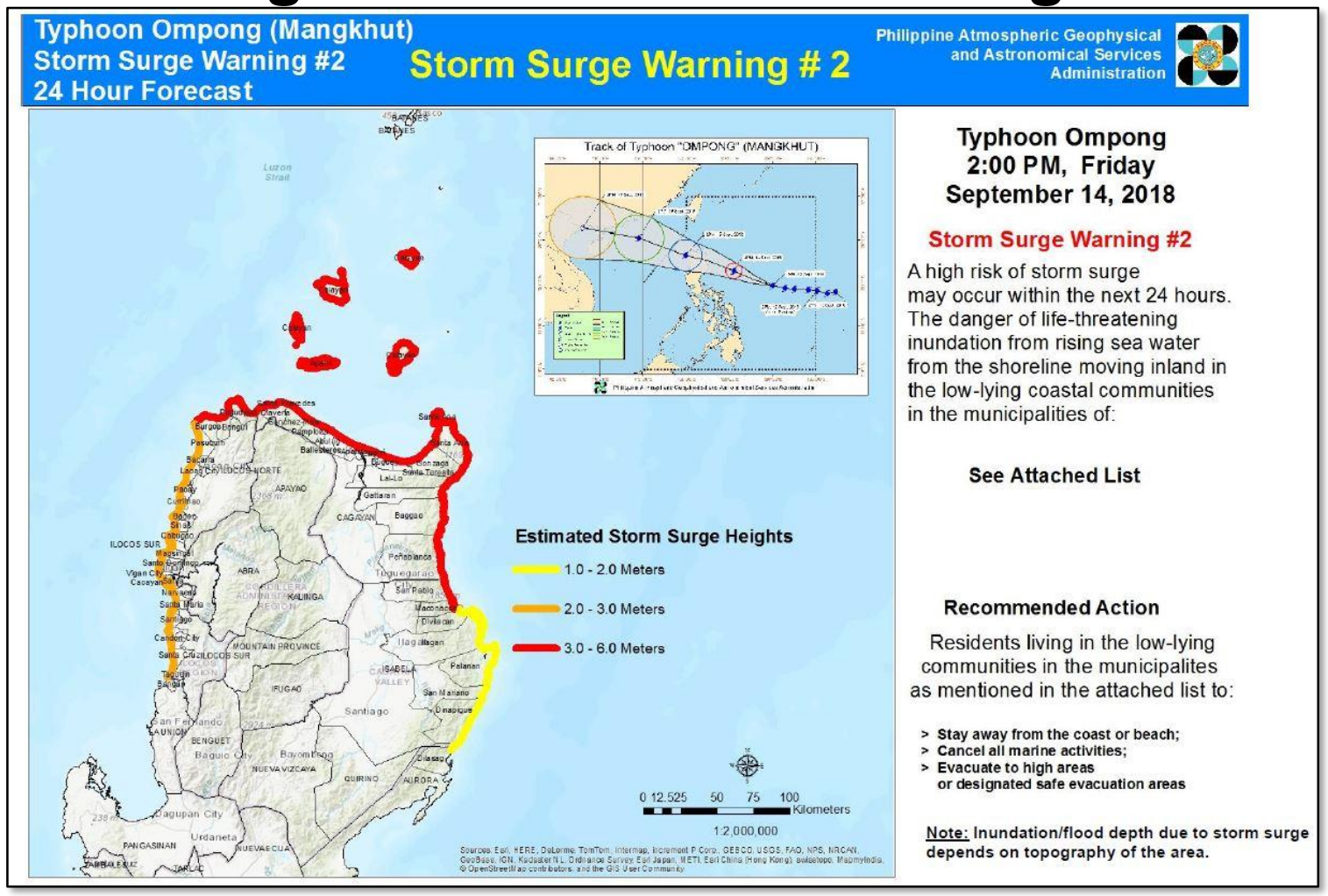
# Validation of Storm Surge Forecasts with Actual Tide Observations from NAMRIA




