Users Guide for the NorthWest Pacific Tsunami Advisory Center Enhanced Products for the Pacific Tsunami Warning System

December 2017

This Users Guide has been drafted based on Users Guide for the Pacific Tsunami Warning Center Enhanced Products for the Pacific Tsunami Warning System. IOC Technical Series No 105, Revised edition. UNESCO/IOC 2014 (English; Spanish) and the Operational Users Guide for the Pacific Tsunami Warning and Mitigation System (PTWS). IOC Technical Series No 87, Second Edition. UNESCO/IOC 2009 (English only.)

The draft version of the Users Guide was sent by circular letter 2702 dated 14 December 2017 to Member States in the region for evaluation before publication in the IOC Technical Series mid-2018.

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Executive Summary

Since 2005, the Northwest Pacific Tsunami Advisory Center (NWPTAC) of the Japan Meteorological Agency (JMA) has implemented Northwest Pacific Tsunami Advisory (NWPTA) services for Northwest Pacific countries in its role as a sub-regional Tsunami Service Provider (TSP) for the Pacific Tsunami Warning System (PTWS).

Following the successful launch of the Pacific Tsunami Warning Center (PTWC) Enhanced Products and a series of recommendations by ICG/PTWS, NWPTAC plans to enhance its existing products in 2018 in order to provide recipient countries with greater utility via detailed tsunami threat assessments for local coastal areas. Upon approval from the PTWS Steering Committee, NWPTAC will start email issuance of the enhanced products in an experimental phase at 03:00Z on 20th December 2017 in parallel with its existing products. This introduction and familiarization period is intended to support training on the new products and recipient country implementation of the necessary Standard Operating Procedure (SOP) updates.

This User's Guide describes NWPTAC Enhanced Products and provides related examples. In addition to text-based products, additional graphical products with more information and much greater levels of detail will also be available. These include maps showing deep-ocean tsunami amplitude forecasts, tsunami travel time forecasts and expected maximum wave amplitudes in coastal areas.

1. OVERVIEW

1.1. Introduction

The successful launch of the Pacific Tsunami Warning Center (PTWC) Enhanced Products in October 2014 demonstrated the mature capacity of Member States to utilize advanced graphical products. This prompted the Japan Meteorological Agency (JMA) to consider providing Northwest Pacific Tsunami Advisory Center (NWPTAC) Enhanced Products along with additional graphical information to meet user requirements. As the output of graphical products requires advanced tsunami forecasting capacity, JMA decided to take steps to add real-time simulation to its existing database-driven predictions.

In recognition of the importance of providing concise, easy-to-understand conventional text messages containing information on forecast amplitudes for selected individual Forecast Points (FPs), JMA decided to continue to issue its existing text products in conjunction with the graphical products.

Appendix II lists the FPs for which data are reported in NWPTAC products. The list has been modified in consideration of those used for PTWC products and user countries' requests.

To avoid public confusion, NWPTAC products are provided exclusively to national authorities responsible for domestic tsunami alerts in NWPTAC's Area of Service (AoS).

1.2. Governance and Approval

Since 1978, in-depth discussions have been held by the International Coordination Group for the Tsunami Warning System in the Pacific (ICG/ITSU, now renamed ICG/PTWS) on the establishment of regional tsunami warning centers to issue tsunami advisories tailored to individual Pacific regions. At the 14th session of the ICG/ITSU (Tokyo, 1993), the Republic of Korea proposed that JMA operate such a center for the Northwest Pacific region.

At the ICG/ ITSU 17th session (Seoul, 1999), a JMA proposal to establish a regional tsunami warning center for the Northwest Pacific was approved. At the 19th session (Wellington, 2003), JMA reported on its readiness for the center's operation. In 2004, the Executive Council of the Intergovernmental

Oceanographic Commission (IOC) adopted a resolution at its 37th session (Paris, 2004) to start the services of the regional center at JMA by March 2005.

Based on such international consensus, JMA initiated the operation of the regional center within the Tsunami Forecast Centre at its headquarters in March 2005 to provide tsunami advisory services to the Northwest Pacific. At the 20th session of the ICG/ITSU (Viña del Mar, October 2005), JMA reported on the inauguration of NWPTAC. At the same session, the Group asked JMA to also provide interim tsunami advisory services for the South China Sea region. JMA upgraded its system and began the service in April 2006.

At the ICG/PTWS 22nd Session (Guayaquil, 2007), the ICG/PTWS began the process of improving PTWS international alert products starting with PTWC products. At its 24th Session (Beijing 2011), it accepted a PTWC proposal for Enhanced Tsunami Products. After approval of the final products and the proposed target changeover date at the 25th Session (Vladivostok, 2013), PTWC began issuing its new enhanced products on 1 October 2014.

In pursuit of improvement for PTWS tsunami warning products, Japan announced at the IOC Executive Council in July 2014 that NWPTAC would also be developing new products based on the requirements of user countries. The PTWS Steering Committee met later in the same month and agreed on a timeline targeting full transition to NWPTAC Enhanced Products by 2018. It also recommended that JMA continue the process of developing NWPTAC Enhanced Products for PTWS.

At the ICG/PTWS 26th Session (Honolulu, 2015), it was agreed that NWPTAC should proceed with its development of enhanced products for the Northwest Pacific region. Accordingly, Exercise Pacific Wave 2016 (PacWave16) and Exercise Pacific Wave 2017 (PacWave17) were conducted in 2016 and 2017, respectively, to evaluate NWPTAC Enhanced Products.

At the ICG/PTWS 27th Session (Tahiti 2017), it was agreed that NWPTAC should start issuance of its experimental NWPTAC Enhanced Products in parallel with its existing products in the second half of 2017 and set a target change-over date for around six months to a year from the date of introduction.

1.3. Implementation Timeline

To support the transition to the new products, PTWS organized two international exercises in 2016 and 2017.

Exercise Pacific Wave 2016 (PacWave16) served to introduce the proposed products and allow for feedback on their format and content. This feedback was considered in the development of the final products. For more on PacWave16, see:

http://itic.ioc-unesco.org/index.php?option=com_content&view=category&id=2168&Itemid=2642.

Exercise Pacific Wave 2017 (PacWave17) will be (was<P>) conducted in February 2017 to allow evaluation of Member States' interpretation of the new products accurately and in a timely manner. For more on PacWave17, see:

http://itic.ioc-unesco.org/index.php?option=com_content&view=category&layout=blog&id=2222&Itemid=2734.

The SC Task Team on PacWave Exercises oversaw the planning, execution and post-exercise evaluation of the new products and worked with PTWS WG2 Task Team on enhancing products for successful implementation.

At the 27th Session of the ICG/PTWS (Tahiti, 2017), Member States endorsed the Northwest Pacific Tsunami Advisory Center's plan to begin issuing in experimental mode its new NWPTAC Enhanced products in 2017.

The ICG/PTWs 27th session also decided a targeted change-over date around one half to one year from the experimental NWPTAC Enhanced Products provision for the official full switchover to the new products.

2. AREA OF SERVICE AND CRITERIA FOR ISSUANCE

- NWPTA information is issued when NWPTAC detects an earthquake of magnitude 6.5 or greater in its AoS (see Figure 1), which covers the northwestern Pacific and a portion of its southwestern part as well as the South China Sea region on an interim basis.
- Data from observation reports received by NWPTAC are included in subsequent NWPTA messages as necessary.

- If the location/magnitude of an earthquake are revised on the basis of subsequently obtained seismic data and/or tsunami observation data, an updated NWPTA is issued.
- If the Centroid Moment Tensor (CMT) solution becomes available after the above NWPTA is issued, NWPTA text and graphical products based on real-time simulation are provided.

