EUROPEAN COMMISSION
JOINT RESEARCH CENTRE

01 Oct 2018 17:00 UTC

Mw 7.5 Earthquake in Indonesia, 28 Sep 2018

GDACS Earthquake RED Alert, GDACS Tsunami ORANGE Alert

01 Oct 2018 - Emergency Report - UPDATE #1

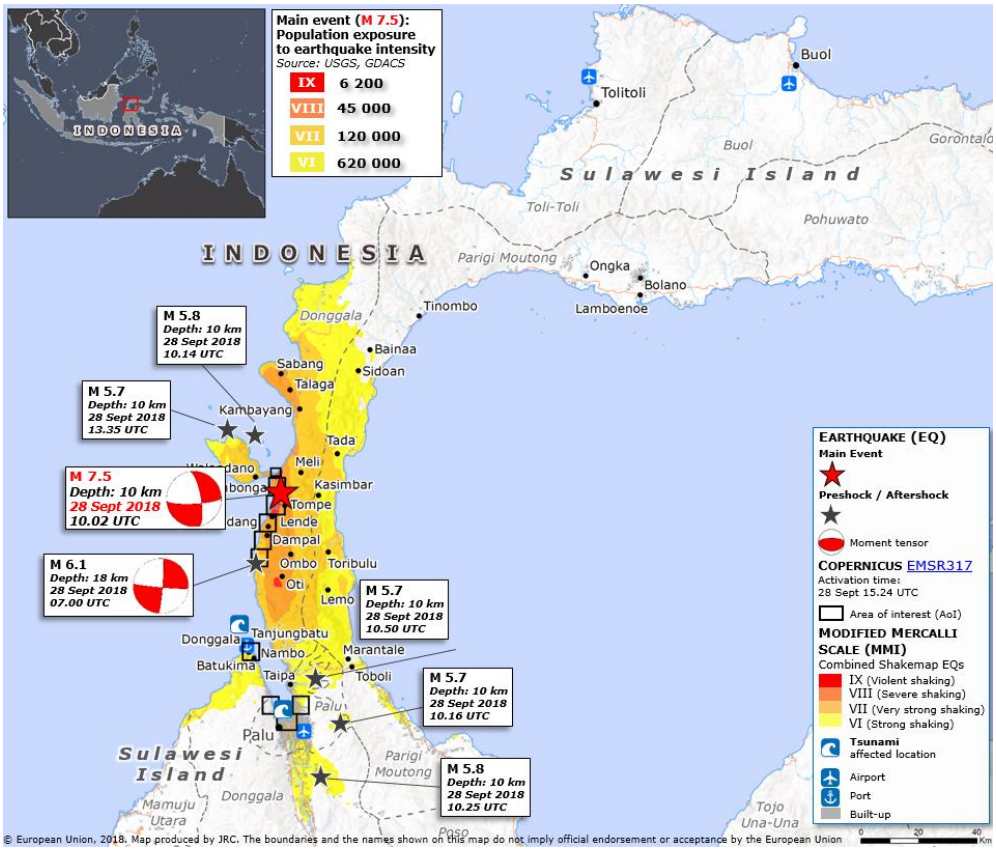


Figure 1 *- Location of the Mw 7.5 Earthquake event and the other 6 earthquakes in Indonesia, with the overall shakemap of all the earthquakes.*

1 Executive Summary

- As a result of the strong 7.5 Mw earthquake that hit the island of **Sulawesi** (Sulawesi Tengah province/Central Sulawesi, Indonesia) on **28 Sep** at **10:02 UTC** at a depth of **10 km,** and the consequent Tsunami that was generated, the humanitarian situation appears severe.
- The fatalities balance continues to increase; at the time of writing the death toll reached **844** in Donggala, Palu, Parigi Moutong, Sigi; 90 people are missing but search and rescue operations

are still ongoing. Some of the remote villages have not yet been reached and therefore the balance could become worst.

- Several discussions are ongoing in the International Community on the Tsunami Early Warning System that either did not work or was however unable to save lives. BMKG provided details on the system working conditions but some of the choices still need some clarification.
- There is not yet a clear general overview of the Tsunami impact occurred in the area; two cities are largely mentioned in the media (Palu and Donggala) but a clear extended mapping is still ongoing. Copernicus and International Charter have been activated and are providing important information on this point.
- From scientific point of view the Tsunami that occurred is not fully understandable by considering the source mechanism that has been determined. In order to have such a large effect other reasons must be invoked and the most mentioned hypothesis attributes the reason to a submarine landslide. Other teams referenced to possible resonance effects but have not been demonstrated yet.
- International rescue teams have been authorized by Indonesian Government to reach the country and therefore they are mobilizing.
- Over the next three days, cloudy conditions with the possibility of light rainfall in Palu city and moderate (locally heavy) rainfall in some areas of central and western Sulawesi.
- This report contains an updated situation respect to the first one and to have an overall picture they should be read together.

2 Situation Overview

2.1 Situation

- Seven main earthquakes of magnitude Mw between 7.5 and 5.7 hit the island of Sulawesi (Sulawesi Tengah province/Central Sulawesi, Indonesia) on 28 September, within 7 hours and in 100 km. The main shock of magnitude 7.5 Mw was at 10:02 UTC at a depth of 10 km and it triggered a tsunami wave of more than 3 meters that hit the northern parts of Sulawesi Island.
- The earthquakes and the consequent tsunami caused extensive damage and killed at least 844 people. Search and rescue operations are still on-going (see Section 2.2).
- Several discussions are ongoing in the International Community on the Tsunami Early Warning System that either did not work or was however unable to save lives. BMKG provided details on the system working conditions but some of the choices still need some clarification.

2.1.1 Tsunami warning timeline

On the 28 of September, at 10:11 UTC, the Indonesian Tsunami Service Provider (IOTWMS TSUNAMI SERVICE PROVIDER INDONESIA InaTEWS-BMKG) issued public tsunami bulletin number 1[1] in which it was stated that based on historical data and tsunami modelling, the earthquake was not capable of generating a tsunami affecting the Indian Ocean region, therefore no further bulletins were expected to be issued unless the situation would have changed.

[1] http://rtsp.bmkg.go.id/publicdetail.php?eventid=20180928171136

On the GTS (Global Telecommunication Service by WMO, the official alert distribution channel) three messages related to this event have been circulated, all of them being the first message of, respectively, IOTWMS-TSP INDIA, IOTWMS-TSP INDONESIA, IOTWMS-TSP AUSTRALIA. The information in these bulletins is not accessible since they refer to a restricted-access website (HTTP://RTSP.BMKG.GO.ID).

BMKG as National Tsunami Provider issued a warning at **10:07:38 UTC** per multiple channels (TV, Radio, e-mails, etc.).

Figure 2 - *Graphic info detail of the national tsunami warning issued at* 10:07:38 UTC
(Source: http://inatews.bmkg.go.id/new/tsunami15.php)

The following timeline for Friday, September 28, 2018 has been retrieved from the information published in the official website of BMKG:

10.02 UTC Earthquake occurrence

10.07 UTC BMKG issued a potential tsunami bulletin. BMKG has activated tsunami early warning with Alert status (high potential tsunami 0.5 - 3 meters) on the western Donggala coast, and Waspada status (tsunami potential height of less than 0.5 meters) on northern Donggala coast, northern Mamuju and West Palu City

10.27 UTC 6 cm change in sea level rise recorded at tide gauge in Mamuju (see next chapter)

10.36 UTC Based on the results of the updated earthquake source mechanism with strike type and observation of the height of the tsunami wave, and the estimated time of arrival of the

tsunami, the Tsunami Early Warning (PDT) was ended.

Below the timeline provided by AHA Centre, on courtesy of BMKG:

Figure 3 - *Timeline of Tsunami Early Warning System – Sulawesi Earthquake and Tsunami 28 September 2018 (Source: AHA report[2], courtesy: BMKG)*

[2] https://ahacentre.org/wp-content/uploads/2018/10/AHA-Situation_Update-no3-Sulawesi-EQ.pdf

2.1.2 Analysis if the Mamuju tide gauge signal

BMKG published the plot in Figure 4, to demonstrate the reason why they lifted the alert.