- Based from San Fernando Tidal Station data, deviation of 0.061m from the predicted height started at September 14, 2018 at 7 AM
- On September 15, 2018 at 10AM – the highest deviation from predicted tide was recorded with 0.478m
- The last deviation of tide from the predicted happened on September 16, 2018 at 3AM with height of 0.066m
- **Highest storm surge height coincided with the LOW TIDE**

# Case of Typhoon Ompong (Mangkhut) 2018

## Storm Surge Forecasts and Warnings



# Case of Typhoon Ompong (Mangkhut) 2018

## Storm Surge Forecasts and Warnings

REPUBLIC OF THE PHILIPPINES
**Department of Science and Technology**
Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA)
Science Garden, Agham Road, Diliman, Quezon City 1100

**STORM SURGE WARNING #2**
**FOR : TYPHOON "OMPONG" (MANGKHUT)**
**11AM, 14 September 2018**

| SS Height | Provinces | Low Lying Coastal Areas in the Municipalities of: | IMPACTS | ADVICE/Actions to Take |
|---|---|---|---|---|
| 3-6 meters | Cagayan | Abulug<br>Aparri<br>Ballesteros<br>Buguey<br>Gonzaga<br>Pamplona<br>Sanchez-Mira<br>Santa Ana<br>Santa Teresita<br>Babuyan Islands | • Storm Surge is **CATASTROPHIC**<br>• **Life-threatening and extensive inundation** from rising sea water moving inland from the shoreline.<br>• Extreme damage to communities and coastal/marine infrastructures.<br>• River flooding is aggravated due to storm surge. | • **Evacuation is enforced** in low-lying coastal communities.<br>• All marine activities must be cancelled. |
| | Ilocos Norte | Pagudpud | | |
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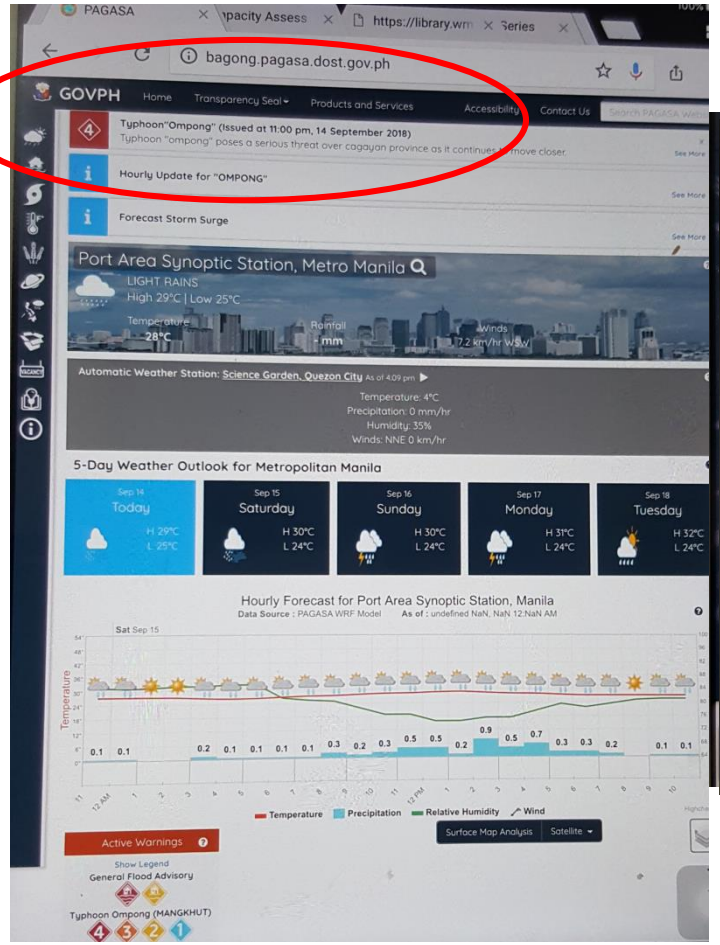
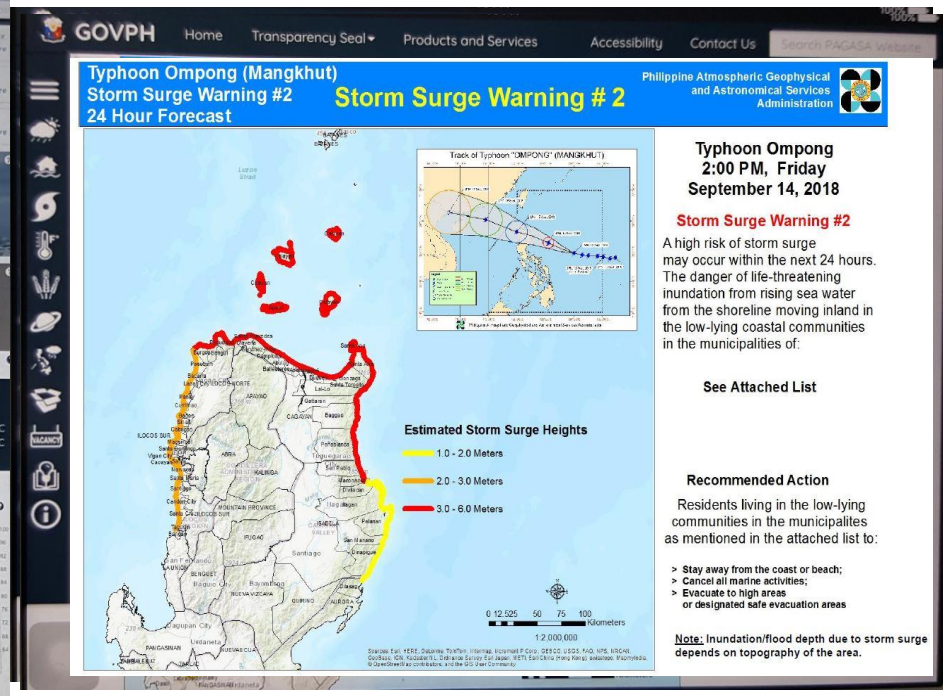
| | Ilocos Sur | Caoayan<br>Santa Catalina | | |
| <1 meter | | | • Minor damage to communities, coastal/ marine infrastructures and disruptions to all marine-related activities.<br>• Flooding is possible in low-lying areas | • Public is advised to stay away from the coasts or beaches.<br>• Be aware and follow the latest weather updates from PAGASA. |