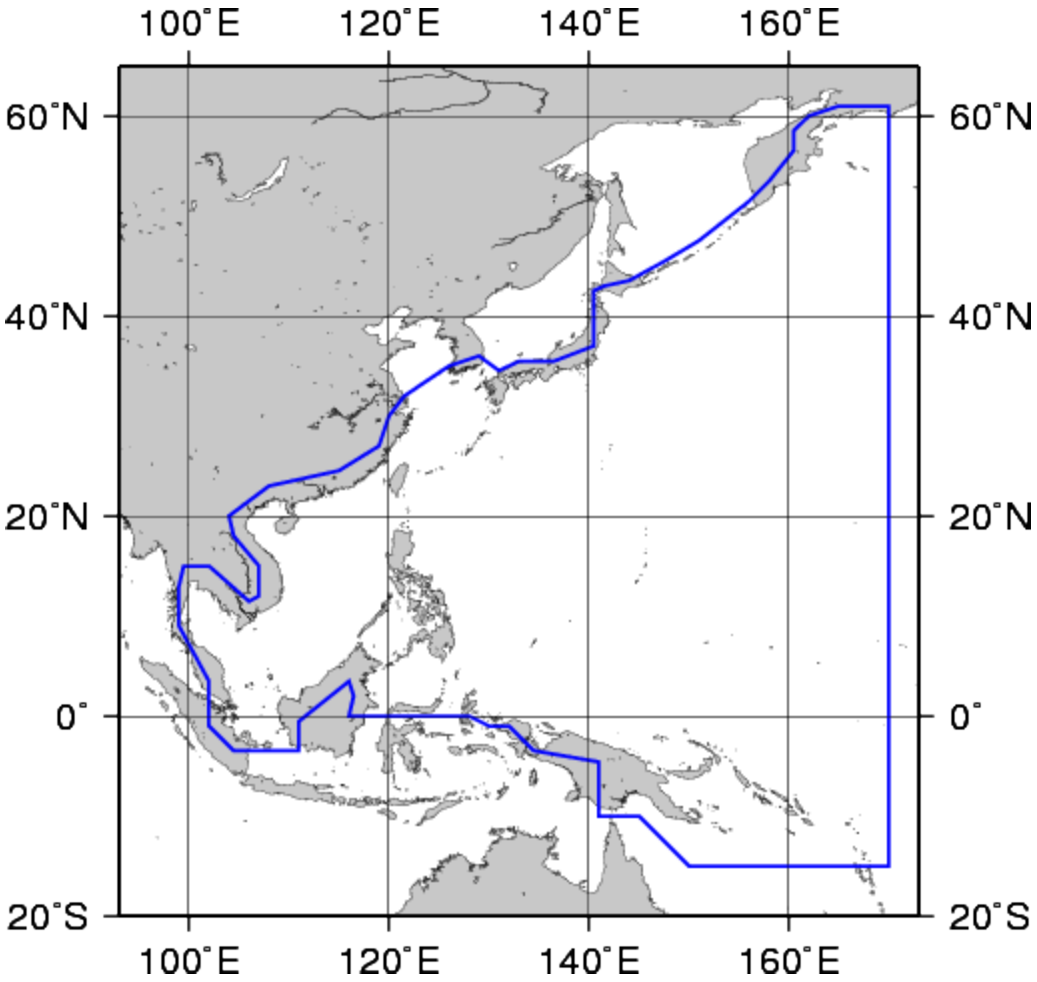

Figure 1 NWPTA Area of Service (AoS)

3. NWPTAC ENHANCED PRODUCTS

3.1. Outline of NWPTAC Enhanced Products

NWPTAC Enhanced Products consist of initial text messages compiled from a pre-established tsunami simulation database and subsequent text messages

accompanied by graphical products based on real-time simulation techniques. The products will be distributed exclusively to national authorities of user countries.

The product specifications are as follows:

a. Text products
   - Forecast method
     - First message (and second message in the event of an earthquake parameter update) from tsunami forecast database using preliminary determined hypocenter and magnitude
     - Subsequent messages from real-time simulation using the CMT solution
   - Contents
     - Earthquake parameters (origin time, location, magnitude)
     - Tsunamigenic potential
     - Coastal blocks
     - Forecast amplitude and arrival time
     - Observed amplitude and arrival time
   - Distribution channels
     - GTS, fax, e-mail

b. Graphical products (maps)
   - Forecast method
     - Real-time simulation
   - Contents
     - Deep-ocean tsunami amplitude forecast map
     - Tsunami travel time map
     - Coastal tsunami amplitude forecast map
   - Distribution channels
     - E-mail

Appendix I provides examples of NWPTAC Enhanced Products.

3.2. Text Products

3.2.1. Earthquake Information

a. Origin time

b. Epicenter coordinates (latitude and longitude)

c. Location (geographical area)

d. Depth (for earthquakes occurring at depths of 100 km or more)

e. Moment magnitude (or JMA Magnitude, indicated by “(MJMA)”)

REFERENCE

UNESCO, IOC Technical Series No. 87 "Operational Users Guide for the Pacific Tsunami Warning and Mitigation System (PTWS)", Second Edition, Annex II, 2011.

3.2.2. Tsunamigenic Potential

Tsunamigenic potential is evaluated from earthquake magnitude as follows:

M6.5 – 7.0: Very small possibility of a destructive local tsunami

M7.1 – 7.5: Possibility of a destructive local tsunami within 100 km of the epicenter

M7.6 – 7.8: Possibility of a destructive regional tsunami within 1,000 km of the epicenter

M7.9 – : Possibility of a destructive ocean-wide tsunami

No tsunamigenic potential is associated with earthquakes occurring inland or at depths of 100 km or more.

3.2.3. Tsunami Estimated Amplitude and Arrival Time

A tsunami amplitude and an arrival time are estimated for each forecast point in coastal areas (Appendix II). This information is listed in NWPTA messages with the names of forecast points and their latitudes/longitudes (to the nearest 0.1 degrees) in coastal-block groups.

Amplitude here is defined as the maximum distance between the crests of tsunami waves and the undisturbed sea level. Estimated tsunami amplitude is shown only for forecast points expected to experience tsunami with heights of

0.3 m or more. The classifications are 0.3 – 1 m, 1 – 3 m, 3 – 5 m, 5 – 10 m and Over 10 m. If no tsunami with an amplitude of 0.3 m or more is expected for any forecast point, NWPTA message states “Estimation at forecast points – no tsunami waves with an amplitudes of 0.3 meters or more are expected at any forecast point.”

3.2.4. Tsunami Observation

Information on the amplitude of the largest wave (to the nearest 0.1 m) and other data on tsunami waves observed at tidal stations with telemetric links to NWPTAC are provided as necessary.

Graphical Products

3.2.5. Tsunami Travel Time Map

This shows the estimated travel time based on the earthquake location (hypocenter or centroid) and magnitude determined.

Limitations

Actual arrival times may differ from forecast times for reasons including:

- Tsunami source uncertainty (The area of seafloor deformation is assumed from earthquake location and magnitude.)
- Bathymetry uncertainty around the observation point and elsewhere
- Nonlinear effects on tsunami propagation that are not considered in travel time estimation (Such effects may be more significant in shallow water.)
- Difficulty of determining first-wave arrival times from sea level observation data

3.2.6. Coastal Tsunami Amplitude Forecast Map

This shows individual coastal points with coloring based on the forecast tsunami amplitude at each point.

The greater of two forecast amplitudes based on a conjugate fault set determined via CMT analysis is used for each point.

Limitations

Actual coastal amplitudes may differ from forecasts for reasons including:

- Tsunami source uncertainties (Two rectangular faults are assumed from CMT analysis.)

- Uncertainties regarding tsunami/coastal interaction (Green's Law is used as a general approximation.)

Results can easily vary by a factor of two due to these uncertainties.

3.2.7. Deep-Ocean Tsunami Amplitude Forecast Map

This shows the maximum tsunami amplitude at each place in the deep ocean.

It shows how the tsunami is 1) directed away from the tsunami source, 2) focused and defocused by the shape of the seafloor, and 3) dissipated due to spreading.

Two maps based on a conjugate fault set determined via CMT analysis are provided.

Limitations

Actual deep-ocean tsunami amplitudes may differ from forecasts due to tsunami source uncertainties (two rectangular faults are assumed from CMT analysis) and other factors.

This map should not be used to estimate coastal tsunami amplitudes or impacts.

3.3. Product Issuance Timeline

The timeline of NWTPA issuance shown below is typical but approximate and conservative.

00 h 00 m	A large earthquake occurs in the Northwest Pacific region.
00 h 10 m	NWPTAC receives an initial text product from PTWC.
00 h 20 m	**The first NWPTAC text product** based on information from a tsunami forecast database is issued along with data on preliminary earthquake parameters consistent with those in the initial PTWC message.
	Another NWPTAC text product is issued if the preliminary earthquake parameters are updated.
00 h 40 m	The CMT solution is obtained and real-time simulation is started.
00 h 45 m	Real-time simulation is completed.
00 h 50 m	**The second NWPTAC text product** and **graphical products** based on real-time simulation are issued.

4. DISTRIBUTION CHANNELS

NWPTAs are provided via the GTS with the heading of WEPA40 RJTD and by e-mail and fax. Users are strongly advised to adopt multiple communication channels in order to ensure receipt.

5. COMMUNICATIONS TEST

NWPTAC conducts communications test approximately twice a year on links to user organizations. Advance notice of test is provided via an IOC Circular Letter. In the test, users are asked to acknowledge receipt of a test message using a reporting form provided with the Circular Letter.