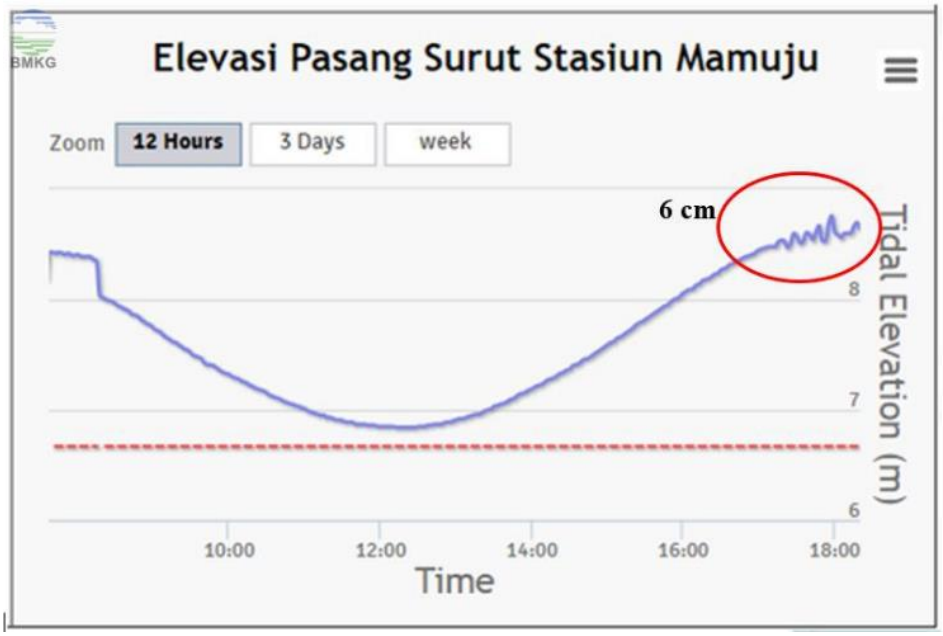


Figure 4 - Mamuju tide gauge signal, on the basis of which the alert was cancelled

In order to understand the timeline and the following actions, we have processed the signal of Figure. 3 by digitizing the signal and subtracting the continuous component (see Figure. 4). From the residual curve (orange curve) it is possible to note that the oscillation visible at 10:00 cannot be attributed to the Tsunami because the time needed to reach Mamuju, located about 180 km from the epicentre, is in the order of 50-55 minutes (see Figure 5).

Indeed at **10:53** an increase of the oscillations is visible together with a change in the oscillation frequency. Those information could suggest that at **10:27** UCT the 6 cm signal indication that suggested BMG to cancel the alert could be related to a local oscillation eg. shaking induced by the earthquake). At that time the Tsunami had not yet reached Mamuju location (reached instead at 10:53 UTC).

From the BMGK report[3], automatically translated: '*Based on the results of visual monitoring and equipment at sea for about 30 minutes no changes in sea level and tsunami were observed, BMKG stated that the tsunami early warning ended on 9/28/2018 at 17.39 WIB. Thus the tsunami does not occur. Conditions are safe and people can return to their place'*. This type of action is not normal and in other Monitoring centers there is a time to wait of at least 2 h before lifting the alert. In this case the alert removal after 37 min seems however too optimistic.

[3] https://www.bnpb.go.id/gempa-berkekuatan-magnitudo-77-peringatan-dini-tsunami-sempat-diaktifkan-namun-sudah-berakhir

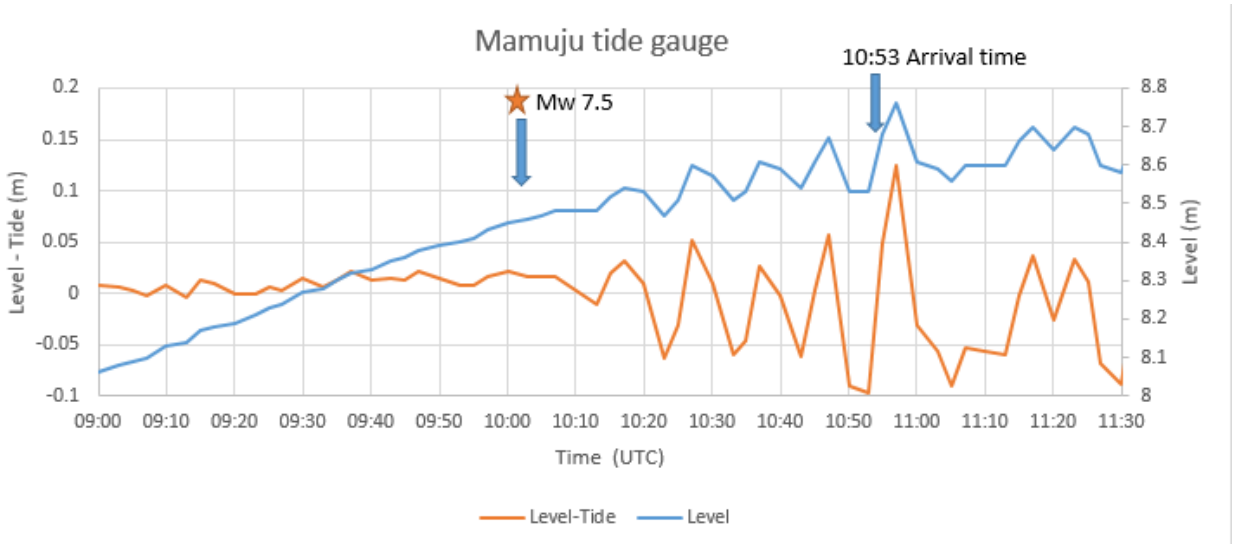


Figure 5 - Processing of Mamuju tide gauge signal

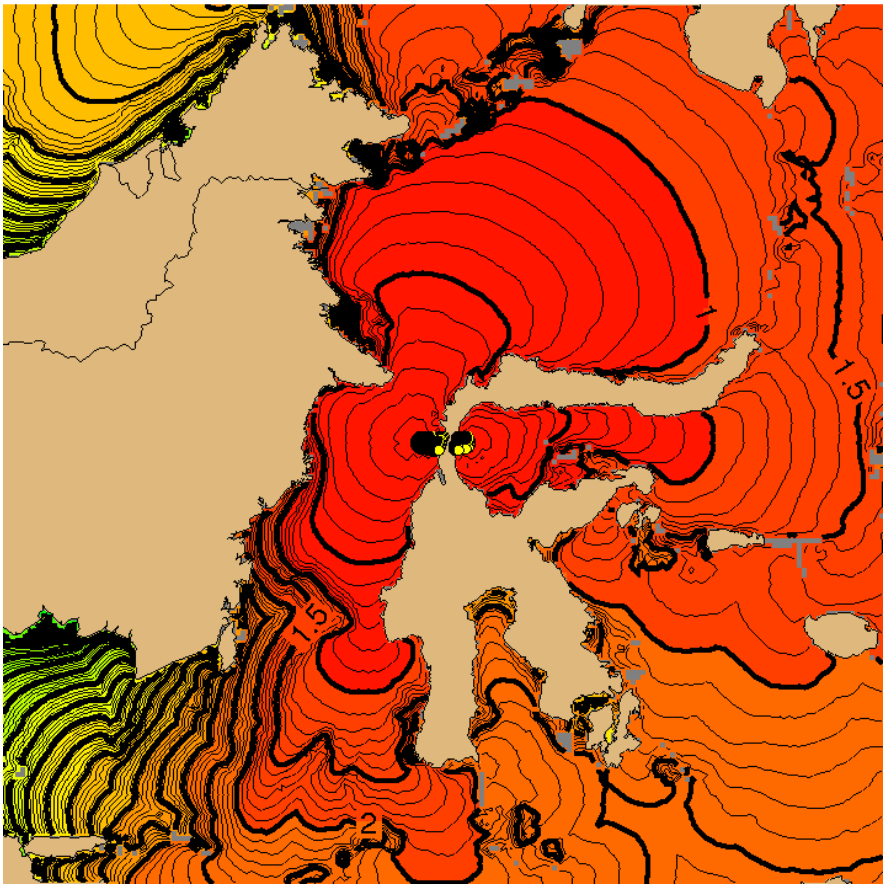


Figure 6 - Theoretical Tsunami Travel time

2.2 Humanitarian impact and response

The updated humanitarian impact (as of 01 October at 17:00 UTC) is shown in the table below. Search and rescue operations are still on-going, the full scale of damages and humanitarian needs are not yet known.