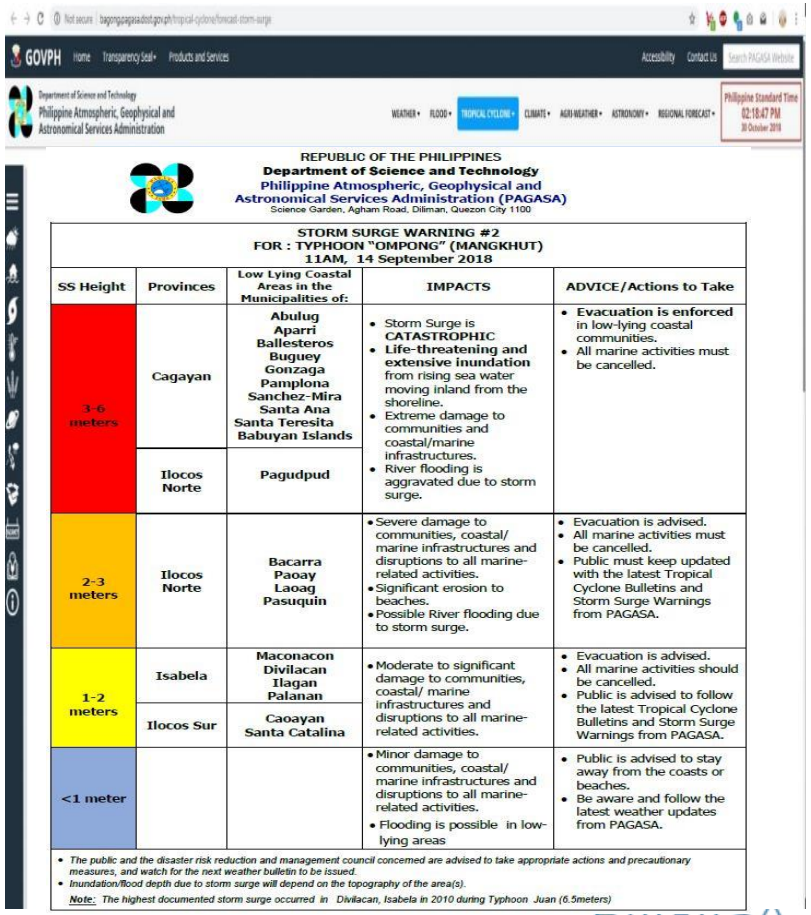
- *The public and the disaster risk reduction and management council concerned are advised to take appropriate actions and precautionary measures, and watch for the next weather bulletin to be issued.*
- *Inundation/flood depth due to storm surge will depend on the topography of the area(s).*