6. STATUS OF NWPTAC PRODUCTS

NWPTAC Enhanced Products are provided alongside PTWC tsunami products to support user countries in taking timely and appropriate action against tsunami threats. However, it is important to note that the products are simply advisories to support user countries' efforts in alerting people to hazards; the actual issuance of evacuation advisories is the responsibility of the countries themselves. The accuracy of tsunami amplitude/arrival estimation times in the products and the timing of forecast issuance depend on the availability of seismic data and the technology used for hypocenter/CMT determination and quantitative tsunami forecasting. Accordingly, user countries are strongly advised to optimize their use of NWPTAC products with careful consideration of the technological background as described in this User's Guide.

NWPTAC makes every effort to provide its products as quickly as possible. However, people may need to be alerted in advance of NWPTA issuance in the event of large earthquakes in coastal areas, as tsunamis may reach land quickly.

NWPTAC products do not refer to the lifting of warnings in subsequent issues because NWPTAC itself does not issue warnings. These should be officially

issued and lifted by the authorities of the countries concerned, as tsunami characteristics depend on coastal terrain.

In the event of any difference in tsunami severity evaluation between PTWC and NWPTAC products, the severer one should be adopted.

JMA's NWPTA operation system is duplicated in case of partial malfunction. However, the possibility of catastrophic failure cannot be eliminated. If NWPTA products are not issued in an emergency, NWPTA user countries/organizations should take appropriate action with reference to PTWC products.

7. NWPTA TEMPLATE

This section details NWPTAC text product, which is based on the following template:

```
WEPA40 RJTD DDhhmm                                                    <--- (1)

TSUNAMI BULLETIN NUMBER NNN                                           <--- (2)
 ISSUED BY NWPTAC(JMA)
 ISSUED AT hhmmZ DD MMM YYYY
 PART nn OF NN PARTS

HYPOCENTRAL PARAMETERS                                                <--- (3)
 ORIGIN TIME: hhmmZ DD MMM YYYY
 PRELIMINARY EPICENTRE: LAT LL.L[NORTH][SOUTH] LON LLL.LEAST
  Geographical Area (Regional Scale)
  Geographical Area (Wider Scale)
 MAG: M.M[MJMA]

EVALUATION                                                            <--- (4)
 Tsunamigenic Potential

THIS BULLETIN IS FOR                                                  <--- (5)
 Coastal Block 1
 Coastal Block 2
 Coastal Block 3
 ...

ESTIMATED TSUNAMI ARRIVAL TIMES AND WAVE AMPLITUDES:                  <--- (6)
Coastal Block 1
 LOCATION     COORDINATES          ARRIVAL TIME    AMPL
 FP1-1         LL.L[N][S] LLL.LE    hhmmZ DD MMM    AMPLM
Coastal Block 2
 LOCATION     COORDINATES          ARRIVAL TIME    AMPL
 FP2-1         LL.L[N][S] LLL.LE    hhmmZ DD MMM    AMPLM
 FP2-2         LL.L[N][S] LLL.LE    hhmmZ DD MMM    AMPLM
 FP2-3         LL.L[N][S] LLL.LE    hhmmZ DD MMM     AMPLM
 ...
```

AMPL – MAXIMUM AMPLITUDE IN METERS FROM THE UNDISTURBED SEA LEVEL TO THE CREST **...** MEASUREMENTS OR REPORTS OF TSUNAMI LOCATION COORDINATES ARRIVAL TIME AMPL **STATION-1** **LL.L[N][S] LLL.L[E][W]** MAXIMUM TSUNAMI WAVE **hhmm**Z **DD MMM AMPL**M **STATION-2** **LL.L[N][S] LLL.L[E][W]** MAXIMUM TSUNAMI WAVE **hhmm**Z **DD MMM AMPL**M **...** MAXIMUM TSUNAMI WAVE -- HALF THE AMPLITUDE FROM THE TROUGH TO THE CREST **Remarks**	<--- (7)

7.1. Heading

The heading of messages on the GTS circuit (WEPA40 RJTD) appears at the top. **DDhhmm** represents the day, hour and minute of issuance in UTC.

7.2. Bulletin Number

NNN is the number of the bulletin, and increases with each issuance. **hhmm**, **DD**, **MMM** and **YYYY** represent the hour, minute, day, month and year of issuance in UTC. Overly long NWPTA messages may be issued in separate parts. **nn** is the number of the part, and **NN** is the total number of parts. For non-separated messages, **nn** and **NN** are both 01.

7.3. Earthquake Parameters

This part contains the following items:

- Origin time
- Epicenter coordinates (latitude and longitude)
- Location (geographical area)
- Depth (for earthquakes occurring at depths of 100 km or more)
- Moment magnitude (or JMA Magnitude, indicated by “(MJMA)”)

hhmm, **DD**, **MMM** and **YYYY** represent the hour, minute, day, month and year of the earthquake’s origin in UTC. **LL.L** and **LLL.L** represent the latitude and longitude of the epicenter, respectively. **"NORTH"** or **"SOUTH"** is added for latitude, while the longitude is always "EAST". **Geographical Area** is the

epicenter region based on Flinn-Engdahl regionalization*. **M.M** is the magnitude of the earthquake, and "**(MJMA)**" is added for Mjma values. The focal depth is included only for depths of 100 km or more. When parameters are revised in a subsequent message, "(REVISION)" appears on the first line of this part.

*See also https://earthquake.usgs.gov/learn/topics/flinn_engdahl.php.

To ensure consistency and minimize confusion among users, NWPTAC and PTWC coordinate their earthquake parameters prior to official bulletin issuance using agreed-upon arrangements, and use identical earthquake parameters in their first text products to the maximum extent possible.

7.4. Tsunamigenic Potential

Tsunamigenic potential evaluation is based on earthquake magnitude as follows:

Criteria	Tsunamigenic potential
Inland or deep undersea (100 km –) NW Pacific event in AoS, M6.5 –	No possibility of a tsunami
Shallow undersea NW Pacific event in AoS, M6.5 – 7.0	Very small possibility of a destructive local tsunami
Shallow undersea NW Pacific event in AoS, M7.1 – 7.5	Possibility of a destructive local tsunami near the epicenter
Shallow undersea NW Pacific event in AoS, M7.6 – 7.8	Possibility of a destructive regional tsunami
Shallow undersea NW Pacific event in AoS, M7.9 –	Possibility of a destructive ocean-wide tsunami

NWPTAC criteria for tsunamigenic potential evaluation

7.5. Coastal Blocks

If a tsunami with an amplitude of 0.3 m or greater is expected for any FP, the **Coastal Blocks** containing the relevant FPs are shown in this part. If no tsunami of this scale is expected at any FP, the report states, “Estimation at forecast points – no tsunami waves with an amplitude of 0.3 meters or more are expected at any forecast point.” (Addition), (Revision) or (Cancellation) is specified as described below (Section 7.6) in subsequent information issued due to

earthquake parameter updates or observation of unexpectedly significant tsunami.

7.6. Forecast Amplitude and Arrival Time

Tsunami amplitude and arrival time are estimated for each coastal FP. The estimated amplitudes (**AMPL** in meters) and arrival times (**hhmm DD MMM** in UTC) are listed with the names (**FP1-1**, etc.) for each FP along with its latitude and longitude (**LL.L[N][S] LLL.LE** to the nearest 0.1 degrees) in **Coastal-Block** groups.

Amplitude here is defined as the maximum distance between the crests of tsunami waves and the undisturbed sea level. It is estimated in categories of 0.3 – 1 m, 1 – 3 m, 3 – 5 m, 5 – 10 m and Over 10 m, and shown only for FPs expected to experience tsunami with heights of 0.3 m or more. If no tsunami of this scale is expected at any FP, this part does not appear in the message.

If new FPs need be added or the expected arrival time/amplitude of tsunami need to be changed in a revised issue due to earthquake parameter updates or observation of unexpectedly significant tsunami, (Addition) or (Revision) is specified in the line for the relevant FPs. For FPs that appeared in the previous NWPTA message but need to be removed due to revision, (Cancellation) is stated in the revised issuance.

7.7. Tsunami Observation

Information on tsunami waves recorded at sea level stations with telemetric links to NWPTAC is provided as necessary. The amplitude (**AMPL** in meters) of the largest wave to the nearest 0.1 m and the arrival time (**hhmm**Z **DD MMM**) are listed along with the station name (**STATION-1**, etc.) and its latitude and longitude (**LL.L[N][S] LLL.L[E][W]** to the nearest 0.1 degrees).