Government of Indonesia, through BNPB and Ministry of Foreign Affairs, have welcomed offers of international assistance as of 1 October 2018. This statement was also delivered by BNPB during Emergency Briefing and Coordination Meeting Partners at AHA Centre Emergency Operations Centre on 1 October, 10.00 hrs. And repeated during BNPB's Press Conference at 1300 hrs (source: https://ahacentre.org/wp-content/uploads/2018/10/AHA-Situation_Update-no3-Sulawesi-EQ.pdf).

Indonesia - Situation *(as of 01 Oct)*	
Deaths / missing	**At least 844 deaths** Donggala, Palu, Parigi Moutong, Sigi. **90 Missing** Search and rescue operations are ongoing.
People Injured	At least 632 major injuries
People displaced	48,025 displaced people in about 200 sites
Damaged houses/ infrastructures	Thousands houses damaged / destroyed Several roads damaged Power outages Palu airport reopened
Areas mostly affected	**Central Sulawesi (Sulawesi Tengah),** *- Donggala Regency* *- Palu City* *- Parigi Moutong Regency.* *- Sigi Regency*

Table 1 *- Indonesia - Situation (as of 01 October at 17:00 UTC), Sources: AHA Sit. Rep 3, UNOCHA*

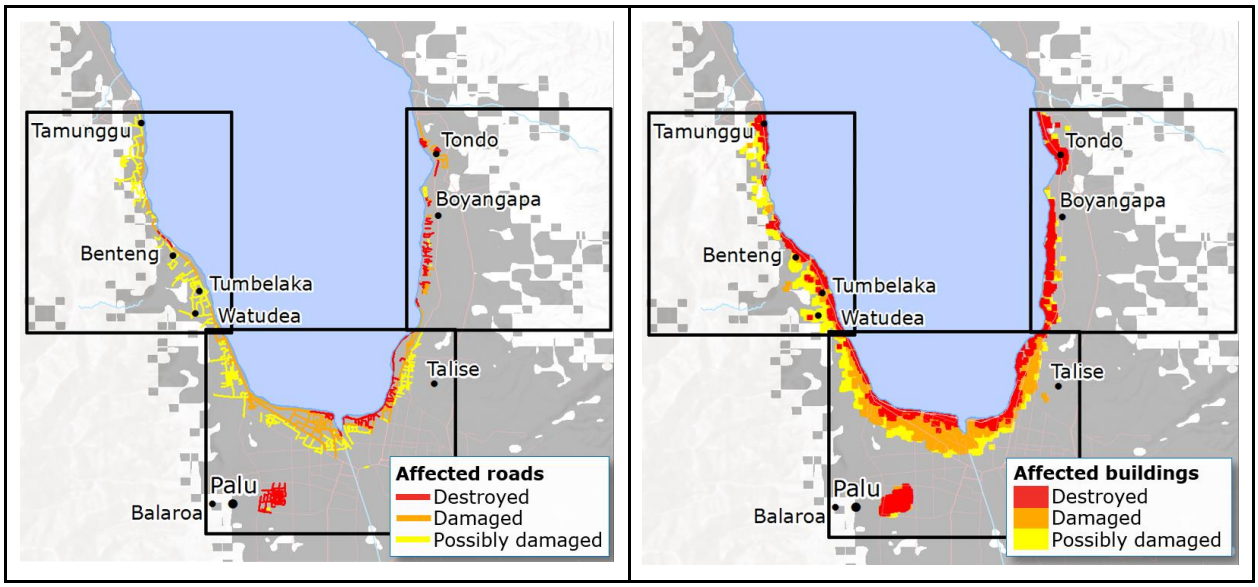


Figure 7 *- Affected roads and buildings over the whole town of Palu extracted from Copernicus EMS © 2018 EU, [EMSR317] . From the preliminary assessment of the damage data, the combined effects of the tsunami (along the coast) and of the earthquake are detected. On the South-West of the city, an area affected by liquefaction.*

Figure 8 *- Tsunami impact (source: https://www.bbc.com/news/world-asia-45663054)*

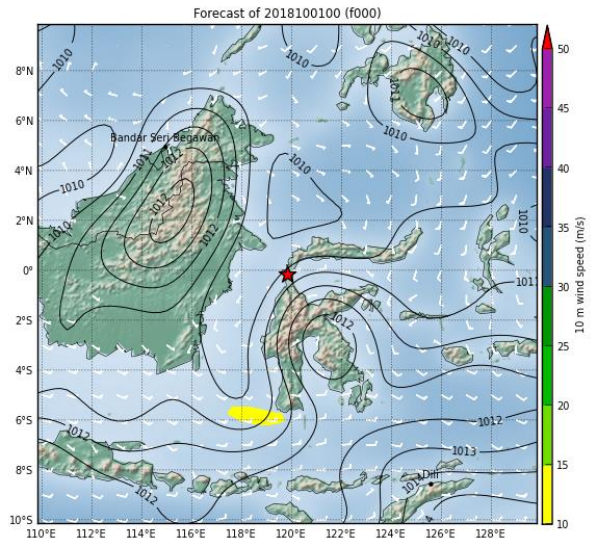
Figure 9 *- Earthquake impact in Palu (source: https://www.theguardian.com/world/gallery/2018/sep/30/Aerial-footage-shows-tsunami-destruction-in-sulawesi-in-pictures - Photograph: Social media/Reuters)*

Figure 10 - *Earthquake impact: liquefaction in Balaroa Housing areas (Source: AHA report - Courtesy: BNPB).*

2.3 Meteorological Situation

Current Condition: In Palu city, cloudy, with the possibility of light rain. Details on the current weather are shown in the figure on the right, containing the surface weather map - isobars and winds - valid for 01 Oct 00 UTC; the areas of wind speeds higher than 35 km/h are shaded by yellow colour (data source: NOAA-GFS, see GDACS). The current weather radar image is shown below, as of 01 Oct, 10:40 UTC, source: BMKG)

More information on the current weather in Palu: http://www.bmkg.go.id/cuaca/prakiraan-cuaca.bmkg?Kota=Palu&AreaID=1200106&Prov=29



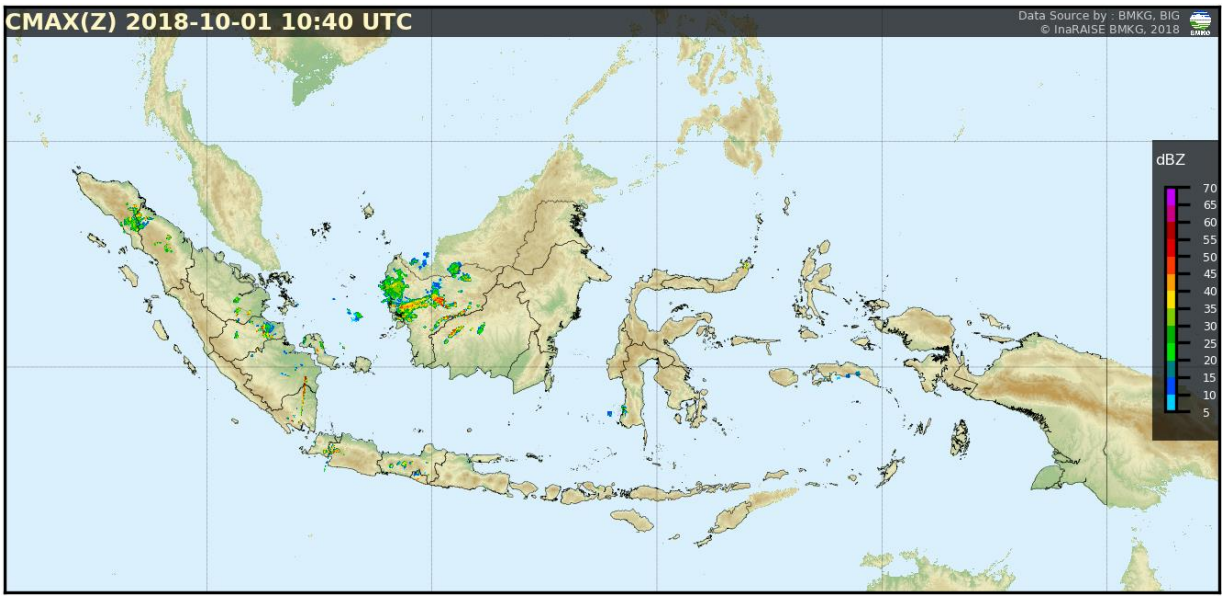
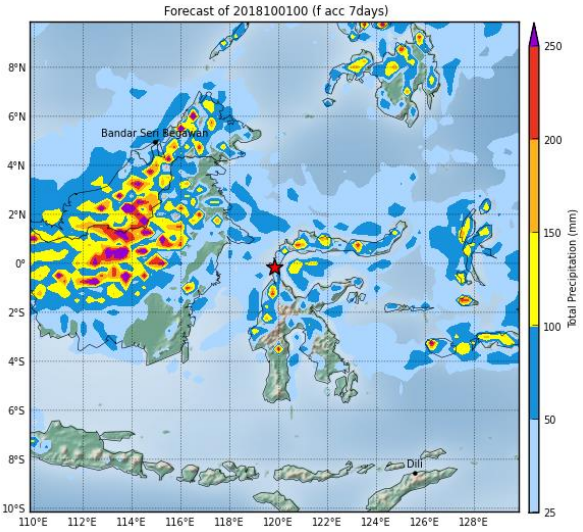