*Note: The highest documented storm surge occurred in Divilacan, Isabela in 2010 during Typhoon Juan (6.5meters)*

# Storm Surge Warnings posted at the PAGASA Website during TY Ompong (IN: "Mangkhut")



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**DOST-PAGASA**
The Weather and Climate Authority

# • Field validation of Storm Surge Forecasts and Warnings

## One-on-one Interviews

## Measuring Water Level Heights

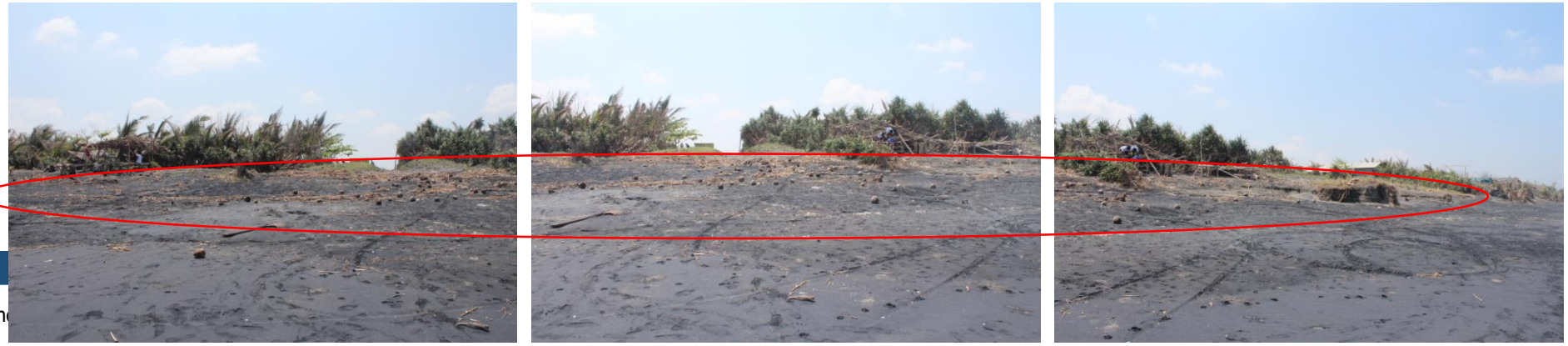
## Storm Surge Impacts

DOST-PAGASA
The Weather and Climate Authority

Payong PAGASA

# Visible Markers

Visible markers in the beach (such as debris lines or beach erosion) distinct from normal tide variations markers, if present, serve as additional evidence of coastal flooding.



# Measuring Water Level Heights

- Measurements relative to the water heights and debris lines or flood marks (if present) were undertaken using a laser rangefinder and high precision altimeter.
- Precise location of measurements were taken using a handheld GPS.