To minimize confusion among user countries/organizations, NWPTAC generally adopts values of Maximum Tsunami Height (measured with respect to the normal tide level) for PTWC products in correspondence to those of Maximum Tsunami Wave Amplitude in NWPTAC products.

7.8. Qualitative Expressions for Huge Earthquakes

In the event of a huge earthquake close to Japan, the qualitative terms "Huge," "High" or "----" and the magnitude expression "MAG OVER 8" may be used in

NWPTAs. Such expressions can be shown when NWPTA follows JMA domestic tsunami warnings in which similar qualitative expressions are used because the earthquake is so massive that it is impractical to estimate the appropriate magnitude value within the few minutes available until domestic tsunami warnings need to be issued. In such cases, tsunami scale estimation is based on a predefined possible maximum magnitude.

Mw values can usually be determined within around 15 minutes of an earthquake in time for initial NWPTA issuance. If not, JMA issues initial messages using qualitative expressions with a note specifying that the advisory is based on predefined magnitude values.

8. FORECAST MODEL

8.1. Tsunami Forecast Database

JMA uses a tsunami forecast system in conjunction with a numerical simulation technique for quantitative tsunami warnings. Tsunami propagation scenarios based on various fault types/locations were simulated in advance, and data on calculated tsunami arrival times and amplitudes were stored in a database along with information on magnitudes and hypocenter locations. The presumed epicenter locations are shown in Figure 2. For each one, faults with four magnitudes (M8.5, 8.0, 7.5 and 7.0) and six depths (0, 20, 40, 60, 80 and 100 km) are determined. Once an earthquake occurs and its hypocenter and magnitude are determined, the nearest scenario is retrieved for NWPTA formulation. Specifically, the scenario with the closest fault location is selected, and tsunami amplitudes are estimated via interpolation or extrapolation relating to magnitude and depth. For tsunami propagation simulation, the model described in 8.2 is used.

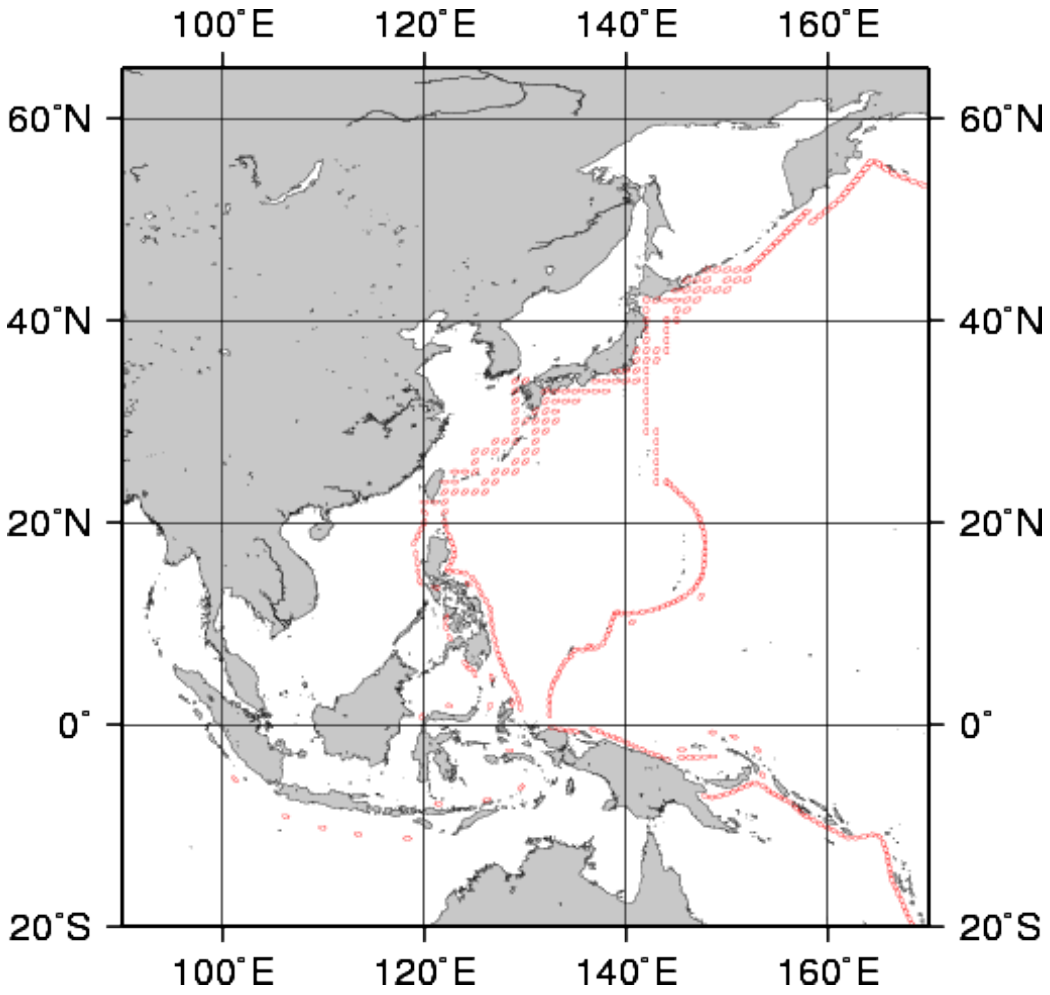

Figure 2 Assumed fault locations for NWPTAC tsunami forecast database

8.2. Numerical Simulation

In the calculation of tsunami propagation for tsunami forecast database information and real-time forecasting, JMA uses a numerical tsunami simulation model based on the non-linear long wave theory. This model incorporates the effects of Coriolis force and sea floor friction, and has a grid resolution of 1 arc-min (e.g., Satake (2002)).

The long wave theory can be applied when the wavelength of a tsunami is considered to significantly exceed the sea depth and when the wave amplitude is considered to be much less than the sea depth. However, these conditions are not applicable for tsunamis heading toward coastal areas in shallow water. Hence, estimation of tsunami amplitudes at coastal points is based on the

simulated value for a corresponding offshore point several to several tens of kilometers offshore using Green's Law (e.g., Satake (2002)) as described below.

$$A_{coast} = A_{offshore}\left(D_{offshore}/D_{coast}\right)^{1/4}$$

Here:

A_{coast} : tsunami amplitude at coast

$A_{offshore}$: tsunami amplitude at offshore grid point

$D_{offshore}$: ocean depth at offshore grid point

D_{coast} : ocean depth at coast

The coastal ocean depth is set to be 1 m.

Meanwhile, the tsunami arrival time at the offshore point as determined from numerical simulation is regarded as that at the corresponding coastal point without conversion. The arrival time is defined as the point at which the estimated amplitude initially exceeds 5 cm.

It should be noted that actual tsunami arrival times and amplitudes may differ from predictive data depending on coastal and sea bed topography, especially in coastal areas where fine-mesh bathymetric data are not used in numerical simulation for tsunamis. Accordingly, although estimated arrival times for each forecast point are given to the nearest minute, data are not necessarily accurate to the order of a minute. Tsunamis may arrive earlier or later than NWPTA estimated times.

REFERENCE

Satake, K. 2002. Tsunamis. *International Handbook of Earthquake & Engineering Seismology*, Part A, III-28. Academic Press.

8.3. Tsunami Travel Times

Calculation of tsunami travel times shown on Tsunami Travel Time Maps is based on the long wave theory, meaning that wave speed is computed from the square root of the quantity water depth multiplied by the acceleration of gravity. Accordingly, times shown on these maps may not precisely match the times in NWPTA text messages.