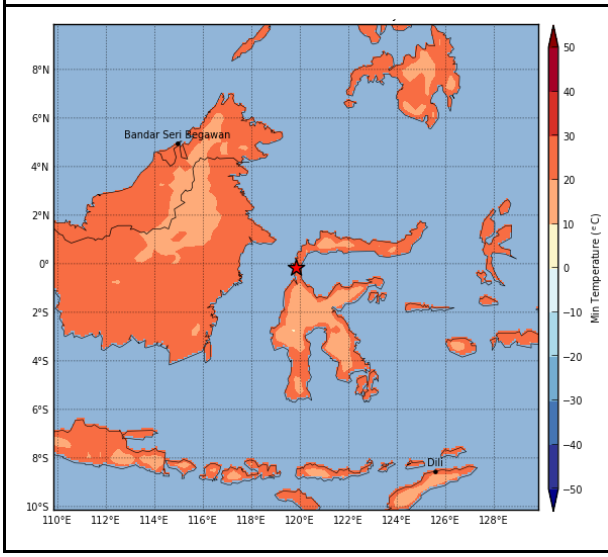
Figure 11 - 12 *- TOP-RIGHT: Surface weather analysis map (isobars and winds) valid for 01 Oct 00 UTC Data Source: GFS (Global Forecast System of NCEP / NOAA, as of 01 Oct, 00 UTC), see GDACS. BOTTOM: current weather radar image, as of 01 Oct, 10:40 UTC (source*: BMKG)

Forecast: Over the next 7 days, locally heavy rains and strong winds / thunderstorms could affect parts of Indonesia (especially Kalimantan and Sumatra), moderate (locally heavy) rains in some areas of central, northern and western Sulawesi (see next 7 days rainfall accumulation in the image on the right, red star=epicenter).

In **Palu city** (02-03 Oct), cloudy, with the possibility of light rainfall during the afternoon/evening. Maximum temperatures forecast: 34°C on 2 Oct, 31°C on 3 Oct. Minimum temperatures: 26°C during the early hours of 2 October, 24°C on 3 October (see BMKG and WMO).

Indonesia 3-days weather warnings: http://www.bmkg.go.id/cuaca/prakiraan-cuaca-tigaharian.bmkg?lang=EN





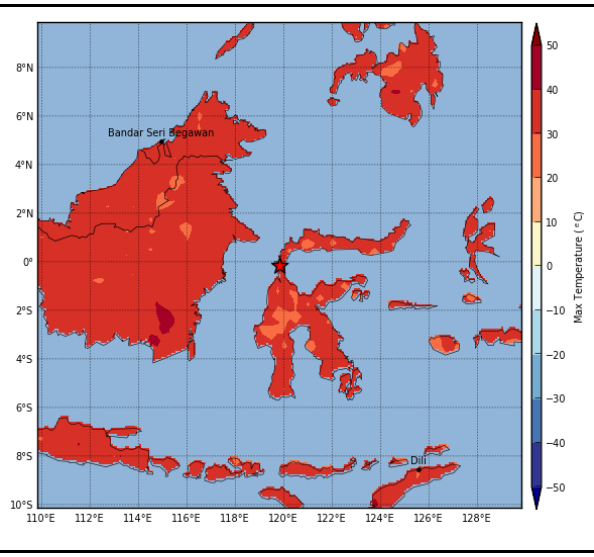


Figure 13-15 *- 7-days precipitation accumulation forecast, Minimum temperature (Bottom-LEFT) and maximum temperatures (Bottom-RIGHT) over the next 7 days*
Data Source: GFS (Global Forecast System of NCEP / NOAA, as of 1 Oct, 00 UTC), see GDACS

2.4 Seismotectonic of the area

In this section, in depth information are provided with respect to the previous report.

According to Cipta et al., 2016[4], the island of Sulawesi is characterised by high seismic activity rates, both along fast-slipping crustal faults including the major Palu-Koro–Matano Fault System and in regions of distributed deformation, contribute to moderate–high earthquake hazard over all but the SW part of the island. Of particular concern in terms of seismic risk are the numerous cities sited on soft sedimentary basins that have formed due to movement along presently active structures and that can be expected to amplify earthquake ground motions, including the provincial capitals of Palu and Gorontalo.

It is expected that earthquakes of this magnitude and this system, will produce significant aftershock activity.

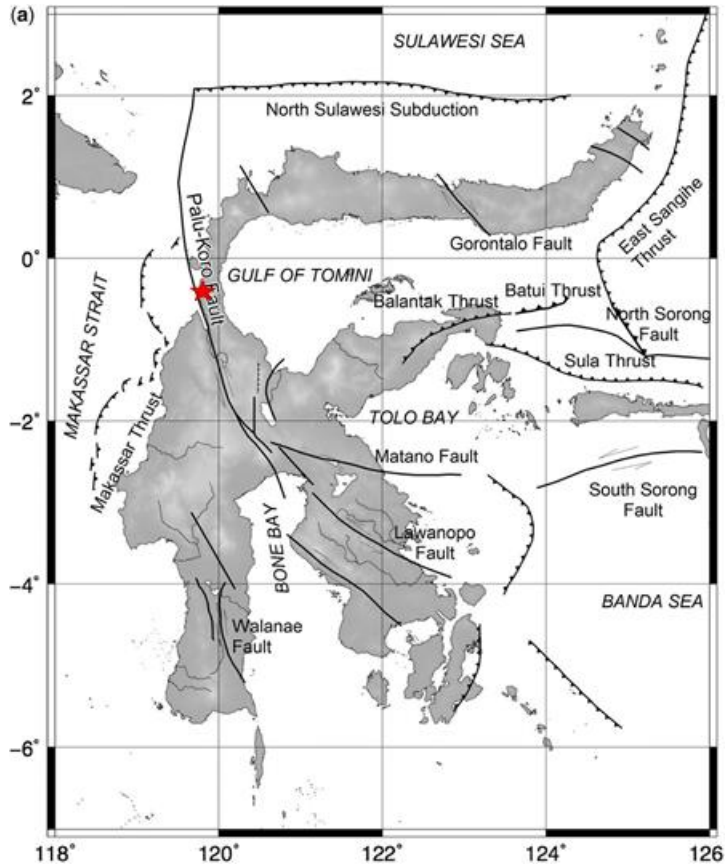


Figure 16 *- Map of the main active fault structure of the Sulawesi region (modified from Cipta et al., 2016). The Mw 7.5 earthquake of 28 Sept 2018 is marked by the red star.*