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The Weather and Climate Authority

# Combined Storm Surge and Strong Wave Impacts

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The Weather and Climate Authority

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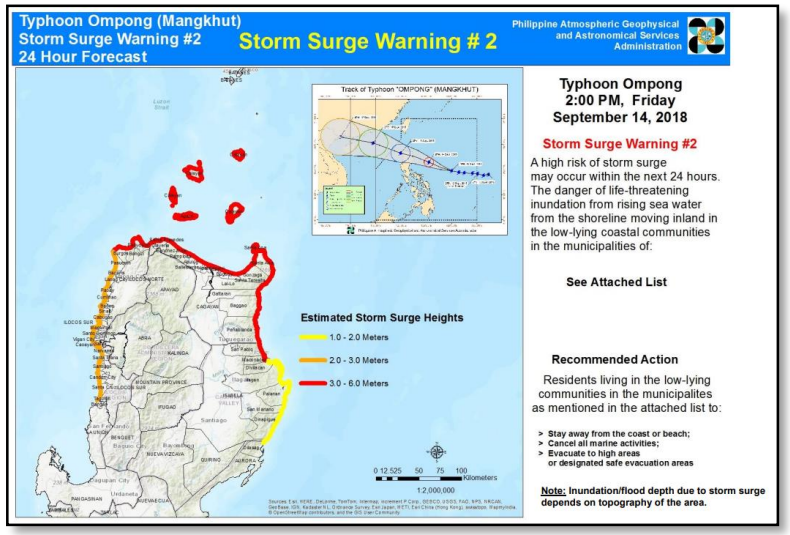
# Storm Surge Warning System

## Ground Validation Results

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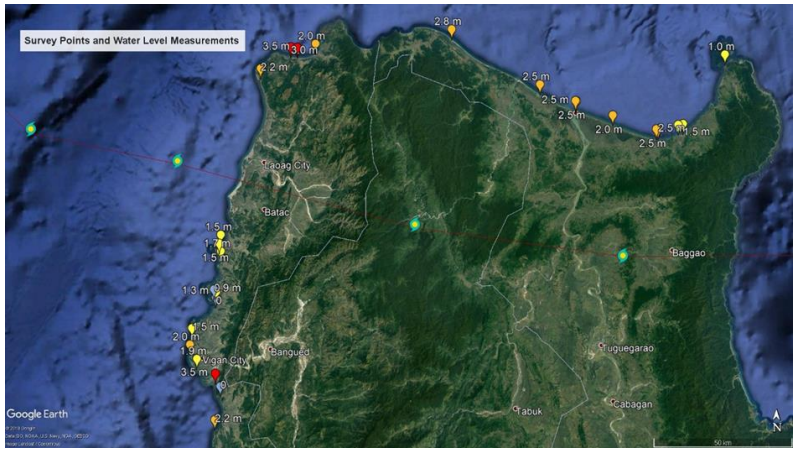


| Province | Area | Forecast | Measured Water Level (m) |
|---|---|---|---|
| Cagayan | Masisit, Sanchez Mira | >3.0 | 2.8 |
| | (Fish Port) Tangatan, Santa Ana | >3.0 | 1.0 |
| | Batangan, Gonzaga | >3.0 | 1.5 |
| | Minanga, Gonzaga | >3.0 | 1.8 |
| | Caroan, Gonzaga | >3.0 | 2.5 |
| | Caroan, Gonzaga | >3.0 | 2.5 |
| | Paddaya Weste, Buguey | >3.0 | 2.0 |
| | San Antonio, Aparri | >3.0 | 2.5 |
| | Centro 13, Aparri | >3.0 | 2.5 |
| | Santa Cruz, Ballesteros | >3.0 | 2.5 |