APPENDIX I. EXAMPLES OF NWPTAC ENHANCED PRODUCTS

a. First Text Product (when coastal tsunami with heights of 0.3 m or more are expected)

```
WEPA40 RJTD 240904

TSUNAMI BULLETIN NUMBER 001
   ISSUED BY NWPTAC(JMA)
   ISSUED AT 0859Z 24 MAR 2017
PART 01 OF 01 PARTS

HYPOCENTRAL PARAMETERS
ORIGIN TIME : 0858Z 24 MAR 2017
PRELIMINARY EPICENTER : LAT 3.0SOUTH LON148.0EAST
EASTERN CAROLINE ISLANDS, MICRONESIA
PACIFIC BASIN
MAG : 8.2
BY PTWC

EVALUATION
THERE IS A POSSIBILITY OF A DESTRUCTIVE OCEAN-WIDE TSUNAMI

THIS BULLETIN IS FOR
EAST COASTS OF PHILIPPINES
NORTH COASTS OF IRIAN JAYA
CELEBES SEA

ESTIMATED TSUNAMI ARRIVAL TIMES AND WAVE AMPLITUDES:
EAST COASTS OF PHILIPPINES
 LOCATION          COORDINATES  ARRIVAL TIME  AMPL
 LEGASPI           13.2N 123.8E 1257Z 24 MAR  0.3-1M
NORTH COASTS OF IRIAN JAYA
 LOCATION          COORDINATES  ARRIVAL TIME  AMPL
 MANOKWARI         00.8S 134.2E 1116Z 24 MAR  1-3M
 WARSA             00.6S 135.8E 1046Z 24 MAR  1-3M
 JAYAPURA          02.4S 140.8E 1002Z 24 MAR  1-3M
CELEBES SEA
 LOCATION          COORDINATES  ARRIVAL TIME  AMPL
 MANADO            01.6N 124.9E 1304Z 24 MAR  1-3M

AMPL - MAXIMUM AMPLITUDE IN METERS FROM THE UNDISTURBED SEA LEVEL TO THE CREST

IN SOME COASTAL AREAS (PARTICULARLY NEAR THE EPICENTER), TSUNAMI WAVES MAY BE HIGHER AND/OR ARRIVE
EARLIER THAN ESTIMATED FOR NEARBY FORECAST POINTS.
AUTHORITIES SHOULD BE AWARE OF THIS POSSIBILITY.

THE EVALUATION OF TSUNAMIGENIC POTENTIAL AND ESTIMATED ARRIVAL TIMES FOR TSUNAMI WAVES MAY ALSO
DIFFER FROM THOSE OF PTWC DUE TO DIFFERENCES IN ESTIMATED EARTHQUAKE PARAMETERS AND THE TSUNAMI
FORECAST MODEL.
AUTHORITIES SHOULD REFER TO EARLIER ARRIVAL TIMES FOR GREATEST SAFETY.

THIS WILL BE THE FINAL BULLETIN UNLESS CHANGES IN THE POTENTIAL FOR TSUNAMI GENERATION ARE DEEMED
POSSIBLE BASED ON EARTHQUAKE RE-EVALUATION OR REPORTS INDICATING TSUNAMI OBSERVATION ARE RECEIVED.
```

b. First Text Product (when coastal tsunami with heights of 0.3 m or more are not expected)

```
WEPA40 RJTD 102318

TSUNAMI BULLETIN NUMBER 001
   ISSUED BY NWPTAC(JMA)
   ISSUED AT 2318Z 10 MAR 2017
PART 01 OF 01 PARTS

HYPOCENTRAL PARAMETERS
ORIGIN TIME : 2252Z 10 MAR 2017
PRELIMINARY EPICENTER : LAT07.0SOUTH LON148.3EAST
EASTERN NEW GUINEA, PAPUA NEW GUINEA, REGION
NEW GUINEA AREA
MAG : 6.7
BY PTWC

EVALUATION
THERE IS A VERY SMALL POSSIBILITY OF A DESTRUCTIVE LOCAL TSUNAMI

ESTIMATION AT FORECAST POINTS - NO TSUNAMI WAVES WITH AN AMPLITUDE OF 0.3 METERS OR MORE ARE EXPECTED
AT ANY FORECAST POINT.

HOWEVER, IN SOME COASTAL AREAS (PARTICULARLY NEAR THE EPICENTER), HIGHER TSUNAMI WAVES THAN
ESTIMATED MAY ARRIVE.
AUTHORITIES SHOULD BE AWARE OF THIS POSSIBILITY.

THIS WILL BE THE FINAL BULLETIN UNLESS CHANGES IN THE POTENTIAL FOR TSUNAMI GENERATION ARE DEEMED
POSSIBLE BASED ON EARTHQUAKE RE-EVALUATION OR REPORTS INDICATING TSUNAMI OBSERVATION ARE RECEIVED.
```

c. First Text Product (when Mjma is judged as underestimated and Mw is unavailable in a timely manner)

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WEPA40 RJTD 240904

TSUNAMI BULLETIN NUMBER 001
   ISSUED BY NWPTAC(JMA)
   ISSUED AT 0859Z 24 MAR 2017
PART 01 OF 01 PARTS

HYPOCENTRAL PARAMETERS
ORIGIN TIME : 0858Z 24 MAR 2017
PRELIMINARY EPICENTER : LAT 3.0SOUTH LON148.0EAST
EASTERN CAROLINE ISLANDS, MICRONESIA
PACIFIC BASIN
MAG OVER 8

THIS INFORMATION IS BASED ON THE PREDEFINED MAGNITUDE

EVALUATION
THERE IS A POSSIBILITY OF A DESTRUCTIVE OCEAN-WIDE TSUNAMI

THIS BULLETIN IS FOR
EAST COASTS OF PHILIPPINES
NORTH COASTS OF IRIAN JAYA
```

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NORTH COASTS OF PAPUA NEW GUINEA
CELEBES SEA

ESTIMATED TSUNAMI ARRIVAL TIMES AND WAVE AMPLITUDES:
EAST COASTS OF PHILIPPINES
 LOCATION            COORDINATES  ARRIVAL TIME  AMPL
 LEGASPI             13.2N 123.8E 1257Z 24 MAR  ----
NORTH COASTS OF IRIAN JAYA
 LOCATION            COORDINATES  ARRIVAL TIME  AMPL
 MANOKWARI           00.8S 134.2E 1116Z 24 MAR  HIGH
 WARSA               00.6S 135.8E 1046Z 24 MAR  HIGH
 JAYAPURA            02.4S 140.8E 1002Z 24 MAR  HUGE
CELEBES SEA
 LOCATION            COORDINATES  ARRIVAL TIME  AMPL
 MANADO              01.6N 124.9E 1304Z 24 MAR  ----

AMPL - MAXIMUM AMPLITUDE IN METERS FROM THE UNDISTURBED SEA LEVEL TO THE CREST

IN SOME COASTAL AREAS (PARTICULARLY NEAR THE EPICENTER), TSUNAMI WAVES MAY BE HIGHER AND/OR ARRIVE
EARLIER THAN ESTIMATED FOR NEARBY FORECAST POINTS.
AUTHORITIES SHOULD BE AWARE OF THIS POSSIBILITY.

THE EVALUATION OF TSUNAMIGENIC POTENTIAL AND ESTIMATED ARRIVAL TIMES FOR TSUNAMI WAVES MAY ALSO
DIFFER FROM THOSE OF PTWC DUE TO DIFFERENCES IN ESTIMATED EARTHQUAKE PARAMETERS AND THE TSUNAMI
FORECAST MODEL.
AUTHORITIES SHOULD REFER TO EARLIER ARRIVAL TIMES FOR GREATEST SAFETY.

MEASUREMENTS OR REPORTS OF TSUNAMI
LOCATION           COORDINATES  ARRIVAL TIME   AMPL
LEGASPI            13.2N 123.8E
              MAXIMAM TSUNAMI WAVE 1303Z 24 MAR 0.5M

MAXIMUN TSUNAMI WAVE - HALF THE AMPLITUDE FROM THE TROUGH TO THE CREST

THIS WILL BE THE FINAL BULLETIN UNLESS CHANGES IN THE POTENTIAL FOR TSUNAMI GENERATION ARE DEEMED
POSSIBLE BASED ON EARTHQUAKE RE-EVALUATION OR REPORTS INDICATING TSUNAMI OBSERVATION ARE RECEIVED.
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d. First Text Product (when the depth is 100 km or more)

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WEPA40 RJTD 060505

TSUNAMI BULLETIN NUMBER 001
   ISSUED BY NWPTAC(JMA)
   ISSUED AT 0505Z 06 APR 2017
PART 01 OF 01 PARTS

HYPOCENTRAL PARAMETERS
ORIGIN TIME : 0443Z 06 APR 2017
PRELIMINARY EPICENTER: LAT7.0NORTH LON138.0EAST
WESTERN CAROLINE ISLANDS,MICRONESIA
CAROLINE ISLANDS TO GUAM
FOCAL DEPTH:120km MAG:6.6

EVALUATION
 THERE IS NO POSSIBILITY OF A TSUNAMI

THIS WILL BE THE FINAL BULLETIN UNLESS CHANGES IN THE POTENTIAL FOR TSUNAMI GENERATION ARE DEEMED
POSSIBLE BASED ON EARTHQUAKE RE-EVALUATION OR REPORTS INDICATING TSUNAMI OBSERVATION ARE RECEIVED.
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e. Second Text Product (with tsunami observations)

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WEPA40 RJTD 240934

TSUNAMI BULLETIN NUMBER 002
   ISSUED BY NWPTAC(JMA)
   ISSUED AT 0929Z 24 MAR 2017
PART 01 OF 01 PARTS

HYPOCENTRAL PARAMETERS(REVISION)
ORIGIN TIME:0858Z 24 MAR 2017
PRELIMINARY EPICENTER:LAT 3.5SOUTH LON148.2EAST
 EASTERN CAROLINE ISLANDS, MICRONESIA
 PACIFIC BASIN
MAG:8.3

EVALUATION
 THERE IS A POSSIBILITY OF A DESTRUCTIVE OCEAN-WIDE TSUNAMI

THIS BULLETIN IS FOR
EAST COASTS OF PHILIPPINES(REVISION)
NORTH COASTS OF IRIAN JAYA(REVISION)
NORTH COASTS OF PAPUA NEW GUINEA(REVISION)
CELEBES SEA

ESTIMATED TSUNAMI ARRIVAL TIMES AND WAVE AMPLITUDES:
EAST COASTS OF PHILIPPINES
 LOCATION              COORDINATES  ARRIVAL TIME  AMPL
 LEGASPI               13.2N 123.8E (ALREADY ARRIVED)
 DAVAO                 06.9N 125.7E 1237Z 24 MAR  0.3-1M (ADDITION)
NORTH COASTS OF IRIAN JAYA
 LOCATION              COORDINATES  ARRIVAL TIME  AMPL
 MANOKWARI             00.8S 134.2E 1116Z 24 MAR  0.3-1M (REVISION)
 WARSA                 00.6S 135.8E 1046Z 24 MAR  1-3M
 JAYAPURA              02.4S 140.8E 1002Z 24 MAR  1-3M
NORTH COASTS OF PAPUA NEW GUINEA
 LOCATION              COORDINATES  ARRIVAL TIME  AMPL
 VANIMO                02.6S 141.3E 0953Z 24 MAR  1-3M
 WEWAK                 03.5S 143.7E 0931Z 24 MAR  3-5M
 MADANG                05.2S 145.8E 0935Z 24 MAR  5-10M
 MANUS_IS.             02.0S 147.5E 0858Z 24 MAR  3-5M
 RABAUL                04.2S 152.3E (CANCELLATION)
CELEBES SEA
 LOCATION              COORDINATES  ARRIVAL TIME  AMPL
 MANADO                01.6N 124.9E 1304Z 24 MAR  0.3-1M

AMPL - MAXIMUM AMPLITUDE IN METERS FROM THE UNDISTURBED SEA LEVEL TO THE CREST

IN SOME COASTAL AREAS (PARTICULARLY NEAR THE EPICENTER), TSUNAMI WAVES MAY BE HIGHER AND/OR ARRIVE
EARLIER THAN ESTIMATED FOR NEARBY FORECAST POINTS.
AUTHORITIES SHOULD BE AWARE OF THIS POSSIBILITY.

THE EVALUATION OF TSUNAMIGENIC POTENTIAL AND ESTIMATED ARRIVAL TIMES FOR TSUNAMI WAVES MAY ALSO
DIFFER FROM THOSE OF PTWC DUE TO DIFFERENCES IN ESTIMATED EARTHQUAKE PARAMETERS AND THE TSUNAMI
FORECAST MODEL.
AUTHORITIES SHOULD REFER TO EARLIER ARRIVAL TIMES FOR GREATEST SAFETY.
```