[4] A. Cipta, R. Robiana, J. D. Griffin, N. Horspool, S. Hidayati and Phil R. Cummins - A probabilistic seismic hazard assessment for Sulawesi, Indonesia. Geological Society, London, Special Publications, 441, 133-152, 26 April 2016, https://doi.org/10.1144/SP441.6

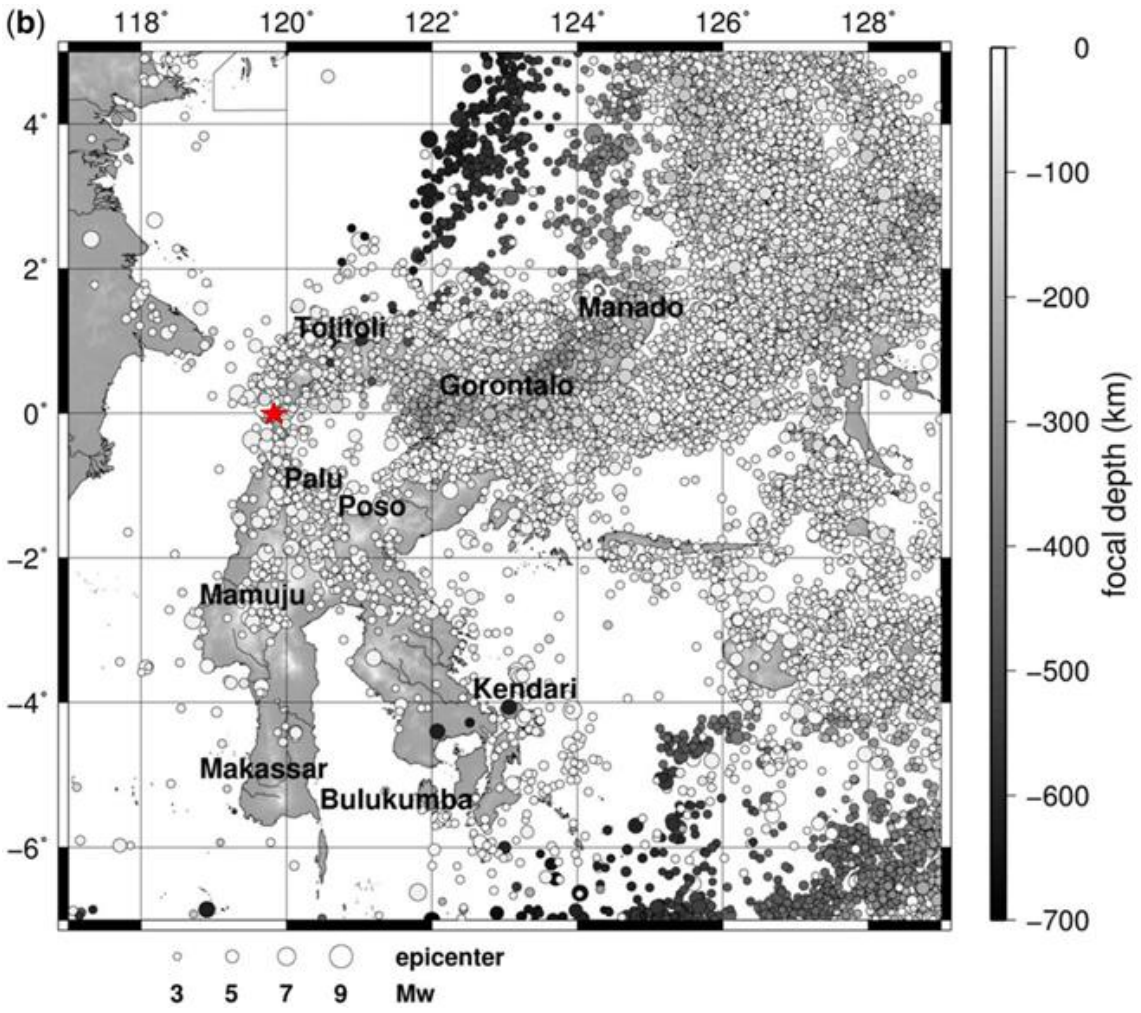


Figure 17 *- Map of the distribution of the earthquake epicenters of the Sulawesi region (modified from Cipta et al., 2016). The Mw 7.5 earthquake of 28 Sept 2018 is marked by the red star.*

2.5 Historical events

According to Pelinovsky et al., 1997[5], tsunamis frequently struck Sulawesi Island. According to catalogues (Soloviev and Go, 1984; Soloviev et al. 1992[6]) a total of 14 tsunami cases were recorded on Sulawesi Island between 1820 and 1982, i.e. one tsunami every 11 years. Four historical destructive tsunamis of the last century are mentioned below, which occurred in the central part of Sulawesi Island where the present tsunami took place. Their parameters are given in Table I (all times are GMT) and the epicentres of the earthquakes are shown in Figure 2. It should be stressed that the epicentres of all those earthquakes are located practically near the coastline. The available information on tsunami indicates a high level of tsunami hazard in the central part of Sulawesi Island.
All the tsunamis occurred almost simultaneously with earthquakes.

According to the information provided in the previous report, none of the recent earthquakes in the Island of Sulawesi required the humanitarian support (from 2000 to now).

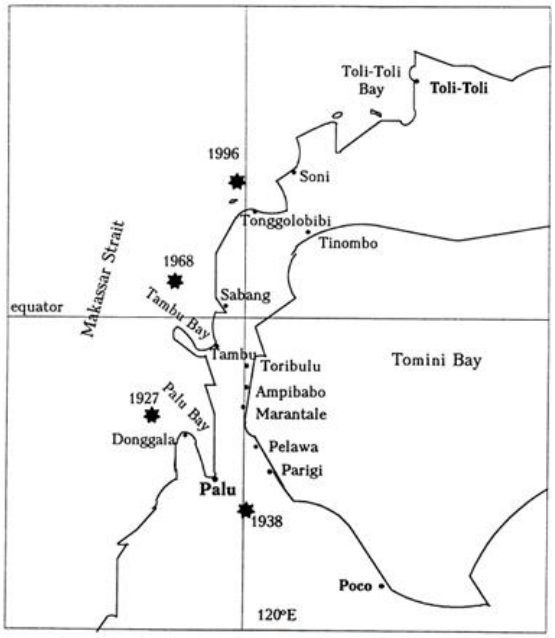


Table I. Characteristics of earthquakes and tsunamis in the central part of Sulawesi Island

Year	Date	Latitude	Longitude E	Magnitude M	Wave height (m)
1927	01.12	0.7° S	119.7°	6.3	15
1938	19.05	1° S	120°	7.6	3
1968	14.08	0.2° N	119.8°	7.4	10
1996	01.01	0.83° N	120.01°	7.7	3.4

Figure 18 *- Map and list of the epicenters of the tsunamigenic earthquakes from 1900 to 1997 in the central part of Sulawesi (Pelinovsky et al., 1997, modified).*

[5] Pelinovsky Efim, Yuliadi Dede, Prasetya Gegar and Hidayat Rahman - The 1996 Sulawesi Tsunami. Natural Hazards 16: 29–38, 1997.
[6] Soloviev, S. L. and Go, Ch. N.: 1984, Catalogue of Tsunamis on the Western Shore of the Pacific Ocean, Canada Institute for Sci. and Tech. Information, Ottawa.
Soloviev, S. L. Go, Ch. N., and Kim, Kh. S.: 1992, Catalog of Tsunamis in the Pacific 1969–1982, Soviet Geophysical Committee, Moscow.

3 JRC contributions

In the period after the end of ARISTOTLE services and the beginning of the new 24 h service that is being prepared, JRC supplies ERCC with a similar service during working hours. ERCC requested an emergency report for this event.

3.1 Tsunami Analyses

The GDACS system starts automatic calculation trying to maximise the potential Tsunami impact. For this reason, for areas where not clear fault database exist (like this), the conservative assumption of normal fault is assumed (Dip angle 45 degree and Rake angle 90 degree); the strike angle is assumed as parallel to the closest fault line. As we do not have the vertical fault line, the closest one was a 90 degree strike.

JRC repeated the analysis of the Tsunami calculations as more information about the source mechanism have been published by USGS. In particular the Moment Tensor solutions and the Finite Fault Model has been considered for further analysis.The source mechanism for this area is strike slip which generally causes much lower Tsunamis.