# Storm Surge Warning System

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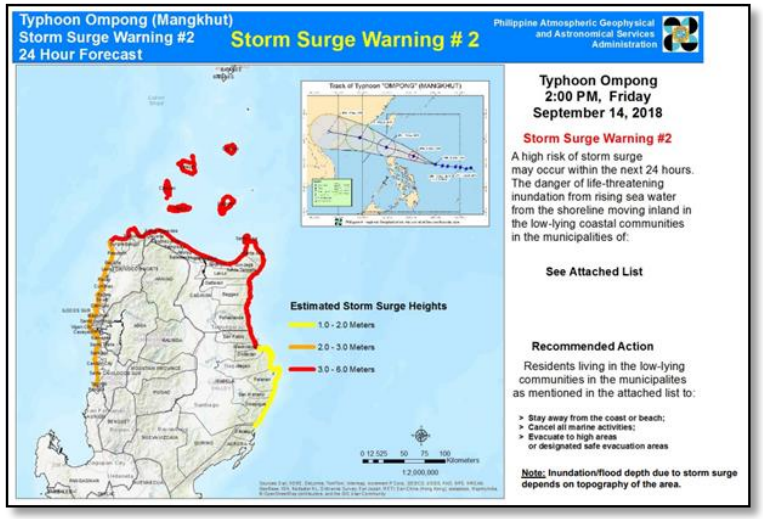


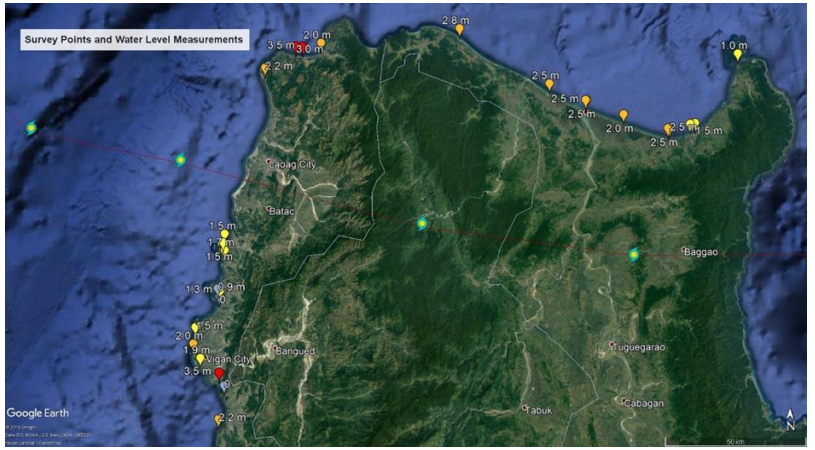


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| Province | Area | Forecast | Measured Water Level (m) |
|---|---|---|---|
| Ilocos Sur | Bateria, San Esteban | 2 - 3 | 2.2 |
| | Sulvec, Narvacan | 2 - 3 | 0.0 |
| | Pasungol, Santa | 2 - 3 | 3.5 |
| | Fuerte, Caoayan | 2 - 3 | 0.0 |
| | Fuerte, Caoayan | 2 - 3 | 1.9 |
| | Paratong, Santa Catalina | 2 - 3 | 2.0 |
| | San Sebastian, San Vicente | 2 - 3 | 1.5 |
| | Saoang, San Juan | 2 - 3 | 0.0 |
| | Camindoroan, San Juan | 2 - 3 | 1.3 |
| | Solotsolot, San Juan | 2 - 3 | 0.9 |
| | Cabangtalan, Sinait | 2 - 3 | 1.7 |

# Summary

- A new forecasting and warning system was developed by PAGASA and was tested during the passage of Typhoon Ompong on September 11 – 15, 2018
- An impact based warning for storm surge was developed;
  - Storm Surge Watch to be issued 48 hours before the landfall
  - Storm Surge Warning to be issued 24 hours before the warning
- There are still issues in the storm surge forecasting especially on the consideration of wave set-up
- PAGASA need to work in partnership with other government and stakeholders (emergency response, mapping agencies, transport, media,users, etc)

# THANK YOU!

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