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MEASUREMENTS OR REPORTS ON TSUNAMI
 LOCATION                        COORDINATES  ARRIVAL TIME  AMPL
 LEGASPI                         13.2N 123.8E
                          MAXIMUM TSUNAMI WAVE 0810Z 10 JAN   0.5M

MAXIMUM TSUNAMI WAVE -- HALF THE AMPLITUDE FROM THE TROUGH TO THE CREST

THIS WILL BE THE FINAL BULLETIN UNLESS CHANGES IN THE POTENTIAL FOR TSUNAMI GENERATION ARE DEEMED
POSSIBLE BASED ON EARTHQUAKE RE-EVALUATION OR REPORTS INDICATING TSUNAMI OBSERVATION ARE RECEIVED.
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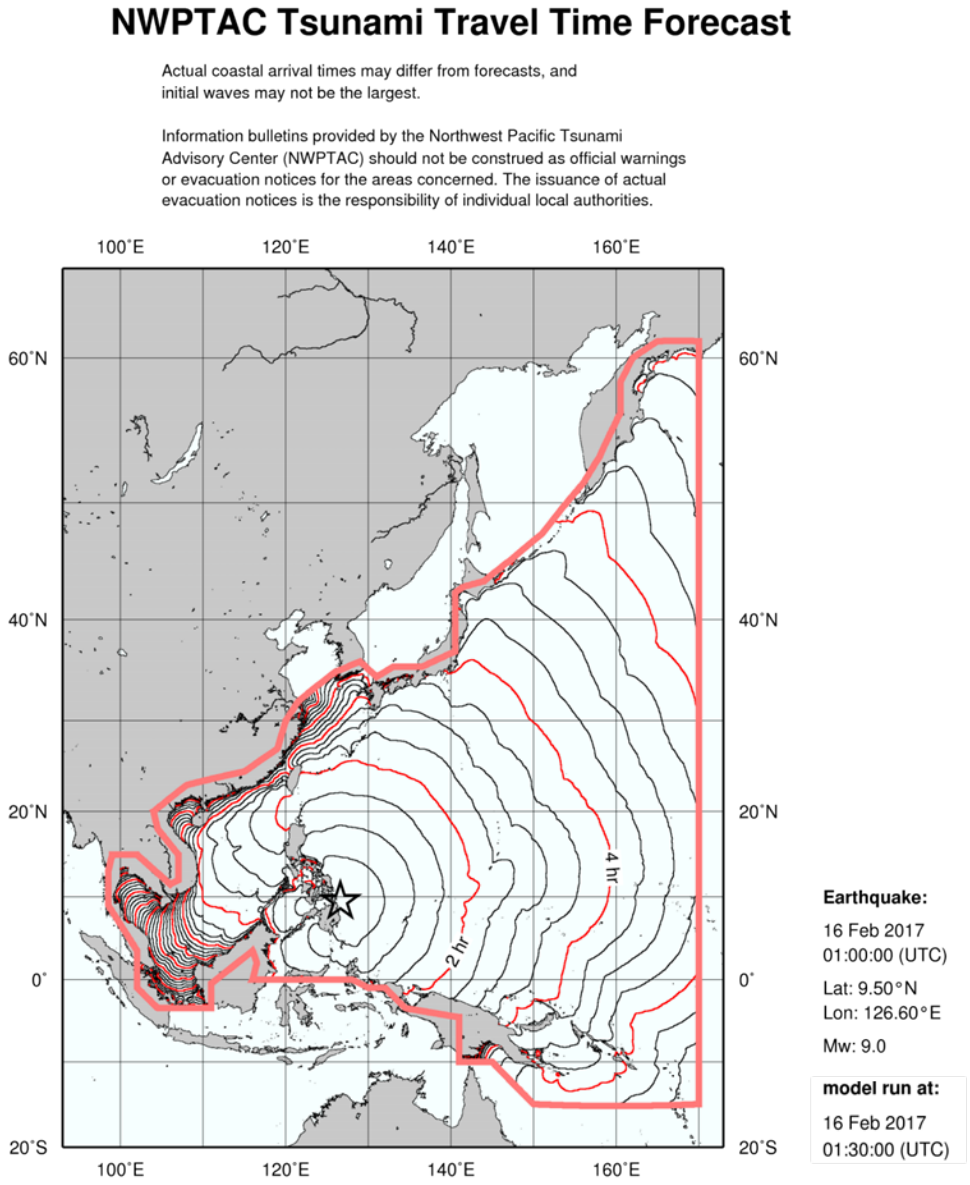
f. Graphical Product