3.1.1 USGS Moment Tensors solution NP2

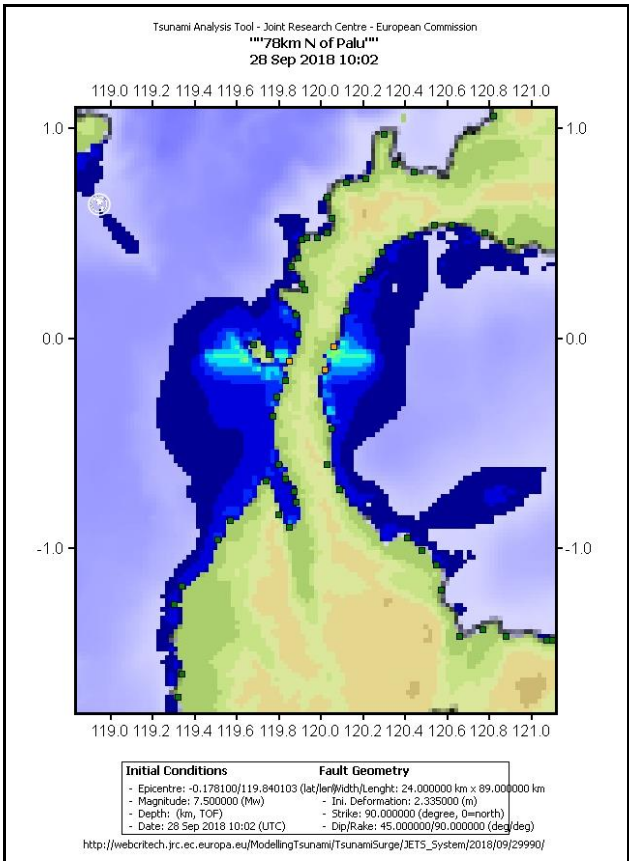
The conditions for the calculations are the following[7]

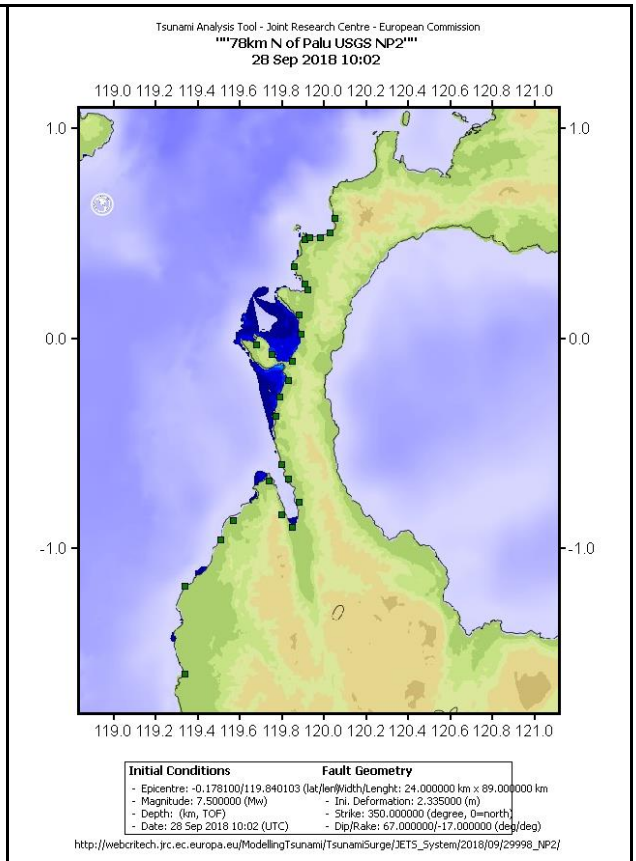
Fault parameters • Lat/Lon: **-0.1781,119.8401** • Length: **89 km** • Width: **24 km** • Magnitude: **7.5 M** • Cell size: **0.25 min** (500 m)	**Okada parameters:** • Slip: **2.3 m** • Depth: **10 km** USGS NP2 • Strike: **350 degree** • Dip: **67 degree** • Rake: **-17 degree**

From the images below it is possible to note that the USGS-NP2 solution tends to have almost or no Tsunami height in the Palu gulf and some impact only close to the epicentre.

This model is therefore unable to justify the large Tsunami generated in the Palu gulf. The comparison of the sea level shows a very low increase.

[7] https://earthquake.usgs.gov/earthquakes/eventpage/us1000h3p4#moment-tensor?source=us&code=us_1000h3p4_mww





Expected Tsunami maximum height in the GDACS standard model	Expected Tsunami maximum height using the USGS-NP2 Moment tensor solution

Figure 19 *- JRC tsunami calculations.*

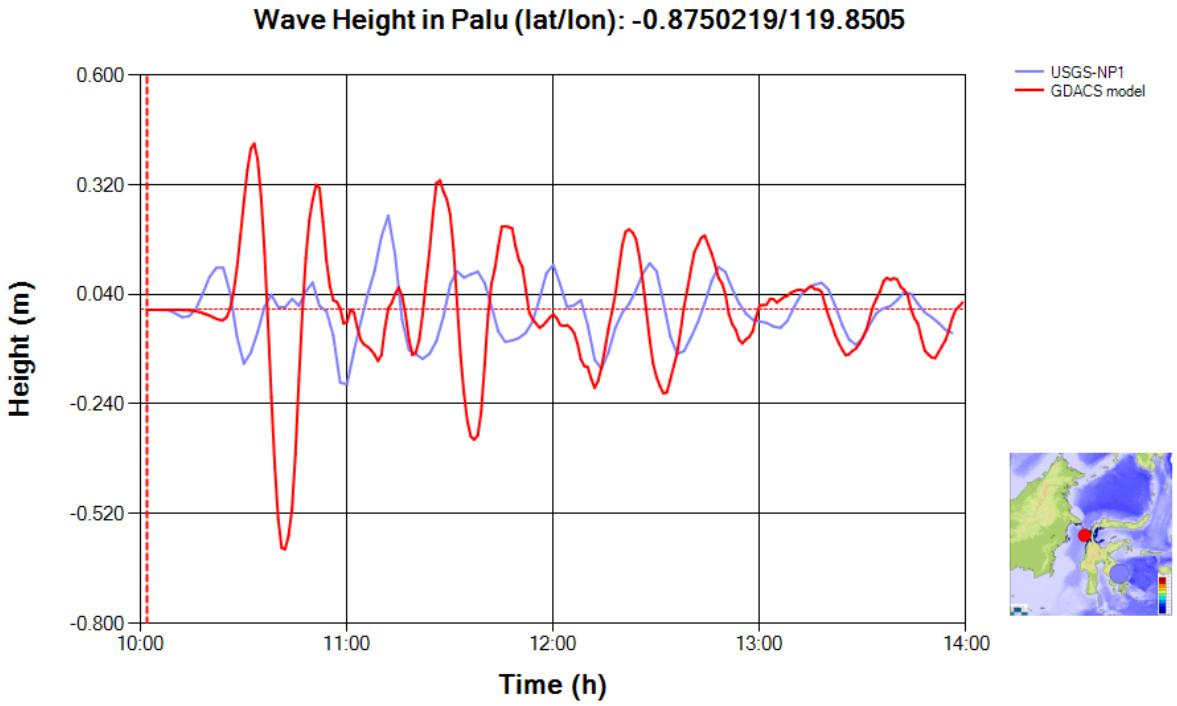


Figure 20 - *Sea level estimated in Palu with the GDACS model (red curve) and the USGS-NP1*

3.1.2 USGS Finite Fault Model

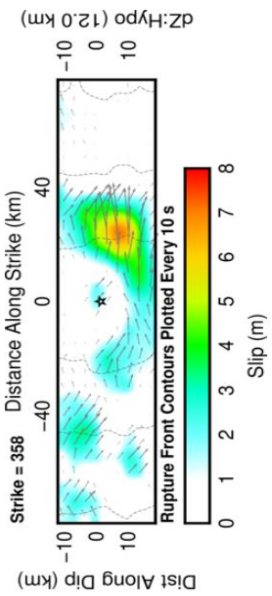
The Finite Fault Model, published on 2018-09-28 12:52:15 is characterized by the following parameters