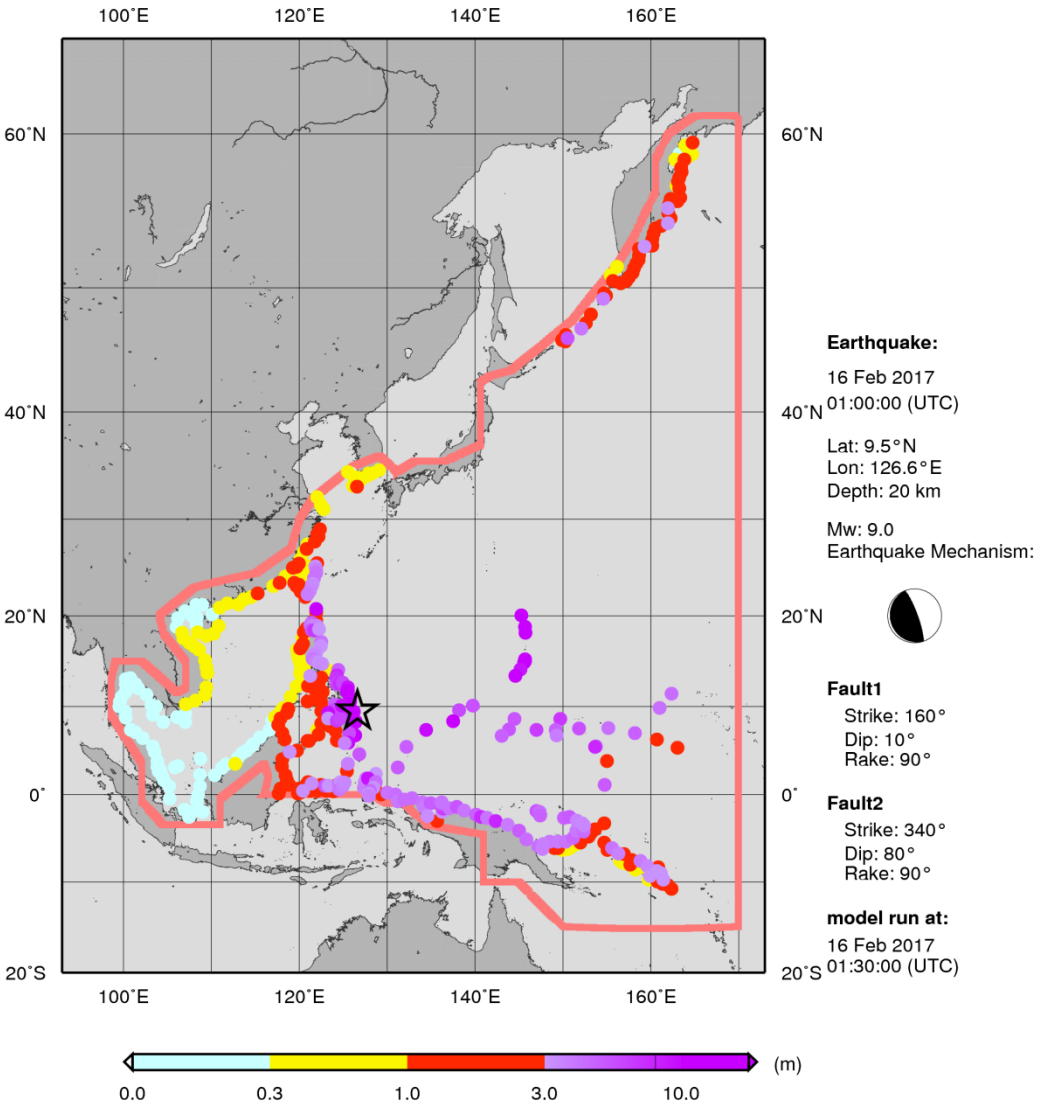


NWPTAC Coastal Tsunami Amplitude Forecast

This map shows the largest maximum coastal amplitudes of two forecasts based on a conjugate fault set obtained from CMT analysis.
Values are shown in meters from the undisturbed sea level to the crest.

Actual coastal amplitudes at the coast may differ from forecasts due to forecasting uncertainties and local topography.

Information bulletins provided by the Northwest Pacific Tsunami Advisory Center (NWPTAC) should not be construed as official warnings or evacuation notices for the areas concerned. The issuance of actual evacuation notices is the responsibility of individual local authorities.

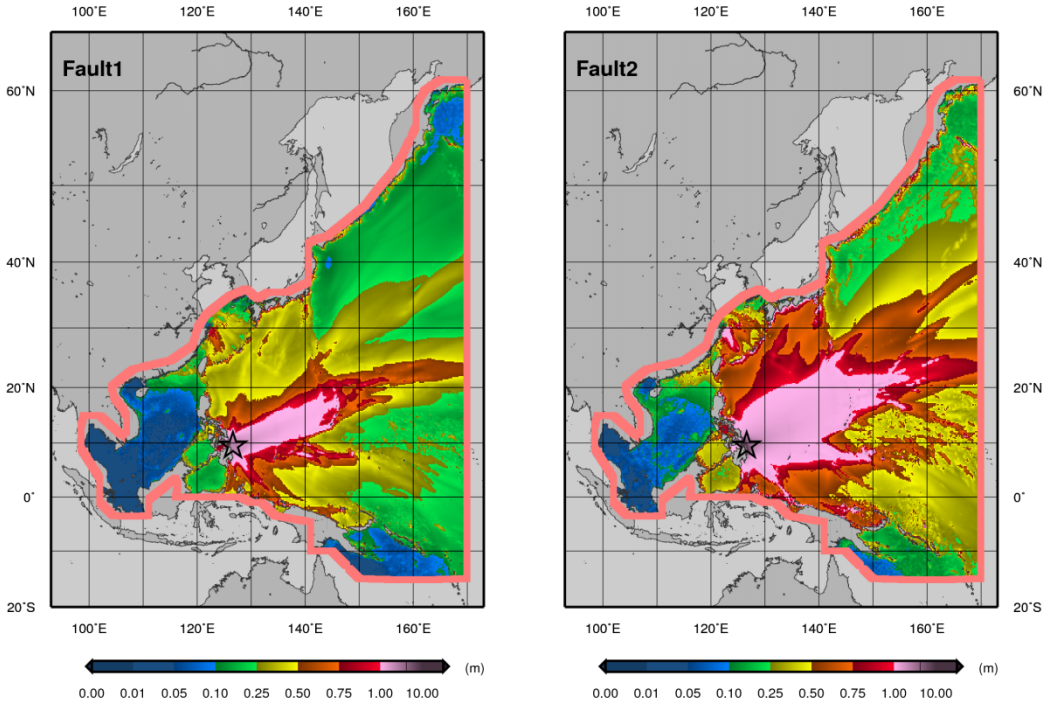


NWPTAC Deep–Ocean Tsunami Amplitude Forecast

The amplitudes shown on these maps are maximum values in meters
from the undisturbed sea level to the crest.

Maps should not be used to estimate coastal tsunami amplitudes or impacts.
Deep–ocean tsunami amplitudes are usually much smaller than coastal amplitudes.

Information bulletins provided by the Northwest Pacific Tsunami
Advisory Center (NWPTAC) should not be construed as official warnings
or evacuation notices for the areas concerned. The issuance of actual
evacuation notices is the responsibility of individual local authorities.



Earthquake: 16 Feb 2017 01:00:00 (UTC)
Lat: 9.5°N, Lon: 126.6°E, Depth: 20 km
Mw: 9.0
Earthquake Mechanism:

Fault1 Strike: 160°, Dip: 10°, Rake: 90°

Fault2 Strike: 340°, Dip: 80°, Rake: 90°

model run at: 16 Feb 2017 01:30:00 (UTC)

APPENDIX II. LIST OF FORECAST POINTS

Coastal Block	Forecast Point	Latitude	Longitude	FP Number
EAST COASTS OF KAMCHATKA PENINSULA	OSTROV_KARAGINSKIY	58.8N	164.5E	1
	UST_KAMCHATSK	56.1N	162.6E	2
	PETROPAVLOVSK_K	53.2N	159.6E	3
	NIKOLSKOYA	55.1N	165.7E	4
KURIL ISLANDS	SEVERO_KURILSK	50.8N	156.1E	5
	URUP_IS.	46.1N	150.5E	6
SOUTH COASTS OF KOREAN PENINSULA	BUSAN	35.1N	129.1E	7
	TONGYEONG	34.7N	128.4E	8
	NOHWA	34.2N	126.6E	9
	HEUKSANDO	34.6N	125.4E	10
	CHEJU_ISLAND	33.5N	127.0E	11
	SEOGWIPO	33.2N	126.5E	12
TAIWAN	CHILUNG	25.2N	121.8E	13
	HUALIEN	24.0N	121.6E	14
	TAITUNG	22.7N	121.2E	15
	KAOHSIUNG	22.5N	120.3E	16
	HOMEL	24.2N	120.4E	17
EAST COASTS OF PHILIPPINES	BASCO	20.4N	122.0E	18
	PALANAN	17.2N	122.6E	19
	LEGASPI	13.2N	123.8E	20
	LAOANG	12.6N	125.0E	21
	MADRID	09.2N	126.0E	22
	DAVAO	06.9N	125.7E	23
NORTH COASTS OF IRIAN JAYA	GEME	04.6N	126.8E	24
	BEREBERE	02.5N	128.7E	25
	PATANI	00.4N	128.8E	26
	SORONG	00.8S	131.1E	27
	MANOKWARI	00.8S	134.2E	28
	WARSA	00.6S	135.8E	29
	JAYAPURA	02.4S	140.8E	30
NORTH COASTS OF	VANIMO	02.6S	141.3E	31