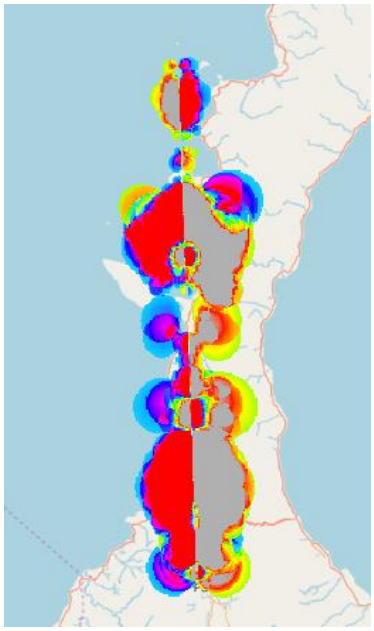
Fault parameters • Length: **150 km** • Width: **30.6 km** • Magnitude: **7.5 M** • Sub fault size: **5 x 3.4** km x km • Number of sub faults: **30 x 9**	**Okada parameters:** • Slip: **variable** • Depth: **variable** USGS FFM • Strike: **358 degree** • Dip: **67 degree** • Rake: **variable**

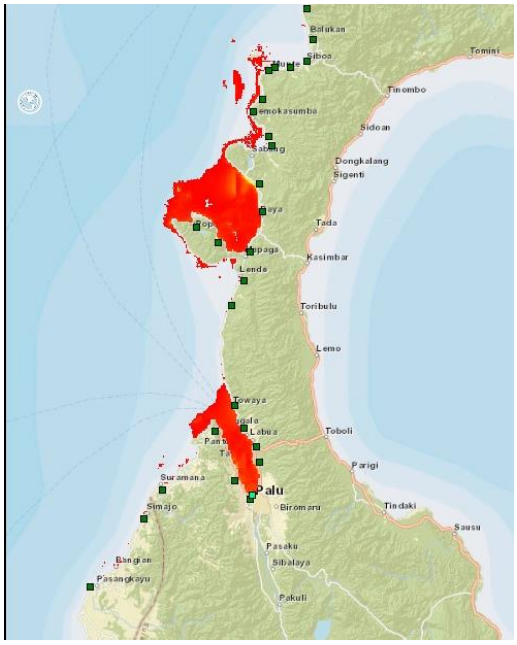
Similarly for the Finite Fault model[8] which suggests for a quite complex fault distribution along the vertical line of the fault. The resulting seafloor deformation is indicated in the central figure below and the Tsunami expected maximum height in the third figure on the right.

Also in this case the sea level estimated in Palu (Fig, 20) shows a minor sea level change; this is another confirmation that neither model is able to correctly estimate the sea level.

[8] https://earthquake.usgs.gov/earthquakes/eventpage/us1000h3p4#finite-fault







Finite fault model (slip distribution)	Resulting deformation	Maximum sea water level as result of the Tsunami propagation

Figure 21 - Results with the Finite Fault Model

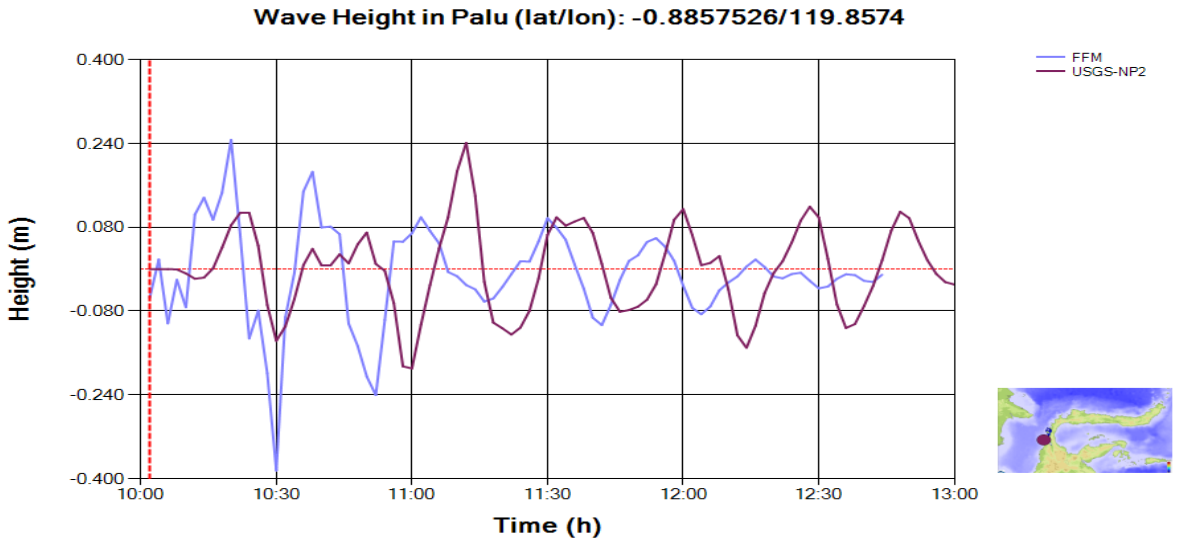


Figure 22 *- Comparison of the Finite Fault Model (blue curve) and the USGS-NP2 model (dark red)*

3.1.3 Discussion on the source model

The calculations above showed that none of the proposed models was able to correctly estimate the Tsunami impact on the coasts and in particular in Palu. The GDACS model, that at first sight seemed it

could justify the impact better (1.6 m maximum), in reality contains incorrect initial conditions because the assumed fault is horizontal instead of vertical one. In addition the maximum height is displayed on the East side of Sulawesi island.

The current possible explanation is the generation of a submarine landslide in the vicinity of Palu that may have generated the Tsunami. At the moment it is not possible to assess this information but historical events indicate this as a solid possibility. In addition witnesses reported that the initial wave was rather muddy while the second one contained clean water. The sediments transported by the Palu river may have accumulated over the years and originated the strong water motion.

Other teams made also reference to possible resonance effects but have not been demonstrated yet.

3.2 Natech analysis

There are some industrial facilities located close to Palu, which include:

- Pertamina Loli Fuel Depot
- Palu Power Plant
- Can Fertilizer Factory
- Gasmindo LPG Depot
- Multi Nabati Sulawesi Palm Oil Refinery

A map of the industrial facilities listed above is available at:
https://www.google.com/maps/d/viewer?mid=18qk8THNfJ3wbD-3Fil_DaFWNrQmoTdsF&ll=-0.7286939493886798%2C119.83934894999993&z=13

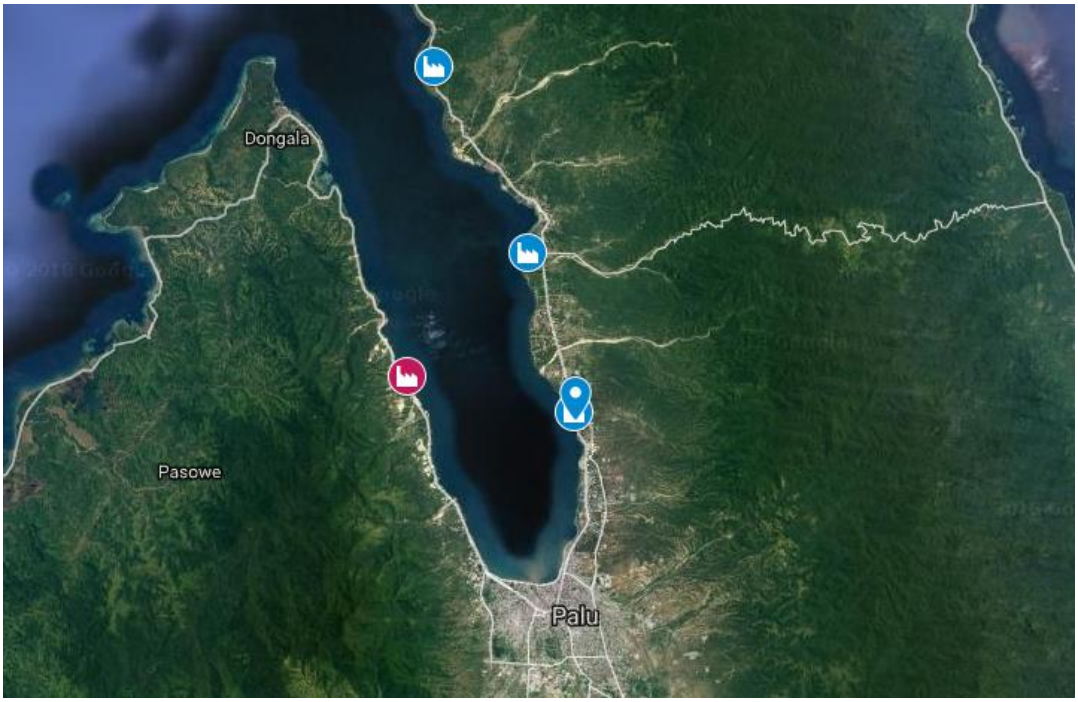


Figure 23 *- Map of the industrial facilities in the area of Palu identified until 2018/10/01, 17:00 CET.*

The map and the list are not complete and cover only the facilities identified until 2018/10/01, 17:00 CET.