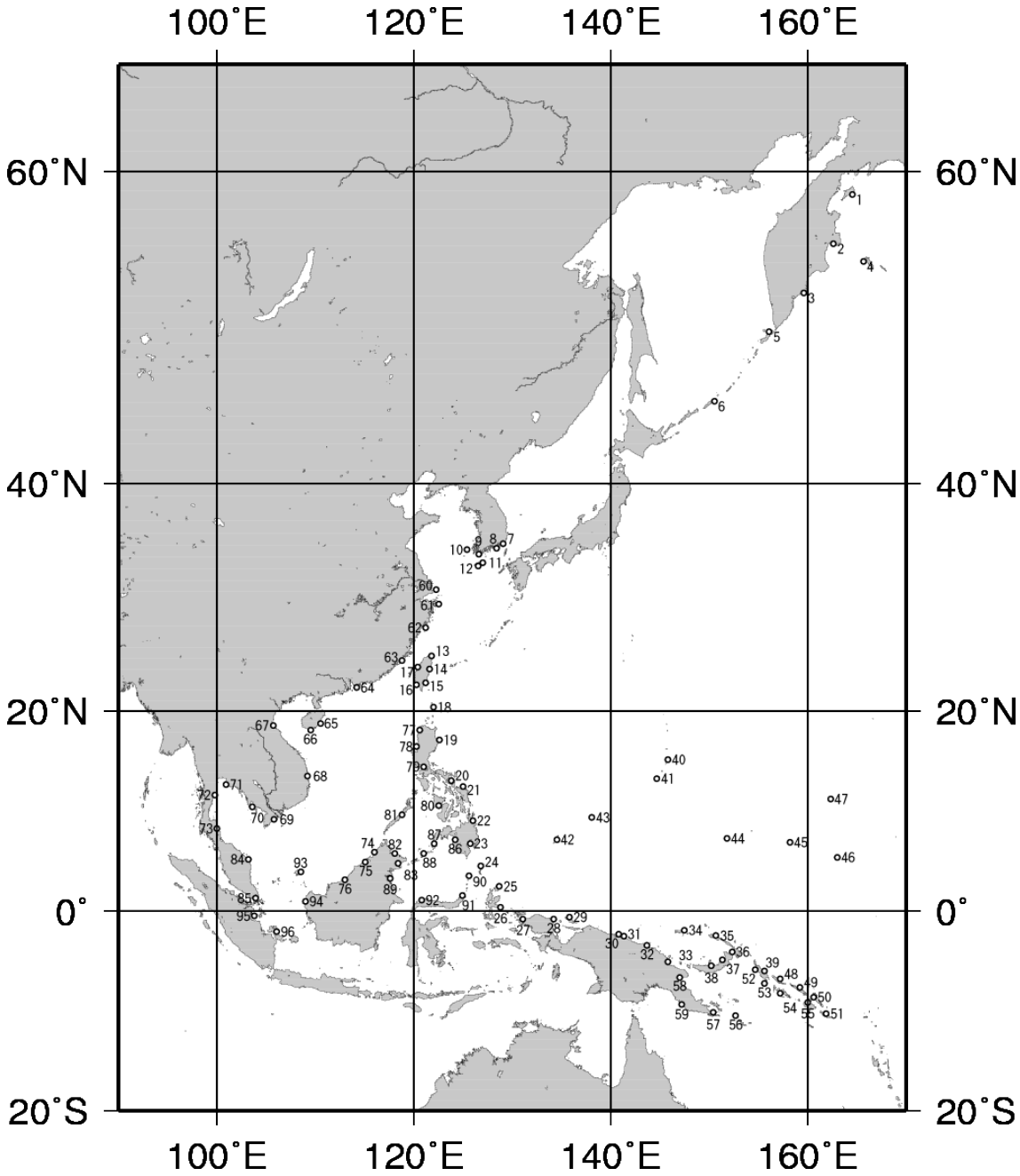
PAPUA NEW GUINEA	WEWAK	03.5S	143.7E	32

Coastal Block	**Forecast Point**	**Latitude**	**Longitude**	**FP Number**
NORTH COASTS OF PAPUA NEW GUINEA	MADANG	05.2S	145.8E	33
	MANUS_IS.	02.0S	147.5E	34
	KAVIENG	02.5S	150.7E	35
	RABAUL	04.2S	152.3E	36
	ULAMONA	05.0S	151.3E	37
	KIMBE	05.6S	150.2E	38
	KIETA	06.1S	155.6E	39
MARIANA ISLANDS	SAIPAN	15.3N	145.8E	40
	GUAM	13.4N	144.7E	41
PALAU	MALAKAL	07.3N	134.5E	42
MICRONESIA	YAP_IS.	09.5N	138.1E	43
	CHUUK_IS.	07.4N	151.8E	44
	POHNPEI_IS.	07.0N	158.2E	45
	KOSRAE_IS.	05.5N	163.0E	46
MARSHALL ISLANDS	ENIWETOK	11.4N	162.3E	47
NORTH COASTS OF SOLOMON ISLANDS	PANGGOE	06.9S	157.2E	48
	GHATERE	07.8S	159.2E	49
	AUKI	08.8S	160.6E	50
	KIRAKIRA	10.4S	161.9E	51
SOLOMON SEA	AMUN	06.0S	154.7E	52
	FALAMAE	07.4S	155.6E	53
	MUNDA	08.4S	157.2E	54
	HONIARA	09.3S	160.0E	55
	MISIMA	10.6S	152.7E	56
	ALOTAU	10.3S	150.4E	57
	LAE	06.8S	147.0E	58
CORAL SEA	PORT_MORESBY	09.5S	147.2E	59
COASTS OF EAST CHINA SEA	SHANGHAI	31.2N	122.3E	60
	ZHOUSHAN	29.9N	122.5E	61
	WENZHOU	27.8N	121.2E	62

COASTS OF SOUTH CHINA SEA	QUANZHOU	24.8N	118.8E	63
	HONG_KONG	22.3N	114.2E	64
	HAINAN_ISLAND	18.8N	110.5E	65

Coastal Block	**Forecast Point**	**Latitude**	**Longitude**	**FP Number**
COASTS OF SOUTH CHINA SEA	SANYA	18.2N	109.5E	66
COASTS OF GULF OF TONKIN	VINH	18.6N	105.7E	67
EAST COASTS OF INDO CHINA PENINSULA	QUI_NHON	13.7N	109.2E	68
	BAC_LIEU	09.3N	105.8E	69
GULF OF THAILAND	SIHANOUKVILLE	10.6N	103.6E	70
	PATTAYA	12.8N	100.9E	71
	PRACHUAP_KHIRI_KHAN	11.8N	099.8E	72
	NAKHON_SI_THAMMARAT	08.4N	100.0E	73
NORTHWEST COASTS OF KALIMANTAN	KOTA_KINABALU	6.0N	116.0E	74
	MUARA	05.0N	115.1E	75
	BINTULU	03.2N	113.0E	76
WEST COASTS OF PHILIPPINES	LAOAG	18.2N	120.6E	77
	SAN_FERNANDO	16.6N	120.3E	78
	MANILA	14.6N	121.0E	79
SULU SEA	ILOILO	10.7N	122.5E	80
	PUERTO_PRINCESA	09.8N	118.8E	81
	SANDAKAN	05.9N	118.1E	82
	LAHAD_DATU	04.9N	118.4E	83
EAST COASTS OF MALAY PENINSULA	KUALA_TERENGGANU	05.3N	103.2E	84
	SINGAPORE	01.3N	103.9E	85
CELEBES SEA	COTABUTO_CITY	07.3N	124.2E	86
	ZAMBOANGA	06.9N	122.1E	87
	MAIMBUNG	05.9N	121.0E	88
	TARAKAN	03.3N	117.6E	89
	TABUKAN_TENGAH	03.6N	125.6E	90
	MANADO	01.6N	124.9E	91

	TOLITOLI	01.1N	120.8E	92
NATUNA SEA	KEPULAUAN_RIAU	04.0N	108.5E	93
	SINGKAWANG	01.0N	109.0E	94
	KUALA_INDRAGIRI	00.5S	103.8E	95
	PANGKALPINANG	02.1S	106.1E	96



Forecast points(FP) of NWPTAC Enhanced Products