Information about the damage at the facilities is limited. However, there is damage at the Pertamina Loli Fuel Depot, which didn't result in any release according to the reports:

> "...Oil company Pertamina said its fuel depot in Donggala had been damaged in the incident though there was no oil spill. Fuel tanks had shifted in the quake and ship loading facilities were disabled among other damage."
> Source: http://www.theborneopost.com/2018/09/29/major-quake-and-tsunami-cause-deaths-in-indonesian-city/

Although there is no spill, damage at the fuel depot caused fuel shortage:

> "... Fuel is still difficult to obtain in Palu City because the fuel depot in Donggala was also damaged by the earthquake so that the supply for Palu City also stopped. ..."
> Source: https://www.antaranews.com/berita/753695/berharap-bbm-normal-di-palu (translated by Google Translate)

There are no reports of damage to oil and gas production fields in the area:

> "... There were no reports of damage to producing oil and gas fields in the area, according to the energy ministry. ..."
> Source: http://www.theborneopost.com/2018/09/29/major-quake-and-tsunami-cause-deaths-in-indonesian-city/

AOIs of the Copernicus activation do not cover the industrial facilities.

3.3 Copernicus activation

The Copernicus Emergency Management Service was activated by DG ECHO-ERCC on 28 September at 13:25 UTC (EMSR317). The request is for damage assessments (grading maps) for 10 areas of interest (AOI) of ca. 6 x 6 km derived from the initial area requested by ECHO ca 20x30 km (see figures below).

At the time of writing this report five grading maps have been produced, three of them over the city of Palu.

New image acquisition is planned for the 2nd of October to complete the map production over the remaining 4 AOI's.

From the preliminary assessment of the grading map of Palu (see figure below), the combined effects of the tsunami (along the coast) and of the earthquake are detected. On the South-West of the city, an area affected by liquefaction.

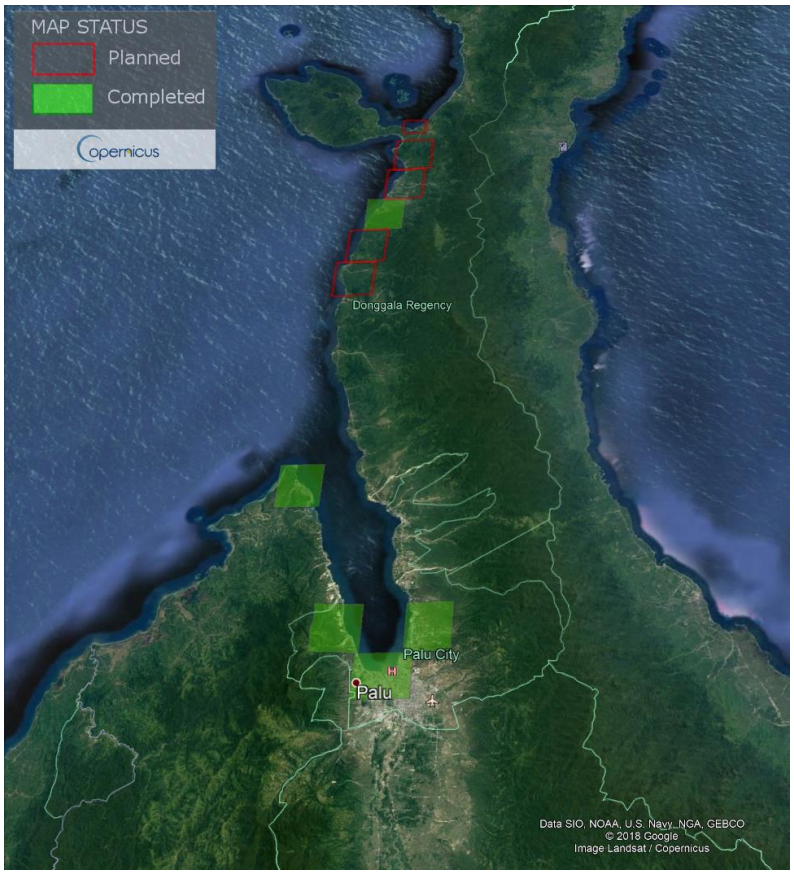


Figure 24 *- Areas of Interest of the Copernicus activation (EMSR317).*

Figure 25 *- Grading map for the town of Palu. The combined effects of the tsunami (along the coast) and of the earthquake are detected (Copernicus EMS © 2018 EU, [EMSR317] Palu: Grading map).*

4. Other Information

4.1 Virtual OSOCC Activation

A new breaking emergency discussion has been initiated in VOSOCC web site on 28 September early afternoon.

Since then a large amount of messages and information has been included in the site, followed by thousands of first responders and humanitarian organizations. The latest information indicated that the Government of Indonesia has stated that they will carefully review and clear all forms of international assistance.

The last situation update from OCHA is the following.

OCHA Situation Update - 1 October 2018 (as at 20:00)
Situation overview
As of 1 October, 844 people were confirmed to have died following the earthquake and tsunami, and more than 600 people have been injured. It is likely that these figures will increase as more areas become accessible and the Government conducts more assessments. With houses damaged or destroyed, and aftershocks continuing, thousands of people are unable to return to their homes, with more than 48,000 displaced people currently staying in over 200 sites.

According to BNPB at the daily press conference at 13:00, the immediate needs are for the continuation of evacuation, search and rescue (heavy equipment will be needed for evacuation, some is available in Palu City, and more to be brought from Mamuju, Gorontalo, Poso and Balikpapan); dead body management, with burial sites to be located in Palu City; reconnecting electricity and communication networks; provision of fuel, particularly for generators at hospitals and cellular operators; and support for IDPs,
including food.

4.2 International Charter activation

The International Charter has been activated on 29 Sept at 19:31 GMT.
https://disasterscharter.org/web/guest/activations/-/article/earthquake-in-indonesia-activation-587-

A first map has been produced and related to the west side of the Palu channel and showing extended damage on the coastal area as well indication of subsidence of this area, shown by the definite coseismic change of the shoreline that appears inland of few hundreds mt, if compared with pre-event images.

Figure 26 *- Damage map from the International Charter for the Palu bay. The changes on the coastline are identified (blu-red line), together with the coast collapsed due to the subsidence caused by the earthquake.*

4.3 Volcanic Hazard

Volcanic Hazard is here reported only because it could affect the transport of Humanitarian goods to the area and because of the Rinjani volcano located on the affected island of Lombok.

As of today's 01 October 2018, the Indonesian volcanoes interested by Volcanic Ash Advisories from Darwin Volcanic Ash Advisories are:

- Dukono,
- Krakatau,
- Manam
- Kadovar.

Source: http://www.bom.gov.au/aviation/volcanic-ash/darwin-va-advisory.shtml

No ongoing significant eruptions.

5 Expected Updates

Further update will be provided if needed.

6 References and contact points within JRC

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For updated information on the disaster, please consult the following web sites:

- GDACS: http://www.gdacs.org/report.aspx?eventid=1157757&episodeid=1229845&eventtype=EQ

- Copernicus EMS: http://emergency.copernicus.eu/mapping
- BNPB: https://www.bnpb.go.id/
- BMKG: http://www.bmkg.go.id